WILD TROUT IV

WILD TROUT IV

Symposium Chairmen
Gardner Grant
Frank Richardson

Planning Committee
Frank Richardson, Chairman
Gardner Grant
Mike Owen
Charles Loveless

Program Committee
Roger Barnhart, Chairman
Paul Brouha
Pam McClelland
Ron Jones
John Peters
Willis King
Gene Hester

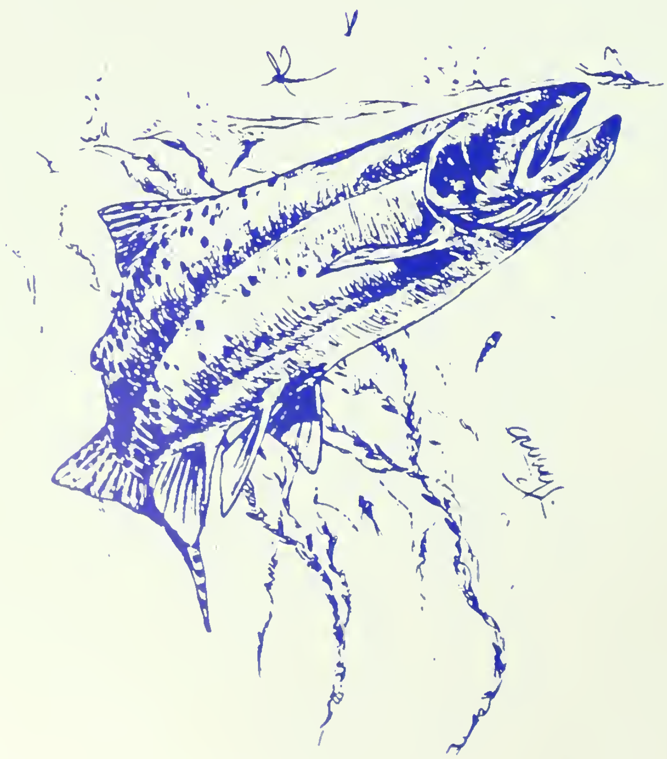
A. Starker Leopold Award
Pete Van Gyteenbeek, Chairman
Marty Seldon
Charles Loveless
Ron Jones

Editorial/Publications Committee
Bob Hamre, Chairman
Frank Richardson

Logistics/Arrangements Committee
Bob Barbee, Chairman
Ron Jones
Roger Barnhart
Frank Richardson
Charles Loveless
Gardner Grant

Photography
Tom Pero
Jim Yuskavitch
Marty Seldon

Cover Art
Roger Cruwys



WILD TROUT IV

Proceedings of the Symposium

Yellowstone National Park
September 18-19, 1989

Technical Editors:
Frank Richardson
Fish and Wildlife Service, U.S. Department of the Interior
R. H. Hamre
Forest Service, U.S. Department of Agriculture

Sponsors:
U.S. Department of the Interior
U.S. Forest Service
U.S. Environmental Protection Agency
American Fisheries Society
Federation of Fly Fishers
Trout Unlimited


SOUTHWEST NATIVE TROUT

Contents

Wild Trout IV: Looking Back, Looking Ahead

Gardner Grant and Frank Richardson

The Proceedings of the first Wild Trout Symposium (September 25-26, 1974) were published under the title *Wild Trout Management*, and indeed, this first effort, sponsored by Trout Unlimited and the United States Department of the Interior, concentrated on management. Recognizing that more than "management" is involved in an ongoing effort to enhance wild salmonid fisheries, the second Symposium and its Proceedings were called simply *Wild Trout II*, and for this conference (September 24-25, 1979, the Federation of Fly Fisherman joined Trout Unlimited and the United States Department of the Interior as a sponsor. Five years later, September 24-25, 1984, the U.S. Department of Agriculture - Forest Service, joined the other three in sponsoring *Wild Trout III*. In September 1989, the U.S. Environmental Protection Agency and the American Fisheries Society joined the foregoing in sponsoring *Wild Trout IV* which, in an agenda-filled 2-day format, examined a broader range of environmental and social factors influencing wild salmonids than preceding symposiums.

This is as it should be. The originators hoped that each symposium would be a building block upon which the succeeding symposium could take hold and provide, in turn, insights and research which future sessions could revisit. The broadening of sponsorship has gone hand-in-hand with this concept.

At a critiquing session after the close of this conference, it was the consensus view that we may have outgrown the facilities at Mammoth Hot Springs, but that we should do everything possible to hold *Wild Trout V* in September 1994 somewhere in Yellowstone National Park.

We have grown, we have gained recognition, and we look forward to expanding our contribution to the cause of wild salmonids. As you read these Proceedings, we hope you will be stimulated in your own thinking and efforts on behalf of our wild salmonid resources, and plan to participate with us in *Wild Trout V*.

For many attendees, *Wild Trout IV* was a homecoming. Nat Reed, Dave Borgesen, Bob Wiley, Ray White, Dick Vincent, John Varley, Bob Brown, Stacy Gebhards, Bob Hunt, Gene Hester, Ron Jones, Charlie Loveless, Jim Mullan, John Peters, Mike Owen, Ernie Schwiebert, Russ Thurow, Dick Baldes, Bob White, Roger Barnhart, Don Bartschi, and yours truly, Gardner Grant and Frank Richardson, were among those who attended the first symposium in 1974 and were back for *Wild Trout IV*. Several of those listed above have participated in all four symposia. Attendees of the *Wild Trout* symposia represent the key people in North America who are providing stewardship for our trout and salmon resources.

We deeply appreciate the roles played by the Mammoth staff of the Yellowstone National Park, TW Recreational Service, Inc., and Fish and Wildlife Service. They were always on the job cheerfully and professionally accomplishing their many assignments in a highly successful manner. We, the Symposium Co-Chairmen, give them our thanks and appreciation on behalf of the 250 anglers, conservationists, biologists, administrators, and students who attended *Wild Trout IV*.

Again, we invite you to begin your planning to attend *Wild Trout V* in September 1994.

Wild Trout IV Whom?[1]

Robert D. Barbee[2]

Fifteen years ago, Wild Trout I was held here in Yellowstone, hosted by late Superintendent Jack Anderson. Jack was, and is still, remembered as a heroic figure among trout fishermen and ecologists for taking on the tough job of restoring trout to their former abundance and vigor in Yellowstone. In tackling that job, Jack and his team of professionals provided the world with one of its best examples of how good public trout fishing could be. They proved that the "tragedy of the commons" could evolve into a "celebration of the commons."

Since then, fisheries managers and anglers around the country have embraced principles that in 1973 only a handful of people--a thimbleful within the agencies--were willing to espouse or promote publicly. In the past 16 years we've seen a proliferation of special regulations, catch-and-release fisheries, and other management devices, and we've seen an increasing enthusiasm among anglers for wild trout. Yellowstone is no longer a rare example of enlightened wild trout management that people can point to when they want to convince their local fisheries authorities that there may be a better way to manage the neighborhood trout stream. And I'm sure that all over the country managers are just as glad not to hear Yellowstone invoked so often. I also think most trout fishermen and managers would agree that the world of wild trout has come a long way since Wild Trout I.

The question we might be asking ourselves, in the glow of this self-congratulatory mood, is, "Whatever happened to Yellowstone? Could those people possibly have anything new to teach us now?" The answer to that question is yes. It's time to take another look at Yellowstone. Where have we gone since 1973, when so many people saw us as the leader? What new lessons have emerged from our experience? Are we still learning things here?

As it turns out, we're learning quite a lot. We continue to learn about the management of wild trout in lakes and streams. And we continue to be instructed about the value of native species and the preservation of those special gene pools. We continue to refine our understanding of the ecology of trout and the sociology of trout fishermen. We've also learned that trout fishing is big business: The estimated resource value of Yellowstone fishing this year will be about $78 million--entirely supported by wild trout! Imagine that! But we're also learning things beyond the traditional realm of the trout fishermen, and my message to you involves these bigger lessons. It's a lesson even bigger than $78 dollars.

My message is that the world of Wild Trout is being changed from outside. Public perceptions of wild animals are changing. For example, here in Yellowstone, in just 20 years, we've seen a remarkable change in public attitudes toward the wolf. A recent survey of park visitors indicated they favor wolf reintroduction in Yellowstone by a margin of six to one. If you've ever been involved in public attitude surveys, you know how rarely the public ever favors anything even two to one. Public attitudes are not only changeable, they are reversible.

This matters to those of us concerned with wild trout, because here in Yellowstone, we're learning that public attitudes about aquatic resources are changing too. Streams and lakes are no longer solely the domain of sportsmen. Fish and other forms of aquatic organisms have new constituencies. After years of being blackballed from the group of animals called wildlife (witness the name of our sister agency--the U.S. Fish and Wildlife Service), fish are increasingly recognized as a form of wildlife. All the factors that have affected wildlife managers in recent years--such as animal rights, the increasing interest in non-game species, and the entrance into the arena of new, non-consumptive user groups--are appearing here in strength, which means that they are going to appear elsewhere on this planet.

This year, more people will watch fish in Yellowstone than will acquire a free permit to fish for them. Listen to this: Nearly twice as many visitors will watch fish than will angle for them. Many of us here are old enough to remember when the public viewed fish only as something to "limit out" on or cycle through a human digestive tract. Now, there is a growing public out there who view fish not as objects of sport, but as finny friends, kind of underwater butterflies.

---

[1] Introductory paper presented at Wild Trout IV, Sept. 18-19, 1989, Yellowstone National Park, Wyoming.

[2] Superintendent, Yellowstone National Park, Mammoth Hot Springs, WY.

Now, to a great extent, the concerns of many of these people may be addressed by the way we manage the trout here. We treat trout more like first-class animals. We recognize their equality with elk and bears. We restrict human consumption of fish, so that trout can play their role in the ecological system by eating smaller creatures and being eaten by larger creatures. We emphasize protection of native species.

The world of wild trout has faced substantial changes in the past 20 years, and there are more of them to come. Meetings like this can make them not only less painful, but positive and constructive. I wish you every success in your deliberations over the next several days!

Elegies and Epilogues[1]

Ernest Schwiebert[2]

Abstract.--Those of us who work in technical and scientific disciplines too often suffer from a myopia of charts and tables and graphs, reducing the poetry of wild things to statistics. It is important to escape the nuts-and-bolts of any technology, to understand its elegance and aesthetic qualities, and to taste the beauty we are attempting to save.

During our sessions this week, I have sometimes been reminded of the Faustian bargains we are continually forced to make between our livelihoods and the probity of science. It was Goethe, the nineteenth century German playwright and poet, who gave us the story of Doktor Faustus and left us with an aphorism that is worth remembering—be careful what you wish for in your youth, for you may get it in your later years.

I have been playing hooky in the Park, something between a pilgrim and a pathologist, and I understand the sadness of Orpheus after losing Eurydice and spending his season in Hell.

It has been some time since Wild Trout One. How many things have changed. I spent most of Sunday on the Gibbon and Firehole and Madison, looking and not fishing, from Slow Bend to the Little Firehole in Biscuit Basin, looking at the fresh silt beds and big alluvial fans of volcanic clays at Seven Mile Bridge, and an entirely new tributary creek spilling its chalky mud into the Nine Mile Hole—checking temperatures at Sentinel Creek and Elk Springs and Iron Springs footbridge to see how their cold, mitigating discharges were faring now that the lodgepoles are gone on the entire fire-blackened plateau that refills their aquifers.

There was a storm while I was on the Firehole, and its winds raised towering clouds of fresh ash and silt until the entire sky seemed filled with blowing earth, like the Great Plains in the Depression Years. The Firehole still has extensive beds of hydrothermal silts from the earthquake of 1959, when its hot springs and geysers erupted and overflowed into the river. Since it has lacked spates to purge such silt beds, we have watched them displaced slowly downstream, sometimes travelling as little as a few hundred yards each year. Those silts smothered out two excellent species of big mayflies in 1959, hatches that have never recovered after thirty years. Watching the billowing storm of blowing soils and ash, I knew that the Firehole would start to have spates in the future, and their fresh erosion would smother its fly hatches and spawning riffles—silts transported in both its fluvial discharges and silts blowing in the wind.

And I drove back along the Fountain Flats, where I first fished the Firehole in 1947, and have collected forty-odd years of memories—many of old friends who loved the Yellowstone and are gone—drove slowly through the charred and fire-lacquered trees at Goose and Feather Lakes, and it broke my heart.

I have not been in the Yellowstone in recent years, because I have spent several weeks each season in Alaska, often concentrating on the Katmai and its Valley of Ten-Thousand Smokes—working on a book.

I will confess that I have not entirely resisted the temptation to fish. But fishing was curiously shrunk to footnotes among its other things. I am still digesting its diet of riches. I have been watching the great bowhead migrations through Unimak Pass in the spring, counting eagles at Admiralty Island when the herring are spawning, watching the black oystercatchers on the dark volcanic beaches along the Shelikof Strait , and avoiding October bears still gorging themselves on the last clean sockeyes at Brooks. I have been watching the caribou spilling north across the mountains like swarming insects, like entire forests drifting across the treeless hillsides—tattered velvet still hanging like catkins from their antlers—coming from their winter range on the Porcupine and Chandalar and Sheenjek in the Yukon country.

---

[1]Banquet address at Wild Trout IV, Sept. 18-19, 1989, Yellowstone National Park, Wyoming.

[2]Ernie Schwiebert -- author, architect, artist, planner, poet, consultant -- is the consummate fisher of trout.--Ed.

The caribou are migrating to their ancestral calving grounds on the Canning and Sadlerochit and Jago, perhaps as doomed as the passenger pigeons and the buffalo, herds flowing north like rivers in the cotton-grass tundra of the last American Serengeti.

And I have seen thousands and thousands of sandhill cranes gathering to travel south, circling higher and higher into the dying light at Kukaklek and Sleetmute and Koktuli—listening to a clamor like children beating on pots and pans—and knowing that these circling flocks would need the acre-footages destined for the troublesome Two Forks project in Colorado once they reached the Platte in Nebraska.

I have a biologist friend working in the arctic who loves its wild emptiness, but is beginning to hate his work—reducing wild things to charts and graphs and tables of numbers, because numbers cannot explain wild things—yet numbers are the only things that Ottawa and Washington seem to understand.

But only accountants and math teachers and tax attorneys actually love numbers, except for the sorry parade of junk-bond experts and stock futures acrobats and arbitragers we have watched in New York and Los Angeles and Chicago in recent months. Their games with numbers threaten our lives, but reducing wild things to numbers threatens us too, because numbers cannot capture their lyric beauty or its magic.

Many years ago, more years than I choose to remember tonight, I asked my mother to stop the car along a little river in Michigan to watch a fisherman. Most people start fishing for sunfish and pumpkinseeds and perch in their boyhood years, and I was no exception, but the fisherman wading that little river was doing something else—something quite beautiful, and I wanted to watch from the bridge.

It has been fifty-odd years, but I can still see it clearly. It was Michigan jackpine country and there were alders and big cedars along the water. The little river was cold and swift and clear. I could see every pebble and stone. The riffle glittered in the sun, and the fisherman was working patiently upstream. He was not watching a red-and-white bobber on a tepid pond. His amber line was silk, working lazily back and forth in the morning light, graceful and almost alive. His fly fell softly, drifted briefly with the current, and he was casting again. I had never seen fishing like that before, but I knew that it was something beautiful—and I wanted to be part of it.

And then the fisherman caught a fish. It was not large, perhaps five or six inches, but I saw its splashy rise. I saw the fisherman tighten, his rod dancing and catching the light, and I ran down from the bridge and asked to see the fish before he let it go. It was not a fish, not like any fish I had ever seen before. Its fins were bright vermilion, delicately edged with ebony and white. Its back was darkly patterned with vermiculations of olive, and it still had its parr markings. It was speckled and spotted. But words like speckled and spotted are not the words to capture its beauty. It was covered with precious stones, with opals and rubies and moonstones. I had never seen such a beautiful fish, but I knew that it was what a perfect fish should look like, and I have never been truly happy fishing for anything else.

Thinking back across the years, holding such beauty in my hands, I know that it was not really a fish—it was a poem.

We have come again to this beautiful place called Yellowstone, and the terrible beauty that has become an epilogue to its fires, and we come from a spectrum of disciplines. Botanists. Fisheries biologists. Climatologists. Forestry experts. Ecologists. Geomorphologists and geologists. Taxonomists. Hydrologists. Agronomists and anglers. Those of us with technical and scientific backgrounds tend to become myopic, intensely involved with the nuts-and-bolts of our disciplines.

We talk together in riddles of riparian plant communities. Aquatic macrophytes. Fluvial impacts. Lacustrine habitat. Geomorphology. Taxonomy. Scale counts and pyloric caeca and gillrakers. Electrophoresis. Soils chemistry. Zoogeography. Genetic diversity. Stream gradients and profiles. Substrate and redd counts. Escapement. Ova and alevins and smolts. Photosynthesis. Fluorocarbons and sulphur dioxide. Aquifer recharge. Biological oxygen demand. Ecosystem. Biosphere. But such arcane language cannot explain the dancing poetry of mating Ephemeroptera flies.

But these words are only tools, only an intricate language we are still inventing to talk among ourselves, a curious poverty of words that cannot describe the beauty we are attempting to delineate and understand. Such beauty is more complicated than we know, perhaps more complicated than it is fully possible to know. But we are not merely in the science and technology business, not when our science is focused on protecting the beauty of trout rivers and their watersheds, and the beautiful species that thrive in such places—we are in the poetry business.

Stephen Vincent Benet, in a narrative poem about the American frontier called Western Star, wrote about the beauty of wild things with these evocative lines:

Daniel Boone's ghost will walk tonight,
  The phantom deer will rise,
And all lost, wild America
  Is glowing in their eyes.

I cannot return to the Yellowstone, and my first childhood trip occurred shortly before the Second World War, without thinking of its wild trout. Its cutthroats still thrive in the Pelican and Thoroughfare and Slough, in the sweeping bends at Buffalo Ford, and in the gentle valley of the Lamar at its picnic-ground cottonwoods—the valley where the ashes of our friend Starker Leopold were scattered.

Few people love cutthroats, but it is painfully clear that we are a people too much in love with practical things, with hyperbole and sweat, too competitive, and much too fascinated with size and muscle and acrobatics. It makes our fishermen love rainbows instead of cutthroats, and throughout too much of our lost frontier, cutthroats are something subtle and half-forgotten. I fished them happily in the tiny Colorado creeks of childhood. My mother's people were western ranchers, and during one of those teenage summers I was packing salt blocks high into summer range. I took a fishing rod along because I wanted to catch cutthroats. I have been ragged throughout my life for succumbing to such minor distractions, and the cowboys who worked for my uncle were scornful about wasting time on fish small enough to use for bait. Thinking back about those brightly jewelled high-lake cutthroats, I must confess that they were eager and gullible and not very large—but neither are diamonds.

And there is something else about cutthroats. The history of their world is already an intricate tapestry of time. The French sent an explorer called Etienne Brulé to the western shores of Lake Superior in 1618, and Brulé left his name on the beautiful river in Wisconsin. Brulé also made contact with the Sioux and listened to their stories of the Great Plains. Jonathan Carver travelled much later into the Great Lakes, reached the Sioux on the upper Mississippi, and they told him that beyond the tallgrass prairies lay the Shining Mountains.

We know the storied names that followed. Meriwether Lewis and William Clark. John Colter. Colonel Andrew Henry. James Bridger. Tom Fitzpatrick. Hugh Glass. Christopher Carson. John Hoback. David Jackson. Lucien Fontenelle. Joseph Meek. William Sublette. Joseph Reddeford Walker. Jeremiah Johnson. Jedediah Strong Smith. Their names are still found throughout this country, scattered along these Shining Mountains from Santa Fe to the Missouri Breaks.

And when we still catch a cutthroat in these Shining Mountains, we too often catch a wild fish that has survived in spite of our sorry husbandry, and it is not merely a fish we are holding in our hands—it is both a poem and a living piece of history.

Everything about such wild trout is beautiful. The cold lakes and rivers that sustain them are beautiful. The methods of catching them are beautiful, the equipment we use is beautiful, and the flies we dress through the winter are beautiful too. Fly fishing is both old and honorable. Its roots lie in medieval chivalry itself, and we share a literature of sport more than five centuries old. It is filled with bright rivers tumbling swiftly toward the salt, the deft choreography of swifts and swallows working to a hatch of fly, and the quicksilver poetry of the trout themselves.

And, in seeking their beauty, we may still discover that beauty itself is the most endangered thing of all.

From Wild Trout to Wild Ecosystems: Fifteen Years of Evolving Stewardship[1]

Nathaniel P. Reed[2]

As we assemble here for the fourth Wild Trout Symposium in Yellowstone, I am first impressed by how my personal and our collective perspectives have changed in the past fifteen years.

At Wild Trout I, we focused upon managing just that: wild trout, the species. At Wild Trout II, Fred Eiserman summarized our growing perspective by stating that wild trout management was more than fisheries management, it was fisheries habitat management.

At Wild Trout III, Ben Dysart further broadened our viewpoint when he suggested that trout habitat management was really watershed management. And he went on to say that we needed to focus public attention on managing the ecosystem - for the benefit of fisheries, wildlife resources and a host of public values.

As we gather here in the aftermath of the previous summer's great fire, my second impression is that Ben's comments are even more appropriate today; nothing more graphically illustrates our failure to explain ecosystem management to the general public than their reaction to the Yellowstone fires.

Firestorms raged over the mountains and valleys; a towering inferno more captivating than any TV movie! The fires made a mockery of man's most valiant efforts - the brawn of thousands was backed by the evolved technology of millions and to no avail. Extraordinarily dry conditions, overall below average precipitation for more than a decade, high winds, and the first spark brought forth a scenario that was predictable, but awesome nonetheless. It is not that Yellowstone could have burned - or could be burned - at will. The natural burn cycles are immense - perhaps as much as 250 years. It takes just the right combination of events to produce a great fire.

While we lacked the technology to stop the fires, we did possess a heretofore untopped ability to promote it, into virtually every living room in America. Fire line by fire line, it was carried by print and video to the American public.

The tragedy of the Yellowstone fires is not what they did in the park, but rather what happened outside the park. Our tendency to accept simple cause and effect is a keystone of the media's "sixty second summaries." As you all know, understanding ecological complexities takes a tad more time. The failure to accurately convey to the American public the true biological implications of the Yellowstone fires reflects the concern Ben expressed here five long years ago . . . .

I don't believe that Yellowstone National Park can ever be destroyed by wild fire. But the park and its fisheries can be destroyed by ignorance, greed, lack of care and concern, and unwise development within the park. They can also be destroyed by insensitive, stupid decisions made both within the agency and by other agencies on the park's boundaries.

As we gather here today, I'm convinced that the ecological equation within Yellowstone is the healthiest it's been this century.

It seems appropriate as we gather here in the grandeur of our "mother" park to address ever more complex issues, to think back to two key men - neither of them fisheries biologists - who have influenced the direction of much of our scientific endeavors.

I speak of Starker Leopold and Durward Allen. They provided the foundations for the rebirth of Yellowstone and an ecological blueprint for conservation into the next millennium.

Can you imagine Starker Leopold's reaction to the so-called experts and their pronouncements on last summer's fires and on the state of fish and wildlife in Yellowstone? How would he have characterized the headline grabbers and their fabricated nonsense purveyed so shamelessly? Starker knew bullshit as bullshit - as well as any man.

I share with a host of mutual friends the joy of Luna Leopold's presence here today. Twice in my career in Washington - at Big Cypress and in Redwoods - Luna Leopold stepped forward and literally took command of two impossibly difficult

---

[1]Keynote Address presented at Wild Trout IV, Sept. 18-19, 1989, Yellowstone National Park, Wyoming.

[2]Former Assistant Secretary of the Interior, Current address: Hobe Sound, Florida.

situations. Luna works - I underline works today - as did Starker - to solve problems - in the finest sense of the dedicated scientist and human being. Luna - welcome and thanks!

Such fine work contrasts to the mean spiritedness that has characterized so much of the public debate over the management of Yellowstone.

I cherish my memories of Starker Leopold. I had the pleasure of working with Starker as a grand mentor to solve problems.

In that huge human frame was the most thoughtful, brilliant, kind, understanding, patient man - a giant among men. In recent years, many of Starker's legacies have been ineffectively pummelled by park commentators, men who can only flicker in Starker's long shadow. I understand jealousy, but good solid science commands my respect. Starker was so respected, so famous, so useful to government (and even to industry) as we all grapple with myriad environmental issues, that I can readily perceive that lesser lights swimming in small whirlpools off the main current might be jealous.

There is another difference between Starker and some current croppers: Starker was willing to work to solve the problems and serve Secretaries of Interior, the Assistant Secretaries and the Directors of the Park and Fish and Wildlife Service. Many a park superintendent received thoughtful counsel from Starker - just for the asking. So many of the present critics could never dare to serve - their role is limited to critic at large - gadflies. Starker liked to roll up his sleeves and plunge into the maelstrom.

Many of his devoted friends and admirers are in this room. Those who knew him learned to love and respect him.

My perspectives on the recent fire actually date to one crisp September day in 1974. I flew by helicopter with Starker and then-Yellowstone Superintendent, Jack Anderson, from Mammoth Hot Springs to Grand Teton to visit with then-Superintendent Gary Everhardt, who was at his wits end coping with a large fire that had burned down to Jackson Lake. The fire refused to burn itself out. I had invoked the so-called "let it burn" concept for our parks and poor Gary was the first guinea pig!

On the flight to Grand Teton, high over Yellowstone, I asked Starker and Jack what would happen if the combination of a low snowfall winter, a very warm, dry spring and summer, and a lightning strike occurred.

In response, Starker ordered the helicopter pilot to land us in a meadow high up on the Yellowstone plateau within easy walking distance of a lodgepole pine thicket. Starker plunged into the midst of this horizontal and vertical jungle - it was filled with dead trees, snags and deadfalls. The forest floor resembled a giant's residue of the game "pick up sticks." It was piled six feet high with tinder-dry poles. Starker just picked up a handful of dry tinder and passed it to me. "What will Americans think when this fire in the making ignites?" I asked.

Jack and Starker weren't sure. The implications, though obvious, were complex. It depended, they thought, on education and public sophistication and on how many knowledgeable, influential American ecologists and environmentalists would stand up and speak for the benefits of the predictable fire.

Starker made this profound point - fire was neither good nor bad. Fire was like hurricanes, tornadoes, and earthquakes - fires were natural occurrences, beyond the power of puny men to control. Fire was a happening - a natural sequential happening. It had to be carefully explained or the idiots would have their day.

In the ensuing controversy over the Teton fire, I learned a great deal about fire: the issue of the economic return the parks represents to parasitic local communities - and I hasten to add I use this term in the technical sense as "any organism that grows, feeds and is sheltered on or in a different organism" - and not disparagingly - I recognize the strain and public relations backlash on the public that only a fire in our parks can have.

I lost a friend in the ensuing embroglio - the Chairman of Grand Teton Park's Advisory Board who could not understand why a fire should not be promptly controlled during the tourist season. I was vigorously reminded by Wyoming's Senators of the depressing economic impact that fires have on adjacent communities whose income is so dependent on visitation. Nevertheless, with the Secretary's support, I stuck to my guns and refused to order the fire "controlled." I must admit to a great sense of relief when the last flickering flame was smothered by a September snow storm.

In essence, the reaction of the American public depends on the Park Service's devotees and the scientific community. I want to commend the articulate spokesmen of the past from the conservation community, such as Tom McNamee of the Greater Yellowstone Coalition and Professor Norman Christensen of Duke University and his post-fire assessment committee, as well as Professor Henry Wright of Texas A&M, the father of modern fire ecology.

During the approximate same time frame that we first confronted the public flames of fire management, we embarked on what was to prove one of the most successful restoration programs in park ecology in America: the recovery of Yellowstone's fisheries. Again, Starker and many of you in this room were integrally involved and played major roles in this phenomenal success story.

In the late 1960s, we recognized the collapse of Yellowstone's cutthroat fishery. Superintendent Jack Anderson led the charge and, with your ardent support, we began to overhaul the management of the rivers in the park in 1973. On the periphery of the park and throughout the west, Starker's plea to look at watersheds as an ecosystem bore fruit.

Bill Platt's studies have confirmed Leopold's theory that unrestricted livestock grazing and/or recreation use can seriously degrade streamside areas. We now know that the condition of riparian areas is central to the survival of wild trout and their habitat. In the park, we began to overhaul our fishing policies in Yellowstone Lake in 1975. The condition of the park's fisheries was so bad that it took seven long years to work our way out of ecological collapse to a return to healthy populations.

Since the mid-1980s, Yellowstone's fisheries have been restored to their historical health and abundance to the enjoyment of thousands and thousands of anglers and, I might add, contributing substantially to the economy of surrounding communities.

There are two chapters to this story that are too seldom read to the public. First, it was this group gathered here today that propelled and supported the implementation of restorative policies. Back in the early 1970s, you were the small minority proposing intelligent, biologically based management. What you proposed was heresy. It was not supported by the general public, by the state fish and game agencies, or by many in the Park Service and other federal agencies. The only vocal and forceful constituency for no-kill fishery management policies was the fly fishing community.

Within some limits a system can and will heal. We have seen it heal and you have helped to achieve it. We do not know the exact point of destruction - but what is important is that healing will occur if we allow it to occur. We need to repress our driving desire to manage, to control. Yellowstone did quite well without any of us for thousands of years. It made it without us. As a matter of fact, the world may have been a far better place before biologists, bureaucrats, gurus, philosophers playing biologists--even before former Assistant Secretaries.

Rereading the symposiums, I am reminded of how far we have come. The vast majority of the state fish and game commissions gradually have become sufficiently enlightened and have implemented restrictive limits on many blue ribbon trout streams. Many fisheries across the West have responded from these restrictions and more enlightened land and riparian management policies and have rebounded with robust fish populations. Today, I feel as if I stand at a reunion of Robin Hooders reliving days gone by; it is hard to believe how heretical our programs once were.

The second chapter is even more impressive, but perhaps not known to you, whose primary responsibility is fisheries management. That is the recovery of those other wildlife populations in the park dependent upon the fishery. Osprey populations have rebounded; nesting pairs are up 70 percent from the late 1960s. Bald eagle populations have more than doubled; nesting pairs now over fifty, up 131 percent. The eradication of DDT obviously was also a major factor in the recovery of these two species. White pelicans nesting in the park during the 1980s have recorded the highest nest productivity in this century.

To the general public, no species is more closely associated with Yellowstone than the grizzly bear and the grizzly has been a major beneficiary of Yellowstone's restored fishery. This has been a major chapter in the successful recovery of grizzly populations in Yellowstone today.

Let me pause in my telling of grizzly events - and no issue has given me such a mauling, and I still bear the scars - the puns are intended: to pay tribute to another giant in our ecological pantheon, Durward Allen. Durward has a greater understanding of the role of major predators in the ecological community than any man alive in America. His pioneering work and that of his grad students on the wolves of Minong on Isle Royale is a towering monument of Eiffel proportions in the world of biological science.

Durward always has a twinkle in his eye, like an Irish leprechaun, which masks an unparalled sagacity not only for the creatures of the biological world but also for the dynamics of humankind. Durward has always had his finger on the human pulse and over the years has provided insightful advice to Interior officials at every level.

In his address to the 50th anniversary conference of the North American, he stated:

> "When we look closely at major issues of today, they quickly broaden out into what we properly call human ecology. This intermingle of causes and effects has components ramifying into environmental biology, population dynamics, sociology, human behavior, economics, living standards, - divisions and subdivisions without end."

In so speaking, Durward must have had the story of Yellowstone's grizzlies in the past two decades in his mind's eye. It is a story too complex to retell, but again, there are two chapters that bear relating.

The recovery of the grizzlies of Yellowstone can be traced from my informal interagency discussions held each September here in Mammoth Hot Springs. Starker and Durward would join me for five days of work and fishing. The meetings were open - public workshops. There were structured morning sessions - a notable biologist would give a paper, then would be questioned and debate initiated. What fun! Many of the great biologists of our time came at their own expense to join the fun, and what fun it was.

The informal gathering did not continue, especially after Starker's untimely death. But the foundation had been built and our successors finally realized that a formalized Interagency Grizzly Bear Committee had to be formed and supported. How intelligent, how sensible - oh, but so very difficult. To those persistent, nameless champions - we give thanks, grateful thanks. Those of you in this audience who made it work - thank you - thank you - thank you.

Founded in 1983, the committee, as in the case of the fly fishing community's involvement in the Yellowstone fishery, began as a lone wolf, to borrow a metaphor from Durward. It faced opposition, suspicion, and rhetoric from the scientific community, the environmental community, and many segments of the state and federal agencies. And yet it has been an unparalleled success story and a model for other contentious wildlife issues such as the spotted owl.

The recovery criteria for Yellowstone's grizzlies is a three-tiered equation: (1) A minimum of 15 females with cubs on a running six-year average; (2) occupancy by females with young in 15 of 18 bear management units; and (3) mortality of no more than two adult females per year, or seven bears total. Last year, in 1988, we came within a hair of meeting these criteria; we met the first (female with cubs) and the third (five bears lost but no adult females) and had occupancy in 14 of 18 units, with occupancy by bears in two additional but non-designated areas.

So far this year we have another excellent report card: as of August 29 we had 14 unduplicated females identified and no human induced mortalities in the Yellowstone ecosystem. The occupancy units have yet to be determined but I am optimistic and enthusiastic. The bears are doing very well this year. Last year's fires combined with the first normal winter of precipitation in six years have provided a bounty of carrion. Further, this year has produced a bounty of white-bark pine nuts, in fact, the highest crop and production levels recorded since study began. The bears are doing well - they are preying on elk calves and cutthroat trout throughout the recovery zone.

The extent to which the cutthroat spawning streams have become a major food source for grizzlies has been documented thoroughly in recent years. We have known since the early 1970s that grizzlies feed extensively on cutthroats, although the Craigheads reported no such feeding as part of their studies in the 1960s. Today, at least 60 individual bears are known to feed on the 140 spawning streams in the park. One of the reasons the bears are doing so well today is because of the recovery of the Yellowstone Lake fishery. The National Park Service is managing the ecosystem better.

Steve and Marilyn French, with their marvelous camera work and patient study, have documented this feasting behavior and the bear's almost gluttonous enthusiasm. One bear was observed to eat 28 fish averaging a pound and a half apiece, in twenty minutes. It has not been uncommon to observe bears consuming as many as 80 to 100 fish over a three hour period. Grizzlies prefer to feed early in the morning or in the early evening, but they also are feeding at night when it is difficult to document the numbers of fish taken. Over a 10-day period the Frenches have observed bears feeding on five to seven different spawning streams twice each day. These are streams that are only a desk top wide and ankle deep. Concentrations of nine bears have been observed feeding during the same ten day period, although unlike in Alaska, they do not feed shoulder to shoulder, but rather spaced as far as a kilometer or two apart. Teaching catch and release to grizzlies may be somewhat more difficult than teaching it to the average Yellowstone fly fishermen.

As Durward and his students have shown with their magnificent studies, predator-prey relationships are anything but simple equations; they can be highly variable and the menu can change from year to year. Nevertheless, in the case of Yellowstone, there is a clear parallel between the recovery of the great cutthroat fishery and the recovery of the grizzlies of Yellowstone. In the closing remarks of his speech at the North American, Durward said,

> "But we will leave our record for anyone to see. It will be written on the land, in the rivers, and in the sky: The people who care will read it and they will know how well we did."

Look around you today in Yellowstone - at the fisheries and other components. While the park's critics churn out their pulp critiques and bewail the demise of dozens of species and the whole ecosystem, I ask you to tell me what you see. Eyes don't lie. And recent biological and empirical data substantiate the obvious. There are still problems with the park and they abound beyond the borders, but significant progress has been made.

As the Washington Post's T. R. Reid took his fellow media writers to task in his superb article on July 23, 1989 over their handling of last summer's fires, I encourage the academic, conservation, and professional agency communities to stand up and be counted. I ask you to stand behind our parks and fish and wildlife resources in a positive and constructive manner and to defend them from ecological nonsense.

Who is playing "God" in Yellowstone?

Could it be that the advocates for hands-on management really believe they are equipped with the knowledge to order fires started - as if once started they could be put out at will; or that they have the Godlike wisdom to supervise the execution of bison and elk that they decide are in their personal view "surplus?"

Is that not playing at being God?

I prefer the real acts of God. They require patience and discipline, virtues Yellowstone critics do not have as long suits.

That frantic need to manage at all costs has been so carefully taught in the university systems that the thought of letting nature take its course - of letting God play God - which is the principle behind the Park Service's mandate - is driving the critics "nuts." Before we even think of giving up this mandate we must carefully review the many recommendations of the two wise men mentioned earlier.

As one grows older, some things become more precious. I still treasure each fish, and the fishery, and the habitat, and the ecosystem. I need not kill a trout to have a wonderful outdoor experience, but I desperately need to know that a continuum of intelligent, caring men and women are working to restore depleted fisheries and to safeguard those that are in good shape. It is the act of caring - people filled with care - that I want to see continued. You represent those caring people who finally are being heard from coast to coast.

The growing environmental crisis will soon become readily visible even to the most doubting of Thomases.

A younger, more environmentally attuned American, who is more than willing to sacrifice for wild trout and the health of ecosystems - yes, even just for aesthetics - will play a prominent political role in years to come. The question will be timing - will their collective efforts come in time to protect the great wildlife legacy and the ecosystems on which wildlife depend?

That's the test of wills that Durward spoke of. That's the goal that we share with Starker and Durward and Jack Anderson.

We now know there are no forevers - only the constant need to better manage man's rapacious appetites. But you, my friends, by your presence here, are the caring vanguard that will save plant earth and the wild trout that seek to share space with us - demanding mankind.

You have all earned my sincere admiration and respect for your dedication and good solid science in the past fifteen years, and I already look forward to seeing more extraordinary results in five more years. Thank you for the honor of being your keynote speaker at this superbly crafted conference.

Summary of Progress in Wild Trout Management: 1974-1989[1]

Robert J. Behnke[2]

Abstract.--A major impediment to greater emphasis on wild trout management is the reliance on put-and-take catchable trout stocking to supply the demand for angling. A change in this situation will not come about from emotional appeal but from economic analysis of costs of creating angler days by catchable trout stocking compared with various alternatives based on wild trout and put-grow-and-take stocking.

I reviewed the proceedings of the three previous Wild Trout symposia for some clues to help produce a summary statement on the status of wild trout management that can be used in the future as a benchmark for assessing progress. It soon became clear that if this were to be accomplished, the problem of moving from generalities to specifics had to be resolved.

Willis King served as summarizer for the 1984 symposium (Wild Trout III). After three wild trout symposia, Willis noted that, "the status of hatchery vs. wild trout is still not fully understood", and that much discussion on this subject only, "demonstrated the hazards of generalities." Willis' remarks are a good starting point to move from generalities to specifics to more sharply focus on components of the hatchery vs. wild trout controversy. Hatchery trout are any trout hatched and/or raised in a hatchery (including the offspring of wild trout) and can be divided into catchable trout used in put-and-take fisheries, and fingerling or subcatchable trout used in put-grow-and-take fisheries. With both groups of hatchery trout, the main concern of an efficient program is cost-effectiveness. How many fish, weighing how many pounds, costing how many dollars are stocked compared to how many of these fish, weighing how many pounds are caught by anglers to support how many angler days.

The more successful put-and-take fisheries can expect to return 7 to 9 pounds of fish for each 10 pounds stocked. From an economic point of view of maximizing returns on investment, put-and-take management is a loser. In relation to the conservation mission of natural resource agencies to preserve and enhance, put-and-take management is in noncompliance (perhaps a necessary evil but one whose role should certainly be minimized).

Put-grow-and-take stocking is essentially restricted to lakes and reservoirs where natural reproduction is nil or serverely limited. Effective put-grow-and-take fisheries can return 10 to 50 pounds or more of trout for each pound stocked. Obviously, put-grow-and-take stocking can be enormously more cost-effective in creating angler days of use than put-and-take catchable stocking.

In most states, the ratio of surface areas of lakes and reservoirs stocked with salmonid fishes to surface areas of all streams manintaining trout populations ranges from about 5-10:1. It now becomes obvious where the emphasis on the use of hatchery trout should be made: to maximize angling quality and cost-effectiveness of put-grow-and-take stocking. The more successful the put-grow-and-take programs, the less angling pressure exerted on wild trout streams, resulting in an accelerated rate of implementation of wild trout management with special regulations.

A point to emphasize is that the effectiveness of put-grow-and-take stocking can be greatly increased by research on the selective use of wild races of trout for hatchery propagation and stocking (Behnke 1983). Greater effectiveness of put-grow-and-take programs is impaired by an imbalance in many agency hatchery programs burdened with an overemphasis on catchable trout production.

Nathaniel Reed, then Assistant Secretary of Interior, gave the concluding remarks at the first Wild Trout Symposium (1974). Mr. Reed first read a telegram from Secretary of Interior Rogers Morton ... "The future of wild trout, well-balanced with selective use of hatchery trout, is in your collective hands." This telegram probably reflects a plea for caution and discretion on the part of

[1]Summary paper presented at Wild Trout IV Symposium. Yellowstone National Park, September 18-19, 1989.

[2]Robert Behnke is Professor of Fisheries, Colorado State University, Fort Collins, CO.

Mr. Reed as chief spokesman for the U.S. Fish and Wildlife Service--the agency that operates the world's largest system of trout hatcheries. Denigration of hatchery trout would be an embarrassment. If we look upon this telegram as the official position of the U.S. Department of Interior and translate the specific meanings of the general terms "well-balanced" and "selective use", I provide the following interpretation: "well-balanced" means not only a balance between wild trout and hatchery trout but also between hatchery trout used in put-grow-and-take fisheries and hatchery trout used in put-and-take fisheries. "Selective use" means not only maximizing the cost-effectiveness of well-planned stocking programs, but also the selective use of wild races of trout to increase the effectiveness of put-grow-and-take fisheries.

It should be noted that emphasis was made on the "selective use" of wild races of trout to greatly increase the effectiveness of put-grow-and-take programs in previous Wild Trout Symposia (Webster and Flick 1975, Behnke 1980, Leopold 1980).

Wild trout vs. catchable trout management controversies will not be resolved by emotional rhetoric but are amenable to economic analysis. For example, if we ask what it would cost to replace or duplicate the present catch-and-release fishery for native cutthroat trout in the Yellowstone River in Yellowstone Park by catchable trout stocking (without any reference to differential values of an angler day based on angling for a rare, wild native trout compared to a feedlot fish), the following assumptions are made. The cutthroat trout caught by anglers in the Yellowstone River generally consist of fish of ages 4, 5, 6, and 7. Each trout, on average, is caught and released about 10 times during one year. Assuming annual mortality rates near 50%, each trout would, on average, be caught and released about 20 times during its life. The average size of the cutthroat trout caught in the fishery is about 16 inches.
To create a comparable fishery with put-and-take management, assuming a 67% return on stocked catchable trout, 30 catchable trout would have to be stocked to produce a catch of 20 fish. A minimum cost of producing a 16 inch catchable trout in a hatchery is $3.00. Thus, each Yellowstone cutthroat trout in the Yellowstone River wild trout fishery would have a replacement cost of $90.00 if a put-and-take fishery attempted to duplicate the present wild fishery. Such economic logic will be far more effective for attaining proper "balance" in fisheries programs than emotional appeals to ethics and morality (which are viewed by many as manifestations of snobbery and elitism).

Thirty years ago, in 1959, Trout Unlimited was founded in Michigan, specifically to lobby for a more equitable balance between wild trout management and the stocking of catchable trout. The winter, 1980 issue of Trout Magazine contained interviews with T.U. founders George Griffith and Art Neumann who expressed their frustrations in regards to "balance" of the Michigan fisheries program during the late 1950's - "A million and a half catchables a year were being stocked...we knew it was a great waste."

The organized interest in wild trout, promoted by T.U., led to the first Wild Trout Symposium of 1974. Nathaniel Reed's address to Wild Trout I, reflected the contemporary opinion of the audience that the tide had turned in relation to the balance between wild trout and catchable trout management. Reed said: "The age old practice of dumping fish off bridges into all fishable waters will be all too expensive to consider in a very short space of time."

By 1989 and Wild Trout IV, we might assume, based on the past 30 years of organized promotion of wild trout management, that the age of enlightenment is upon us; catchable trout programs are contained and the balance in emphasis and funding in modern fisheries management programs has now shifted to wild trout and their environments. This assumption is implied in the 1989 draft of the T.U. North American Salmonid Policy. Under the section, "Use of Hatchery Fish", the following statement is found: "As a last resort, in urban areas, where stream conditions prohibit year round survival, stocking of catchable salmonids is an acceptable method for introducing an appreciation for trout angling and salmonid ecosystems." The limitations of catchable trout stocking as a "last resort", in "urban areas", only in waters incapable of sustaining wild trout, and as an educational tool, certainly imply that the visionary ideals of T.U. founders have been fulfilled.

Facts and figures tell us otherwise. The 1986 book, Fish Culture and Fish Management, contains data documenting a 25 year trend of hatchery salmonid production summed for all federal and state hatcheries in the United States. In 1958, a total of 169.4 million salmonids were produced in all hatcheries, 50.2 million of which were catchable trout. In 1983, 256.5 million (53% increase) salmonids were produced, of which, 78 million (55% increase) were catchable trout!

It may come as a surprise to many that during the past 30 years since the founding of T.U. and during the past 15 years covering four Wild Trout Symposia, the balance between wild trout and catchable trout management really hasn't significantly changed. How can this be? What can be done about it? As pointed out above, the answer lies not in expression of outrage or emotion, but in the cold logic of economics.

Earlier this year, I collaborated with a graduate student in economics to address this question of proper balance of catchable trout in a fisheries management program (Behnke and Johnson 1989). Table 1 is reproduced here from the Behnke and Johnson paper.

TABLE 1: Comparative data on catchable trout programs of selected states. Numbers of catchable trout and costs from Fisheries, Mar.-Apr. 1988 based on 1982 figures for Colorado and Wyoming (1983 figures for other states). License sales and revenue data from S. F. I. Bull., Aug. 1987 (1986 figures).

State	Catchable Trout Stocked	No. Licenses Sold (No. Catchable Per License)	Total Revenue (Catchable Per Dollar	Cost of Catchable Production	Cost per Catchable	Cost of Catchables per License	Percent of License Revenue
CO	5,419,802	842,367 (6.4)	$ 8,112,431(.67)	$3,047.127	$0.56	$3.62	38%
CA	12,350,000	3,425,717 (3.6)	$36,768,883(.34)	$5,000,000	$0.40	$1.46	14%
ID	2,221,881	469,667 (4.7)	$ 4,259,384(.52)	$ 925,000	$0.42	$1.97	22%
NV	885,335	258,907 (3.4)	$ 2,359,840(.38)	$ 503,352	$0.57	$1.94	21%
NM	1,412,840	262,748 (5.4)	$ 3,153,737(.45)	$ 673,000	$0.48	$2.56	21%
NY	2,138,541	1,140,926 (1.9)	$ 9,446,449(.23)	$2,500,000	$1.17	$2.19	26%
OR	2,351,230	1,115,944 (2.1)	$10,471,777(.22)	$1,500,000	$0.64	$1.34	14%
PA	4,911,600	1,110,054 (4.4)	$12,687,629(.39)	$3,966,800	$0.81	$3.57	31%
UT	1,569,856	421,746 (3.7)	$ 5,715,367(.27)	$ 784,928	$0.50	$1.86	14%
WA	2,528,000	1,156,777 (2.2)	$11,337,798(.22)	$1,280,000	$0.51	$1.11	11%
WY	1,209,172	285,000 (4.2)	$ 3,351,403(.36)	$ 302,000	$0.25	$1.06	9%

We selected states representative of varying amounts of cold water habitat (the potential supply for wild trout, or for put-grow-and-take management) and different amounts of angling pressure (the demand for angler days of recreation). With such basic data, any agency's fisheries program can be evaluated for "balance" in economic terms. I would point out that we found the stated costs of catchable trout production to be vastly underestimated in terms of actual costs to the public. Accepting an agency's undervalued costs of catchable trout production, however, the first step of analysis concerns estimating the percentage of angling license revenue that is devoted to catchable trout production and then estimate the number of catchable trout stocked to support (or create) an angler day of recreation. For example, with a 60% return, and an average catch of three trout per angler day, five trout must be stocked for each angler day dependent on catchable stocking. If, for example, 30% of total license revenue is used to support catchable trout stocking, and this stocking supports one million angler days per year, and the total number of angler days in the state is 10 million, then an economic imbalance is apparent--30% of revenue is used to supply only 10% of the demand.

It is this type of economic analysis that will effect "balance" in fisheries programs. It must be recognized that some options to increase angler use by increasing the abundance of wild trout may not be as cost-effective as stocking catchable trout (even though the economic valuation of an angler day for wild trout is considerably greater than an angler day based on catchable trout). Unless labor, equipment, and materials are donated, stream improvement projects can be very expensive, even if amortized over a 25 year period. The costs of producing increased abundance of wild trout from stream improvement, if the agency pays all of the costs, is not likely to compare favorably with the costs of supplying the additional angler days by stocking catchable trout.

Criticism of catchable trout management and pleading for a better balance in an overall fisheries program, do not provide sufficient basis to effect a change in an agency's way of doing business. Feasible options must be suggested that can produce angler days of recreation at less cost than can be produced by stocking catchable trout --with an assumption that the potentials of these options are not now being fulfilled because of disproportionate funding of the catchable program.

The most obvious and cost-effective option is the recycling of fish in special regulations fisheries. This option is limited by the percent of licensed anglers who would fish in waters where most or all of the fish caught must be released. A "best approximation" of trout anglers who would regularly fish special regulation waters is about 20% (based on Donn Johnson's graduate research on Colorado anglers). This figure suggests that although special regulation waters could be greatly expanded, considering cost-effective increases in angler days for all anglers of a state, two options, emphasized at all previous Wild Trout Symposia, hold great promise.

The first option concerns the "selective" use of wild populations of trout, propagated in hatcheries and stocked as fingerlings in lakes and reservoirs to increase the cost-effectiveness of put-grow-and-take fisheries by increasing the survival, growth, and longevity of the stocked fish and by the stocking of two or more species, subspecies, or races to increase total production by "polyculture" or "niche packing" as discussed by Trojnar and Behnke (1974).

This "selective" use of special races of wild trout appeared to be the intent of Nathaniel Reed's remarks to the Wild Trout I Symposium when he spoke of genetics, stamina, survivability, and ability to grow as the key factors in fish production in the future. Mr. Reed went on to say that he hoped to see the U.S. Fish and Wildlife Service take a leadership role in developing such strains of fish.

I suspect that when Mr. Reed returned to Washington and called in his staff to discuss implementation of this leadership role in strain development, he was given bad advice--to the effect that all of these desired traits could be selectively bred into domesticated hatchery strains (which is comparable to selectively breeding strains of wheat or corn to successfully survive and grow in competition with wild plant species without cultivation, irrigation, herbicides or pesticides).

At Wild Trout II Symposium in 1979, Mr. Reed's successor as Assistant Secretary of Interior, Bob Herbst, told the audience of some "heady results" of a "new brand of management" by the U.S. Fish and Wildlife Service. Herbst discussed the testing of 12 hatchery and 6 wild strains of rainbow trout with an "eye to improving the species". I suspect this is another example of the Assistant Secretary receiving bad advice--there is no way a species can be "improved", in relation to survival in nature by selective breeding under artificial conditions. In any event, during the past 15 years, there has been no leadership role by the U.S. Fish and Wildlife Service or any other agency in the "selective" use of wild races for increasing growth, survival, and total returns from stocking in put-grow-and-take fisheries. There are a few hopeful examples, initiated at the local level, of programs to utilize natural genetic diversity in fisheries management such as the propagation of the native Bear Lake cutthroat trout in Utah and of Eagle Lake rainbow trout and Gerrard strain Kamloops rainbow in Wyoming, but no "leadership role" is yet apparent among the top administrators of any state or federal resource agency. Why this is so might be perceived from examining the data of an agency's hatchery program. In 1988, catchable trout made up 93.5% of the total fish production in all Colorado hatcheries (including all warm-water and all cold-water species). There isn't much room left in the hatcheries to experiment with selective use of strains, or funds to conduct the critical research to learn what strains work best in relation to various combinations of biotic and abiotic factors.

The failure of leadership to promote the selective use of wild strains of trout is illustrated by the case of the Lahontan cutthroat trout native to Pyramid Lake, Nevada, the world's largest cutthroat trout and a genetic resource of great potential value.

Hickman and Behnke (1979) reported that the Pyramid Lake cutthroat, believed extinct since 1938, had been found existing as an introduced population in a small stream on the Nevada-Utah border--and that the genetic resources of the world's largest cutthroat trout were available for fisheries management. The March 17, 1980 issue of Sports Illustrated contained a feature story on, "The fish that wouldn't die." The story mentioned that the U.S. Fish and Wildlife Service would gather eggs and take them to the Hotchkiss, Colorado, National Fish Hatchery--a breeding stock will be developed and fingerlings would be stocked in large reservoirs full of forage fish. In reality, the U.S. Fish and Wildlife Service's "leadership role" terminated when the eggs hatched at the Hotchkiss hatchery--and all of the fish died (not unexpected when wild strains are attempted to be raised in a hatchery specializing in the production of domesticated hatchery strains). The U.S. Fish and Wildlife Service did push ahead to develop a domesticated hatchery strain of Lahontan cutthroat trout at their Gardnerville, Nevada, hatchery for stocking Pyramid Lake. The hatchery selection did reduce production costs, but survival after stocking was so poor, this "selective" strain was abandoned. I doubt that this was the type of selection that Mr. Reed had in mind at Wild Trout I when he discussed the hoped for leadership role by the U.S. Fish and Wildlife Service, or that it represented the "exciting brand of management" of strain development reported on by Mr. Herbst at Wild Trout II.

The November 6, 1989 issue of Sports Illustrated has another article on Pyramid Lake and its cutthroat trout, "Lost and found: a fish story." When the author inquired on progress being made to propagate and utilize the original Pyramid Lake strain, he was told that, "...attempts to reestablish the true Pyramid Lake cutthroat trout in its home waters have been inconclusive, but the effort continues." According to all information available to me, there has been no attempt to "reestablish" and "efforts" to do so were discontinued in 1980 when all of the newly hatched fry dropped dead.

All "efforts", to at least preserve the genome of what is left of the original Pyramid Lake cutthroat trout, have occurred at the local level--from the "bottom-up", not by leadership from the "top-down"--by regional biologists with the Utah Division of Wildlife Resources. The Pyramid Lake cutthroat trout saga illustrates the problems of moving from generalities to specifics, from talk to action, without a clear understanding of the distinctions and the management implications between wild trout under natural selection and hatchery strains under artificial selection. This example also recalls Willis King's observation at Wild Trout III on the "hazzards of generalities."

The second major option I propose to create more wild trout and more angler days at lesser costs compared to stocking catchable trout, concerns better multiple use management on federal lands (mainly BLM and USFS lands). In the 11 western states, from the Rocky Mountains to the Pacific Coast, half of the land and most of the cold water habitat is under federal control. Most of this land is subjected to logging, mining, and, particularly livestock grazing. These commodity uses have historically dominated over fish, wildlife and environmental values when in conflict under "multiple use" management. I served on the Riparian Committee of the Western Division of the American Fisheries Society. Our committee report estimated a degradation of 19,000 miles of trout streams on federal lands in the 11 western states due to livestock grazing alone (I believe the actual amount is greater because many, once excellent streams, have been so degraded they are shown on maps as intermittent, not capable of supporting fish).

Starker Leopold at Wild Trout II and Ben Dysart at Wild Trout III stressed that better wild trout management is inextricably connected to better watershed management. Leopold said: "I urge all of you who administer fisheries programs to assign a high priority to the study of watershed relationships to trout populations." Better multiple use management resulting in better watershed management and restoration of degraded stream habitat has the potential for truly enormous increases in wild trout production. We had a presentation at the present symposium documenting examples of improved multiple use management resulting in restoration of riparian and stream habitat. As with most other similar examples of riparian management, however, the improvements are initiated at the local level, from the "bottom-up", cooperatively conducted by biologists of a state agency, the BLM and/or the USFS, often organized at meetings of local chapters of the American Fisheries Society or the Wildlife Society. The impetus, by-and-large, for implementing fish and wildlife habitat enhancement through better multiple use management, has not come from the top agency administrators to whom Starker Leopold was addressing his remarks.

A state agency overly committed to catchable trout production is not likely to have the funding, staff positions, or expertise available to take a leadership role and vigorously pursue the issue of better multiple use management on federal lands.

To assess the status and balance between wild trout and hatchery trout management and evaluate progress at Wild Trout V in 1994, wild trout enthusiasts should have their facts and figures and their act together to ask hard, penetrating questions of administrators in an attempt to move from generalities to specifics. I do not suggest that a congenial atmosphere be replaced by hostility, but I believe it is not unfair to encourage and expect a higher level of knowledge and credibility among both biologists and administrators involved in wild trout and catchable trout management.

At Wild Trout II, the state director's view was expressed by the late Jack Grieb of Colorado (whom I admired as one of the more knowledgable and credible directors of his time). Jack told the audience that it was unfortunate that criticism of catchable trout programs existed. He cited the fact that 230 Colorado reservoirs of 35,000 surface acres were stocked with catchable trout. Without this stocking there would be reduced angling opportunity, reduced license sales, public outcry, and political pressure on the agency. I would not disagree with these remarks but I would point out that much was left unsaid. It would be fair to inquire on what efforts were made to reduce the cost of producing angler days of recreation in these waters stocked with catchables by also stocking fingerlings or subcatchable trout of selected strains in put-grow-and-take fisheries. Klein (1976) demonstrated that even in a typical put-and-take catchable trout lake (West Lake, which receives more than 2000 hrs./acre/year of angling pressure), costs of stocking to support this high angler use could be greatly reduced, if, in addition to catchable trout, fingerling rainbow trout and brown trout were also stocked for a put-grow-and-take fishery. Klein's report also mentions preliminary results from stocking Snake River cutthroat trout at a size of 950/lb. (these fish were surplus from a research project) in West Lake. The following year, an estimated (by creel census) 47% of these trout were caught, and some trophy sized fish were caught in following years. For each pound of cutthroat trout stocked, about 200 pounds returned to the angler's catch--and in a lake intensively fished at more than 2000 hrs/acre.

Some appropriate questions concerning the 35,000 acres of reservoirs stocked with catchable trout would be: How much of what was learned from the study of Klein (1976) and of Trojnar and Behnke (1974) regarding maximizing cost-effectiveness of put-grow-and-take fisheries have been or are being applied to reduce stocking costs for these reservoirs, and at the same time improving angling quality? Has the state compiled an inventory of drainages on BLM and USFS lands to identify habitat degraded by multiple use management? What actions have been taken to urge (or force) compliance of the mandates of multiple use to restore degraded habitat and increase wild trout production?

Questions such as these should be critically addressed at the next Wild Trout Symposium to allow for clearer resolution of the question of balance between wild trout and hatchery trout in natural resources managment and to assess progress.

LITERATURE CITED

Behnke, R. J. 1980. Research Panel discussion summary. Proc. Wild Trout II:8-9.

Behnke, R. J. 1983. Wild trout sport fisheries and hatchery programs for the future. Pages 31-32 in K. Hashagen (ed.). The role of hatcheries in the management of wild salmonids, proceedings of symposium. Calif. Trout, San Francisco.

Behnke, R. J. and D. Johnson. 1989. The role of catchable trout in a state fisheries program: how much is enough? Proc. 24th Ann. Meet. CO-WY Chapt. Am. Fish. Soc:92-99.

Hickman, T. J. and R. J. Behnke. 1979. Discovery of the original Pyramid Lake cutthroat trout. Prog. Fish Cult. 41(3):135-137.

Klein, W. D. 1976. Fishing use, harvest, and stocking evaluations of West and Dowdy lakes. Colo. Div. Wildlife, Div. Rep. no. 7.

Leopold, A. S. 1980. Summary - Wild Trout Symposium II. Proc. Wild Trout II:2-4.

Trojnar, J. R. and R. J. Behnke. 1974. Management implications of ecological segregation between two introduced populations of cutthroat trout in a small Colorado lake. Trans. Am. Fish. Soc. 103:423-430.

Webster, D. A. and W. A. Flick. 1975. Species management. Proc. Wild Trout I:40-47.

Creating the Environment for More Cold-Water Habitat with Win-Win Situations[1]

Benjamin C. Dysart III[2]

Abstract.--We've come a long way in recognizing the complexities of the cold-water habitat business. We must recognize all the components—in the stream, in the watershed, and in the decision-making arena—and understand the linkages if we're to be successful in protecting, improving, and restoring trout habitat. Success means creating winners for all legitimate players, and that requires rethinking our approach to environmental protection, making smart decisions in time and space, and focusing our efforts, talents, and resources on what it takes to produce good results.

Good afternoon. I'm pleased to be here with you, as part of this fine Wild Trout IV symposium. My congratulations to those who put this together.

As a resource professional, I'm among people whom I respect, people who share my feeling—my conviction—that we're doing something worthwhile for the cold-water fish resources, their habitat, anglers, and society in general.

As an angler—mainly a fly fisherman—I'm among the famous and the accomplished and—as a comparative amateur—have the opportunity to sit at their feet and learn as well as be regaled with their accurate accounts of successfully waging a contest of wits with the wily great trouts, and to be regaled with obvious lies, told with as much expertise as the few non-exaggerated tales.

Yesterday's luncheon speaker said he was taking the Hon. John Turner's place. I was told the same thing. I suppose that, if you're an especially outstanding and able person, as John surely is, then it takes at least two people to replace you.

Speaking of really big men, five years ago both then-Assistant Interior Secretary Ray Arnett and I were on your program here at Wild Trout III. My secretary called to give me a message and talked to the desk clerk here at the Mammoth Hot Springs Inn.

She asked for me, and was asked to describe me. She said "He's big, really big." Response: "OK, I see two of them. Tell me more."

"He's tall, really tall" she said. Response: "No help, I see two of them here in the lobby, tell me more. What does he look like?"

"He's not too bad looking" she said. "Nope, he's not here. Both of these fellows are pretty ugly!" he said, and hung up.

Patsy finally caught up with me, told me about this, and I told the desk clerk that if he'd put on his glasses, he'd see that Ray Arnett was a little bit uglier than I was, and don't forget it! But most people would agree with him, and say it's about a toss-up.

Speaking of truly handsome people in the conservation, resource, and sporting sectors, I'm sure many of you know my friend Jay Hair, CEO of National Wildlife Federation. Jay and I are charter members of the Big Boy Round Face Conservation Leadership Council. It may still have only two or three members. Bill Howard, Chief Operating Officer of NWF, is a provisional member. And, if he'd grow another foot taller, we might let Jack Lorenz apply for membership.

I'd never realized that Jay and I looked so much alike, until I was touring a part of NWF's operations when I was NWF president a few years ago. As I walked down the row of work stations downstairs at our Laurel Ridge Center and speaking words of appreciation and encouragement to the employees, a lady looked up and said—reverently—"Good morning, Dr. Hair."

Not wanting to disappoint her and knowing what Jay—endowed with an overly generous supply of humility—would do, I absolved her of any sins, and offered her a copy of National Wildlife magazine autographed "Best wishes, Jay" across the front.

On the way out west Sunday, I told my associate, Ty Ziegler, that it was just great to be going to a major professional meeting with absolutely no responsibilities. All I had to do for a change was just enjoy and learn from the fine program and informal discussions, enjoy being in a wonderful setting, and enjoy seeing old friends and colleagues—and meeting new people—who share an interest in cold-water habitat and cold-water angling.

But within an hour or so of our arrival Sunday, I fell into bad company, was plied with alcohol by the likes of Charlie Loveless, Ernie Schwiebert, Gardner Grant, Marty Seldon, and Frank Richardson, and was invited to be your luncheon speaker today. I gladly accepted.

I'm proud of my affiliations with the conservation and sporting community, not only NWF and The Conservation Foundation, but also my involvement with Trout Unlimited and the Federation of Fly Fishers. I believe you can tell a lot about people by observing with whom they voluntarily associate. You can get a

---

[1]Luncheon address presented at the Wild Trout IV research symposium, Mammoth Hot Springs, Wyo., 19 September 1989.

[2]Benjamin C. Dysart III is past president of the National Wildlife Federation and a professor of environmental and water resources engineering at Clemson (S.C.) University.

good feel for what their values are, and how they're using their acquired and God-given talents. I'm proud to be voluntarily associated with the sponsoring organizations, with the likes of Frank Smith and Richard Mode, and all of you whom I've had the opportunity to get to know.

In the next few minutes, I'd like to react to—and reflect on—a few ideas that're floating around here at Wild Trout IV, and then pitch an idea or concept whose time has come. First, the reactions and reflections.

Five years ago, I cited, endorsed, and underlined the wisdom, good science, and good sense of Nat Reed, Bob Behnke, Starker Leopold, et al. in the previous two Wild Trout symposia. One of the key thoughts was that wild trout, good habitat, and comprehensive enlightened management were necessary for quality angling.

Another was that biological scientists simply had to be real players along with the policy makers, the business community, foresters, and—yes—even engineers. Another was that perhaps the key determinant of cold-water habitat—be it good, bad, or mediocre habitat—was what happens to and in the watershed.

Another was that water quality in the water column and substrate quality on the stream bottom are direct results of up-slope activity, beyond the traditional province of the fishery experts. Another was—as I recall—that the emphasis in this discipline had systematically shifted from trout to wild trout on to habitat and finally to ecosystem management. That's progress.

All are important thoughts, and they bring us all much more complexity and more components to manage and try to understand. And they also bring us bigger challenges, bigger opportunities for us to hit longer balls.

In his typically eloquent and inspiring keynote address yesterday, Nat Reed spoke of Starker Leopold and his strong preference for problem solving, plunging into the reality, putting his good science and his experience and values and good judgment to work on the ground, where it really counts. You and I can appreciate that.

Our environment is changing, not just our natural environment but the environment in which we work and function as resource professionals. Big changes have taken place—and more are needed and underway—in the politics of resource management, public perceptions, public involvement, and involvement of more publics in the management of their resources.

Starker Leopold wasn't the first—nor the last—to be accused of heresy and irreverence for bucking the safe conventional wisdom and swimming upstream. People with guts and conviction and special insights have always been called to do that at one time or another in their careers. That's when most of the big breakthroughs occur, not from orderly thoughts from the desk-bound—figuratively or literally—keep-it-between-the-ditches, little steps for little feet, tail covering semi-players and naysayers in the shadows or on the safe high ground. And that's part of the difference between leaders and inspiring examples and solvers of big problems, on the one hand, and some of the rest who are muddling along at the heads of some columns, on the other.

We simply have to have the likes of Starker Leopold, putting bigger and better wheels on good science and good research, and making a difference in the real world—which is where all the environment we're trying to manage and engineer and protect is, after all. And that, pushing and producing results, in turn, enhances these people's ability to produce more good science from their research. I'll admit that this is an editorial opinion, in case you didn't suspect it, but one that most people you and I can respect would be pretty comfortable with.

But let's move ahead. It's true, they *don't* make new trout streams, especially blue ribbon and gold medal streams. I've fished a number of them in Canada, Alaska, and here in the west in the lower 48. It's great to have a big rainbow roar out from under a cut bank in southwest Alaska or the Bristol Bay region and destroy a greased mouse, but it's also important for us to have the "little places" that're important to each of us. Such as the little places where we can flip a tiny little spinner under the dense rhododendron and see it attacked by a brightly colored little five-inch wild rainbow, for example in Corbin Creek, a small stream in South Carolina my own Chattooga River TU chapter is working on now.

It's true; they don't *make* any more, but we can *protect* some—perhaps a lot—of the existing streams by protecting their watersheds, and we can *improve* streams and sections of streams where appropriate and feasible. We can do this and we can *restore* some where feasible, where we have good cooperation of volunteer conservationists and sportsmen, state and federal resource management agencies, and the industrial and individual landowners. We can *save* winners, we can make *bigger* winners, and we can move some losers into the *win* column.

That's exciting! That's what makes this business different from mere work, and our good works for streams and the noble cold-water species more than just volunteer citizen activity for some good cause or another.

I think I've finished the "reacting to" and "reflecting on" part of my remarks, and now I'm into pitching what I believe to be an idea, and idea whose time has come—and is, in fact, overdue. Yes, we *can* protect and improve and restore.

But we have to be able to see where the *best* opportunities are for such protection, improvement, and restoration or rehabilitation. We have to, if we're to target the best resource waters and produce the biggest winners. We have to have the data, insights, and perspectives, so the hard—but necessary—trade-offs can be made and made in an intelligent, responsible, sensible manner.

We're talking not just about conventional "resource management" as taught by various departments in our universities, likely focusing on a specific resource category or sub-category or some facet of that category or subcategory. Our business is tougher now, a lot tougher. The sophistication of the publics is greater now. This sophistication may well be greater than that of our conventional resource managers and perhaps even those who train and direct them.

For example, in my own "environmental engineering" discipline, there's a terrific difference between "treating wastewater"—the mission of most traditional sanitary or environmental engineers in this and several previous generations—and actually "protecting the environment", the latter being both a greater technical challenge and, in my opinion, a much more exciting calling.

The complexity of the various publics' objective function is frequently greater than the excessively simplified system definition devised by conventional engineers and scientists. As I recall, Aldo Leopold had some thoughts about those technocrats who would over-simplify the real world and its components, so their standard textbook answers would seem to fit.

Now let me comment fairly briefly on what I've been up to since Wild Trout III. I've been looking a lot harder, in a much more focused and practical manner, at the generic components that we know must be understood to manage watersheds and do a better job of protecting the down-slope aquatic ecosystems—especially if they're cold-water habitat.

While I could give lots of examples, let me illustrate with a very generalized relatively straightforward situation involving soil erosion from land-disturbing activities in the watershed, perhaps from logging, roading, residential construction,row-cropping, building recreational complexes, mining, dam building, or whatever.

We have the following "components": (a) *precipitation* that drives the process; (b) *mobilization* of the soil on disturbed slopes; (c) measures to *reduce* such mobilization; (d) transport of water and soil material *overland;* (e) measures to *catch* some of the soil as it crosses the project boundary; (f) transport in small *tributaries;* (g) transport in and impact on the water column and substrate in *larger* streams—filling pools, sanding up gravels, and muddying the water during run-off events; (h) all sorts of mitigation and *rehabilitation* measures; and (i) transport to a *sink*, such as a lake or the ocean.

Regardless of the specific application, situation, or problem—any way you look at it—you have "components" and "linkages." Our Environmental Management Systems research group at Clemson focuses its research and field work on steep-gradient cold-water streams, looking at the physical, chemical, and biological factors—including extremely detailed physical habitat investigations for many miles of mountain rivers, creeks, and headwater tributaries—in the Southern Blue Ridge Escarpment. Our belief is that you can't manage—much less optimize—what you don't know about, what you don't appreciate, and what you can't start to understand.

Where *are* the good opportunities for cost-effective measures, structural or otherwise, special regulations, appropriate technology, creative designs and configurations, management strategies and mixes of approaches? What makes sense, so far as expenditure of dollars, manpower, political chips, etc. over *time* in an area—and in *space* in an area—on the various streams. We're talking about decision-making in the temporal and spatial dimensions from the start, from the conception and design phases.

What makes sense—the *most* sense—*isn't* a simple matter to answer. But it's the sort of question we *must* be getting used to trying to answer if we're to *produce* winners and *be* winners in the cold-water resource management game today and in the future.

What's our objective? It it's having some sort of development that's desirable and/or necessary, then the question is "Can it be done in a way that *doesn't* preclude off-site public environmental quality values, that *has* a socially tolerable or even beneficial overall impact, in time *and* space?" That's a real challenge to deal with.

And everyone always has to keep in mind that, when you legitimately ask the question "*Can* it be done and produce a winner," the answer sometimes comes back as a "no" that provides no wiggle room for a location, a technology, and scale of development, or whatnot. That can be tough to some, but looking for winning resource-management plans can and should produce some show stoppers. A strong commitment to seeking and producing winners doesn't guarantee that a winner will always be found.

We see linkages, cost implications, linkages, environmental quality and habitat implications, and more linkages. Linkages are everywhere. If engineers, fisheries biologists, other resource managers, regulators, and interest groups—such as TU and the Fly Fishers—are to sit at the table, literally and/or figuratively, then the components and linkages business must be elucidated for the use of all the players, and I emphasize the importance of its being in a usable form.

My goal as an environmental engineer for some years, and especially since Wild Trout III, has been to advance the level of understanding in this area and promote more sensible, scientifically sound, cost-effective, socially responsible resource management and environmental protection trade-offs in the real world. With generous support, mostly from the private sector, we've made real progress on our research. (If anyone wants more details, then contact me.)

One reason Starker Leopold was able to have the impact he did and advise high policy makers on the great issues of his day and the future—as cited yesterday by Nat Reed—was the quality, the commitment, the enthusiasm of his graduate students, back at Berkeley and in the field, doing a lot of—perhaps most of—the work, working on something they all believed was important. I understand this, and have had over 100 master's and PhD graduates who helped develop and advance good ideas on components, linkages, and how they can be used for better big decisions in the land, water, and ecosystem management area.

I value the opportunity to come here and to learn how we're doing—collectively—on some important habitat matters, to learn where more work is needed, to listen to the great, and to learn of the real-world successes and remaining problems and challenges from many of you.

And I value the opportunity to get some ground truth on important issues, on the ground and astream, *between* Wild Trout symposia with some of you. This real-world ground truth isn't so easily available to us enlightened bigger-system environmental engineers in the conventional engineering community and academia.

Win, win, win. I like those situations. Someone said he'd heard of "win-win" situations, but what's this "win-win-win" business I promote. I told him mine was very similar, but at least 50 percent better! I want you all to help me promote this goal, and help find and produce *more* such situations, so we can point to more success stories as suggested by Luna Leopold yesterday.

Let's *create* an improved environment for more winners to happen—winners for fish, winners for anglers, winners for fish habitat, winners for right-headed developers, and winners for the general public. There's a big difference between promoting old hard *positions* and easy though failed paths, on one hand, and effectively advancing the *interests* of our constituencies, on the other.

Join me as we very briefly consider two scenarios. *First* scenario: you can make a developer spend, say, 10 million dollars over X years for erosion control on a major project. Think of a box that represents 10 million dollars. The project is big enough so it can bear the cost. There'll be lots of end-of-pipe marginally effective

environmental control measures—some of which are called "best management practices." The money gets spent, and a program was both required and implemented. But the stream will still take a pretty fair hit in all likelihood.

Second scenario: visualize the same box holding 10 million dollars, but now there are *four* compartments. Compartment *one*: there are dollars for a lesser but still respectable *control* program, maybe with a strong emphasis on *source* reduction. Maybe such an enlightened approach will actually be *superior* in terms of actual environmental protection than the whole of the first option. It's not only possible; in the case of innovative approaches, it's even likely.

Compartment *two*: there are also dollars for *rehabilitation* of the impacted stream. Maybe you speed up recovery, maybe even habitat improvement after recovery to make it better habitat than it was.

Compartment *three*: in return for "using" the stream—taking it out of production for X years—let's pay back and compensate, make a net *winner* for fish, fishing, cold-water habitat, and anglers. Here are just some ideas: (a) Pick out a couple of nearby but unimpacted streams. (b) Make dollars available for better resource management. (c) Such as? How about Y 100s of thousands of dollars per year for X years, to allow the state agency to hire a couple more fish biologists, two or three more enforcement officers, and several technicians plus materials and equipment. (d) And how about Z dollars per year for some more years beyond recovery of the impacted stream. (e) And maybe even some help for the agency in promoting a self-sustaining funding program for cold-water fisheries, now that there are some good—or better—streams.

So what's in the *fourth* compartment, that causes it all to add up to 10 million dollars, or whatever? That's the dollars the developer might end up *saving*, after spending perhaps a *lesser* amount of dollars, but in a lot better, more *effective* manner in both time and space.

Win, win, win, we *all* win. Think about it! What if more big-ticket responsible developers knew there was a good chance of sensible, expedited, no playing games, no foot dragging decision-making, and regulators and interest groups who were able to be—and inclined to be—real players in win-win games, *where* winners are possible. And sometimes that's *not* possible. "No" must always be recognized as a possible answer for a proposed project in a sensitive or environmentally demanding setting.

We could produce positive case studies such as Luna suggested by combining good science, good resource stewardship, and constructive players. Poison pills, pipe bombs, and self-righteous posturing shouldn't be allowed where enlightened good-faith win-win decision-making is underway.

Perhaps I'm being a little idealistic, but I don't really think so. Self interest—hopefully enlightened self interest that's consistent with the broad public interest—makes the world go around. And making winners and being parts of winning teams for better cold-water habitat and better cold-water angling is definitely in our individual and collective self interests. I don't know how any of us could justify calling another game when we're dealing.

Nat said you resource managers had changed a lot more in the past 15 years than the we engineers. While I see good progress in some quarters in the engineering, I tend to agree with Nat. And to you all, I say "Thanks". Thanks for showing the benefits of this necessary evolution on resource management to the engineers. Let's hope we can *all* evolve further, and let's hope there are *more* good examples to cite at Wild Trout V.

The Trout and Salmon Foundation[1]

Thomas E. Donnelley II[2]

Good afternoon. I'm Tom Donnelley, Chairman of the Trout and Salmon Foundation, a public, non-profit 501 (c)3 Foundation. It is indeed a great honor to be able to take a few minutes of your collective time to tell you something about the Trout and Salmon Foundation, its history and our evolving objectives in today's challenging and dynamic environment. By relating all of this, I guess I'm the proxy for all similar small organizations involved in the many facets concerning the welfare and promotion of wild trout and their habitat.

First, I would like to review with you the history of the Trout and Salmon Foundation. It was founded in December 1969, as a public non-profit tax deductible corporation. It's charter was to preserve and enhance the trout and salmon resources of North America through

a. the encouragement, support and funding of meaningful research projects,
b. ownership and management of lands and waters in order to provide natural wild trout and salmon habitat, and
c. sponsoring continuous studies related to the fish environment and the control of water quality.

The Foundation was originally created by Trout Unlimited, largely through the efforts of the late Elliott Donnelley, my father, but soon became a completely separate organization with its own Board of Directors. It is not directly affiliated with any other organization. It is the policy of the Foundation to use only its investment income for the purpose of funding projects via approved grant applications. Further, to stretch the limited dollars available, the majority of the grants are made on a matching fund basis and are primarily related to stream improvements. Currently, the market value of the Foundation assets are just over $515,000 with income from interest, dividends and contributions in excess of $50,000. The funding objective is to increase the asset base to over $1,000,000 in order to attain an income level for grants, etc. of approximately $75,000 to $100,000 per annum. The Foundation does not maintain a paid staff or administrative office so those expenses are minimal.

The Directors of the Trout and Salmon Foundation include Stephen R. Arelt, a Vice President with the brokerage firm of Smith, Barney, Harris Upham & Co. in California; Thomas J. Collins, Missoula, Montana; yours truly, a Vice President of R. R. Donnelley & Sons Company, Chicago, Illinois; Terry J. Kohler, Investor from Sheboygan, Wisconsin; Stephen Lundy, currently President of the Trout Unlimited from Denver, Colorado; Allan R. Phipps, Attorney and Conservationist from Denver, Colorado; Lawrence R.Reno, also an Attorney from Denver, Colorado, with long standing affiliations with Trout Unlimited; Lloyd G. Schermer, Chairman and CEO of Lee Enterprises, Inc., Davenport, Iowa; Dair J. Stewart, President, Rockford Coating Corporation, Rockford, Illinois; Douglas L. Swanson, President, Swanson-Erie Corporation, Erie, Pennsylvania; and Otto H. Teller, Conservationist and Past President of Trout Unlimited from Glen Ellen, California/Hamilton, Montana.

Although the founding date of the Foundation is 1969, the first grants paid were to the national organization of Trout Unlimited in the amount of $15,000 to help pay the legal fees in the Teton Dam case to preserve 17 miles of a stream and a scenic canyon where the wild trout habitat was predominantly Cutthroat. Over the years the Trout & Salmon Foundation has provided grants totalling $187,000 broken down as follows:

a. $33,000 going to the National Trout Unlimited,
b. $70,000 in grants going to either TU state councils or individual chapters,
c. $36,000 to various universities in support of trout habitat research,
d. $18,000 to the Montana Land Reliances for their work on conservation easements supporting the major streams in the state of Montana; and
e. $30,000 going to various other research and/or habitat projects supporting wild trout.

At our 1988 meeting held in Southwestern Colorado, the Board decided to take a more pro-active role in preserving wild trout habitat than just providing grants. We used as a basis the work performed over a four year span on a small stream called Bellows Creek which feeds into the upper Rio Grande

1 Luncheon address Wild Trout IV, Sept. 18, 1989, Yellowstone National Park.

2 Vice President, R. R. Donnelley & Sons; Chairman, Trout and Salmon Foundation.

in the area of Creede, Colorado. This stretch of water is approximately five miles long flowing through 3 miles of meadowland, a mile of canyon and roughly one mile in the form of a small overgrown mountain stream. Bellows Creek had been previously renovated using gabions and other devices to try toimprove the habitat of trout. During the course of many years, hatchery grown trout were also planted in the stream. Although the gabions improved the habitat for a few years, it was just a matter of time before Mother Nature had one of her "100 year run-offs" (a phenomenon occurring about every five to ten years now) which washed out and/or around most of the reconstructed trout holding areas as well as many of the pools. With the initial expense down Nature's drain, so to speak, something different had to be done.

Without getting into any major endorsements, some professionals were brought in from Bozeman, Montana to review the entire habitat area with the intent to restore it to what it should be over a period of time. This second restoration attempt combined the various scientific skills of a geomorphologist, hydrologist, entomologist and of, course, fish biologists. The stream-bed of Bellows Creek, as well as a small feeder creek called Senator's Creek, have been subsequently transformed into highly productive trout waters that work and live with Mother Nature and her fits of temperament rather than resist them. Having seen the "before" and "after" results, many of us decided that perhaps more attention should be given to a pre-planning "how-to" manual than what has been previously on the market.

This major change in direction was further stimulated by one of our 1988 grant requests asking for the support of another "how-to" manual. The intent of the request was positive and in the proper direction but the members of our board did not feel that the grant proposal covered all the elements that had made the second reconstruction of Bellows Creek so successful. Since we did not totally agree with the proposal as presented, our board felt that perhaps the Trout and Salmon Foundation, in conjunction with some professionals experienced in stream restoration, could sponsor our own manual.

Our objective was to emphasize the scientific disciplines and pre-rehabilitation planning necessary to restore a stream. This approach was selected rather than another manual emphasizing the construction aspects of stream improvement. Although we recognize that this part of stream rehabilitation is the nuts and bolts of any project, we felt it would only be as effective as the pre-recognition of the natural forces at work. For the streams in the Rocky Mountains or parts of the East where there is a substantial gradient drop, Spring run-offs can literally wipe out in oneseason all the best intentions and works of man not to mention whatever funds have been expended. Only if all the environmental factors have been properly and scientifically considered, a plan drawn up and followed through on, should a stream be considered as rehabilitated. The real test, however, is one of time.

After various discussions with the requesting organization that was planning to sponsor and publish a new Manual on Stream Rehabilitation, it was decided by our Board not to duplicate the effort by reinventing the wheel, but to sponsor a video in support of most construction-type manuals and to serve as a free standing element on its own merits.

The video concept, itself, is not inexpensive. It is projected to cost in actual Foundation cash outlays somewhere between $40,000 and $50,000 broken down into three phases which include:

a. script writing,
b. production
c. final editing and post-production.

The screen play script portion is estimated to cost between $11,000 and $12,000. The production phase would be $18,000 to $20,000 with the final edit post-production phase tallying out $15,000 to $16,000. Considerably more funds would have been required if it were not for some very generous personal cash and "in-kind" contributions by various Board members and others. The end result is intended to be a video of approximately 28 minutes in length suitable for viewing by local TU chapters, other interested wild trout habitat organizations and hopefully the general public through the various PBS facilities. The outline of the video is broken down into:

a. An introduction, describing the purpose of and need for enhancement work.
b. An overview of determining limiting factors to a fishery population.
c. An overview of river behavior.
d. Some thoughts on construction planning and construction supervision.
e. A brief look at a set of approaches and techniques that have been utilized in various different types of channel.

The time frame for production of this video basically started late this Spring with a script ready for review at the Trout and Salmon Foundation's end-of-July meeting. This timing was important as the Board wanted to be in a position to make a funding commitment to proceed with some of the film production this past summer if we all stillagreed with the project. We did, we are and it is expected that final edit plus the post-production phase will take place next May, June and July for a Fall 1990 roll out. To date over six hours of film footage has been shot. After the editing has been completed for the initial "pilot" film, the Foundation may spin-off other videos relating to different aspects of the same central preplanning theme.

Again, what we are trying to accomplish with the video is first to show why and how people interested in improving wild trout habitat should spend considerably more time evaluating the river or rivers that they want to improve. As part of the evaluation, considerable thought should be given as to how those rivers can be manipulated to provide long term changes in salmonid habitat quality. Our Board wants to provide among other things a medium which will show that the geology the stream flows through and capacity of a river can have a tremendous negative impact if the designers do not provide sufficient area to convey high discharges generated by runoffs.

Our second concern deals with the use of structure in conjunction with bars and bed forms. In general, they should be confined to use as grade controls to increase safety margins and/or to provide a better drift at lower flows. They should not be used to inhibit passage of fish species or as small dams that create ponds upstream of the stucture. After all, the point of habitat improvement is to work with the natural processes, and to enjoy the benefits Mother Nature has to offer after it's all completed. Finally, the purpose behind the video is not to replace any of the current excellent manuals on how to restructure wild trout habitat. What we are basically trying to do is supplement these manuals and emphasize the importance of knowing your stream and its dynamics using the scientific expertise that is available and pre-planning the required improvements in a conceptual sense. Once you know your friend or enemy (in this case Mother Nature is both) you are in a much better position to not only get full value for the substantial time, effort and funds you have spent but have the finished result as a long term investment as well.

Where does all of this history, grant records, and new proactive direction lead the Trout and Salmon Foundation? Like many other small public foundations, we all have our special expertise and niches to fill and as such we and other similar groups can contribute a great deal to the knowledge Symposia like this both stimulate and encourage. Not only is the Trout & SalmonFoundation another catalyst to get people interested in the promotion of wild trout and its habitat we, to the best of our limited resources, contribute funds to help make what we espouse become a reality.

Thank you very much for your attention and the privilege of being part of the Wild Trout Symposium IV. If there are any questions, I'll be glad to try to answer them.

1989 A. Starker Leopold Wild Trout Awards

As memorialized at Wild Trout III, A. Starker Leopold, distinguished naturalist, superb teacher, gifted author, and beloved companion to those that shared his fishing and hunting campfires, died at his home in Berkeley, California On August 23, 1983.

Leopold was born in Burlington, Iowa, the eldest son of Aldo Leopold. Following in his father's footsteps, he became one of the world's most influential and honored authorities on wildlife ecology and management. He attended the University of Wisconsin, the Yale Forestry School, and received his Phd from the University of California at Berkeley, Department of Zoology in 1944. After working in Mexico for the Pan-American Union Conservation Section, he returned to Berkeley where he remained until retiring as Emeritus Professor of Zoology in 1978.

Starker Leopold became heavily involved in public policy at the highest levels. In 1968 he chaired the Special Advisory Board on Wildlife Management of the Department of the Interior which led to significantly new policies for National Parks and Refuges. He held membership on the Advisory Committee on Predator Control and was a recognized international consultant on wildlife conservation policy. He served as a Director and President of the California Academy of Sciences, Director and Vice President of the Sierra Club, and engaged in a broad range of public service activities.

Leopold addressed the negative impacts of multiple use at Wild Trout I. At Wild Trout II he spoke about degraded wild trout populations and the need to give higher priority to land use patterns and the physical condition of our lakes and streams. The following year Starker told the Federation of Fly Fishers in Spokane, "For my part, I believe that the limited budget available for trout management is largely misspent on trivial activities, of no present value, such as the catchable trout program. Unless we bite the bullet and attack the habitat problem with vigor, the future of quality trout fishing on public waters in America is unpromising."

Starker's main goal was a world suited to wildlife and therefore, fit for people. Eminent academic and scientific achievements, love of the outdoors, positive personal warmth, and sensitivity characterized his personality. A. Starker Leopold was a friend to fish and wildlife, and to all of us.

In 1984, the National Wild Trout Symposium Sponsoring Committee established the Aldo Starker Leopold Wild Trout Award. As a continuing memorial, awards are given to a professional and a nonprofessional who over time have made significant contributions to the enhancement, protection, and preservation of wild trout in North America. Prior to each symposium, nominations are solicited from the sponsoring organizations, biologists, administrators, and conservationists that gather in Yellowstone National Park at five-year intervals to review the status of wild trout populations, current biological achievements, related management and sociological issues, and new opportunities for enhancement.

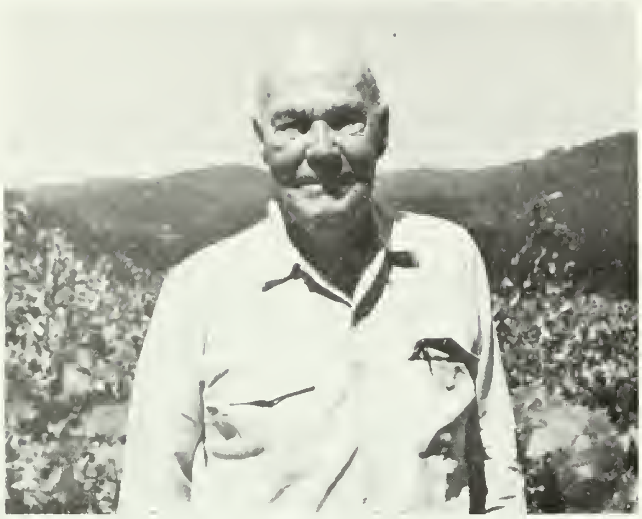
The first A. Starker Leopold Wild Trout Awards were made at Wild Trout III in September, 1984 to Martin M. Seldon, a long-time fisherman-conservationist, Sunnyvale, California and to Dr. Robert J. Behnke, Colorado State University, Fort Collins, Colorado, a noted trout biologist.

The 1989 . A. Starker Leopold awards were made to Otto H. Teller, Glen Ellen, California and Frank Richardson, Lithonia, Georgia.

Otto H. Teller

After waterfowling and pursuing trout and salmon in many parts of our world, Otto "Mose" Teller became aware of serious siltation problems on the lower Gallatin and Bitteroot Rivers in Montana. Frustrated by the role of poor forest management practices on the Bitteroot, he studied forest management at the University of Montana for almost five years and became a fixture at Senate and House Forest Service hearings. Perhaps more than any one person, he made the clear-cut crisis a national issue through personal testimony and his support of a movie and a book.

Teller became President of Trout Unlimited in 1971, where he worked to build the organization into a strong national conservation force. In his desire to preserve and restore cold-water fisheries, organizations such as The Wilderness Society, The Nature Conservancy, The Federation of Fly Fishers, The Montana Land Alliance and many others benefit from his assistance and most leadership. Teller was one



of the founders of the American League of Anglers, and recently created the Teller Wildlife Refuge in Montana's Bitteroot Valley.

Otto Teller has always been early to champion unpopular but scientifically or morally defendable positions, and uses his personal resources to contribute to the preservation of wild trout. Those who have worked with him are pleased to have him the recipient of the 1989 nonprofessional category A. Starker Leopold Wild Trout Award.

Frank Richardson

Frank Richardson attended Rutgers University and North Carolina State University, where he received both BS and MS degrees in Fisheries. He worked as a District Biologist for the North Carolina Wildlife Resource Commission, where he became well-known for his contributions to trout management in the Southeast. In 1963 he joined the U.S. Fish and Wildlife Service, and was assigned in the Great Smokey Mountain National Park, where he became an authority on wild trout management.

Richardson has held many appointments of authority and responsibility with the Fish and Wildlife Service, including a position on the fisheries staff in the Washington office, Associate Regional Director of the Rocky Mountain Region in Denver, Area Manager in the Great Lakes States, Assistant Regional Director for Fisheries of the Southeast

Region in Atlanta, and as Special Assistant to the Director and to the Regional Director of the Southeast.

In his present position he continues to demonstrate his extraordinary abilities to work with people by representing the Service at a broad range of Commissions, Councils and Committees that deal with inland, estuarine and high seas fishery resources. He has an exceptional knowledge of fresh and saltwater fishery resources.

In addition to his occupation as a professional biologist, Frank has devoted a considerable amount of time and energy to volunteer effort for Trout Unlimited and the Federation of Fly Fishers. He has been a Director of both organizations and worked tirelessly to improve wild trout resources. His unfailing attention and devotion made him responsible for the successful TU-sponsored Russian-American Fly Fishing competition in 1988. For many years Frank has chaired the Federation of Fly Fisher's annual conservation symposium.

Richardson was an instigator of the original Wild Trout Symposium and has been the prime mover behind all four meetings, responsible for the infinite number of details necessary to ensure the success of these conferences. His efforts have resulted in the growing number of participants at Wild Trout IV and the recognition of the importance of these meetings as the major forum for professional-to-professional and professional-to-conservationist interaction. Frank is honored this year as the professional recipient of the A. Starker Leopold Wild Trout Award for his many contributions to the cold-water salmonid resource.

Let Rivers Teach Us[1]

Luna B. Leopold[2]

Abstract.— River channels are being altered on a massive scale for many purposes, including flood control, road engineering, fishery improvement and erosion control. Geomorphic principles of river form and process are known to few of the designers of such works. It is proposed that there be established a center for case study storage and dissemination so that knowledge of successes and failures adds to our ability to maintain and improve river environments.

Only a few weeks ago I received notice from one of the federal resource agencies that they plan to do fisheries habitat improvement work in a local wetlands. The improvement will consist of five log drop structures and ten log-and-rock revetments in a reach of 220 feet of channel. This, they say, will reduce erosion and the impacts of sediment deposition.

In recent decades fishermen have become more discriminating and stream managers have become more sophisticated. The angling community increasingly seeks habitat not hatcheries. Unfortunately, many federal engineers and consulting firms have made no attempt to absorb our rapidly increasing fund of knowledge of river process and channel behavior.

Rivers do not construct drop structures. Rivers construct and maintain, by processes of erosion and deposition, channels of particular characteristics—characteristic dimensions, planforms, cross sections, gradients, and distributions of sediment materials. These morphologic parameters are scaled to the size of the drainage basin and the nature of the rocks of the area. But they are scaled appropriately to maintain a quasi-equilibrium.

The idea of check dams or drop structures originated in the western United States in the 1930s, when the newly formed Soil Erosion Service faced the formidable gullies dissecting alluvial valleys. I remember very well the philosophy of those erosion engineers who stated flatly that a check dam in a gully would cause aggradation all the way to the watershed divide and the gully would be filled its entire length.

That this was not in fact what was happening they attributed to the limited time of observation. In time, they said, the gully would fill its entire length. It is clear that the experience over a thousand years in Palestine, in Mexico and elsewhere was quite unknown to the erosion engineers.

It is obvious to most of us today that a grade control structure flattens the channel gradient upstream for only a short distance and intrudes an unnatural anomaly into the fluvial system. Such an anomaly will be attacked by the flow and, given time, will be eliminated. It will ultimately be destroyed by undercutting, by lateral erosion of the abutments, by scour hole erosion at the toe, or by some combination of these.

If a reach of channel is suffering unusual bank erosion, downcutting of the bed, aggradation, change of channel pattern, or other evidence of disequilibrium, a realistic approach to amelioration of these problems should be based on restoring the natural combination of dimension and form characteristic of similar channels in quasi-equilibrium. These characteristics include appropriate values of width, gradient, pool and riffle sequence, length, radius, amplitude of curves and meanders, and hydraulic roughness.

A procedure might, in principle, include the following steps. Inspect the channel upstream and downstream of the reach exhibiting problems. Inspect nearby or similar valleys that appear more natural. Choose a reach of such a natural river which appears to represent the condition of the problem channel before it was disturbed or disrupted.

At this point it is useful to remind ourselves what are the principal morphologic features of the river channel that must be retained or restored. First, the slope or gradient of the channel must be the same as it is in the natural or undisturbed reach of the river. The deviation from this natural slope is the clearest reason that drop structures cannot be permanent and should be avoided.

The second imperative is the channel width. The width must represent the bankfull dimension such that when the normal bankfull discharge is exceeded, the water will overflow onto a flood plain of much greater width. This means that both width and depth at bankfull must be considered and an overflow area provided for greater discharges.

If the river curves or meanders present in the undisturbed reaches have been eliminated or importantly changed in the disturbed area, they must be reinstalled by physically constructing them. The layout of curves is the principal way the desired gradient is maintained or restored. No natural channel

[1]Symposium of Wild Trout IV, Yellowstone National Park, September 1989

[2]Professor Emeritus of Geology, University of California, Berkeley, California. Summer address: Box 1040, Pinedale, Wyoming 82441

is straight, so the reconstruction of curves of appropriate size and shape is a main element in river restoration. The bed elevation should vary, in that pools occur in the curved reach and shallower zones in the crossover.

The dimensions of width, depth, meander, length, radius of curvature, slope, and other features have been published for many regions in the United States. These dimensions can be used as a rough check on those measured in undisturbed reaches of the river in question.

To give a few examples of such dimensions, the channel width tends to increase downstream as the square root of the bankfull discharge. The mean velocity at bankfull is, for small to medium size rivers, about five feet per second. A single sequence of a pool and a riffle usually has a length along the stream of five to seven channel widths. The radius of curvature for most channel bends is about two to three times the channel width. The bankfull level closely corresponds to the mean height or mean elevation of the point bar that commonly extends streamward from the convex bank of a channel bend.

There are a few generalizations drawn from scientific studies of channel form that can be useful in practical problems of river restoration or maintenance. Width is the morphologic parameters most easily altered by the river. If the river is deprived of some of its natural discharge, it will narrow its channel. Bank erosion usually will follow unusual or unnatural alteration in sediment supply or a change in water-sediment relation.

An alteration in channel gradient (slope) is the most disruptive to the natural equilibrium. The increase in gradient is the main reason channel straightening or channelization is so destructive to river systems. Also, river curves provide an essential source of hydraulic resistance necessary for equilibrium.

We have a problem in river restoration that presently is leading to serious consequences but is also possible of solution. The problem is lack of communication and trading of experience. As a result, successes in field restoration are little known, while mistakes are repeated indefinitely.

The Corps of Engineers has certain responsibilities in granting permits for some kinds of work on rivers. Yet various offices of that agency have totally different ideas of what works are harmful and what are beneficial. Experience does not seem to be discussed among offices, much less gathered, collated and disseminated. If there is no central information base in a single agency, imagine the variety of practices among the several federal agencies doing river channel work: the Soil Conservation Service, Forest Service, Bureau of Reclamation, Fish and Wildlife, to name a few. In addition the state agencies do such work using engineers, fishery biologists, highway people. And there are private organizations.

There are a lot of people harming rivers. There are also people who are improving them. But we do not know who is doing what. We are all trying as best we know to do effective maintenance and improvement work, but there is no attempt to learn from each other. No doubt mistakes are repeated. No doubt success goes unnoticed.

There are many handbooks, instruction manuals, and how-to-do-it pamphlets on channel improvement. I have seen only one that makes an evaluation of different techniques, but it is not only too brief, it is not widely known. What is needed is a gradually accumulating file of case studies describing with text and illustration the original condition, an assessment of the basic cause of the problem, the techniques and construction details of treatment, and an objective analysis of the result.

If such a file were initiated and all operatives urged to contribute, it is certain that we would learn from each other and our techniques would become more closely tailored to the type of river and the type of problem.

Trout Unlimited is already planning a modest program of collection of basic information on channels under consideration for cooperative effort. And unquestionably, Trout Unlimited has rapidly acquired and absorbed hydrologic and geomorphic analytical techniques. This effort deserves high praise. But it is not enough.

I propose an expanded effort that hopefully would involve federal and state personnel and experience. Who or what organization should take the lead is not specified. But one thing seems clear. We must let the river teach us. Not just a few of us.

Let the river teach all of us.

Riparian Management: Oregon Recipes[1]

Wayne Elmore[2]

Abstract.--The management and recovery of degraded riparian systems is a major conservation issue. Presently there are many grazing management strategies being applied on the name of the technique with little incorporation of basic stream processes and riparian vegetation requirements. Managers must understand the exact workings of grazing strategies, vegetation impacts and the individual processes of each stream before prescribing solutions to degraded riparian systems.

INTRODUCTION

"Riparian" is a word that strikes fear in the hearts of many, anger in some and feelings of peaceful surroundings to others. It is a word that has grown to mean many things to many people, but is rarely understood. It has become an emotional topic that has led to one of the key public land issues in the United States today.

Early Oregon explorers and residents observed what our riparian areas once looked like. In 1825, Peter Skene Ogden, after traveling through the Crooked River Basin of Eastern Oregon, observed willows from side to side across the valley bottom. Most of this scene is now gone. The Indian word "Ochoco," for which our Central Oregon mountains are named, means "streams lined with willows," yet today willows are uncommon. Senior ranchers in Central Oregon tell stories about the problems once encountered gathering cattle in the "thick willow stands" on Big Summit Prairie. The "thick willow stands" have been reduced to scattered clumps. Historic evidence indicates that most riparian zones have changed dramatically from what they once were.

THE RIPARIAN SYSTEM

In recent years, the specific management of riparian areas has typically been the primary responsibility and interest of wildlife and fisheries biologists (Elmore 1987). Improvements have been primarily judged in relation to habitat for big game, song-birds and fish. But riparian areas are more than just habitat for wildlife. They actually are functioning systems that filter water and store nutrients, stabilize banks, and assist in the recharge of underground aquifers along with the adjacent uplands. Wildlife habitat is a product of those functions, and should not be considered as the only emphasis for managing riparian systems. In fact, many times wildlife benefits are among the lowest economic value received from riparian restoration.

To fully evaluate the benefits of riparian management and incorporate them into land use plans, I believe that we must understand basic functions that riparian areas perform.

These functions include:

1. Physical filtering of water--One of its functions is to slow the flow of water, literally "combing" out sediments and debris. This water purification process also helps to build banks; so channels typically become narrow and deep where once they were wide and shallow. Vegetation, such as grasses, sedges and rushes, lay down under high flows and literally forms a blanket of protection over the banks. This process aids in deposition of sediments. Where deposition has occurred over long periods, extensive wet meadows or flood plains develop (Elmore and Beschta 1987).

2. Bank stability--Riparian vegetation can withstand high velocities of water and still remain intact. The diversity of grasses, forbs, sedges, rushes, shrubs and trees produces a variety of fibrous and tap roots that bind and hold settled soils in place. The binding effect

---

[1]Presented at Wild Trout IV; September 18-19, 1989; Yellowstone National Park; Mammoth, Wyoming.

[2]Wayne Elmore, State Riparian Specialist, Bureau of Land Management, Prineville, Oregon.

of the roots helps maintain the positive factors of the bank building processes during high flows. A combination of both woody and fibrous rooted species have a reinforcing effect. The woody rooted species provide physical protection to the hydraulic forces of eroding water and allow forbs, grasses and sedges to bind the finer particles. In combination, this diversity of plant species is much more effective in promoting bank stability than can be accomplished by any single species.

3. Water storage and recharge of subsurface aquifers--Riparian systems that are characterized by healthy vegetation communities slow the flow of water and allow it to spread and soak into the banks like a sponge, which decreases peak flows, maintains water tables and extends base flows through summer months. Yet streamside aquifers in many areas of the west have gone dry during the last century of intensive land use. For many degraded riparian systems (particularly those that have experienced channel incision and downcutting), high flows are contained in the channel and cannot access the banks or floodplains where water can spread and recharge streamside aquifers. It is widely accepted that we can lower a water table through the use of drainage ditches, or by draining underground moisture through channelization. However, it is not readily recognized that we can reverse that process and store water through recovery of riparian systems and deposition in formerly degraded channels. When banks rebuild through filtering of sediments, they increase the area for water absorption and improve the recharge of streamside aquifers. Thus, functional riparian areas effectively utilize gravity to assist in storing subsurface water.

It is important to recognize upland areas must not be excluded from consideration because they are an integral part of the riparian system. For example, overland and subsurface flows also influence sediment loads, water cycles, and recharge of aquifers. Improving upland vegetation condition through proper livestock use can increase infiltration rates, reducing overland flows, and adding to water stored by stream systems.

Observations of recovering riparian systems in Eastern Oregon that have shown a substantial ecological improvement indicate significant hydrologic changes are underway. These include increases in the base flow (minimum flow level, i.e. the discharge to which the stream returns after storms or snowmelt periods), reduction in the buildup of ice, more moderate water temperature regimes, and physical filtering of sediments by ice and vegetation. Almost all of the negative features that I observed in degraded stream systems became positive factors when those streams returned to good ecological condition. The information and awareness that we transfer to the managers and users of our natural resources must identify these types of changes.

MANAGEMENT EVALUATIONS

Understanding riparian system functions and the role vegetation plays is essential to their management. As we endeavor to restore riparian conditions through livestock grazing systems, we are often applying techniques based primarily on the name given the system and not on what that system actually does to stream function. For example, the Three Pasture Rest Rotation grazing system works well along low gradient streams in Central Oregon that are primarily grass-sedge-rush sites, but it can be a disaster on streams that need shrubs for bank stability or fisheries habitat. If we look "inside" this grazing system, we find that it was designed to fit the physiological needs of grass plants and not riparian shrubs. If we look even closer at what happens under this grazing system in desert rangelands, we can begin to understand why shrubs generally decline. The first year the pasture is grazed early during the growing season. The second year the pasture is grazed after upland grass seeds ripen (usually mid-July), and the third year the area is rested from grazing.

During the spring use period, little if any livestock utilization on willows occurs. Upland grasses are green and growing, providing a more palatable forage source than shrubs. During the second year, the common utilization rate for upland grasses in this grazing system is 60 percent. These grasses are now dry and unpalatable and by the time we have achieved the desired 60 percent utilization on upland vegetation, we have gotten 80 to 90 percent utilization of riparian vegetation. Our observations in Oregon show livestock will begin using the current annual growth on willows during the late summer months (mid-July through September), when herbaceous riparian species utilization reaches about 45 percent. They will increase their use on shrubs again when herbaceous vegetation is used to 65 percent and once again at 85-90 percent utilization. Finally on the third year we rest the pasture allowing no use. In analysis we observe that we are losing three years of growth on willows and only getting two years of growth back. We are, however, meeting the physiological need of the sedges, rushes and grasses. Thus, over time our woody vegetation slowly declines while the sedges, rushes and grasses prosper. (Figures 1 and 2)

There are many things we could do to solve the problem of excessive shrub utilization. One is during the seed ripe treatment year to restrict utilization to 50 percent or less on herbaceous species. Another is to make the riparian area a separate pasture managed according to its unique ecological needs. A third is to add more pastures to achieve more rest, or finally we could exclude the stream from grazing. The point is you must know what vegetation impacts your proposed management will have and how this

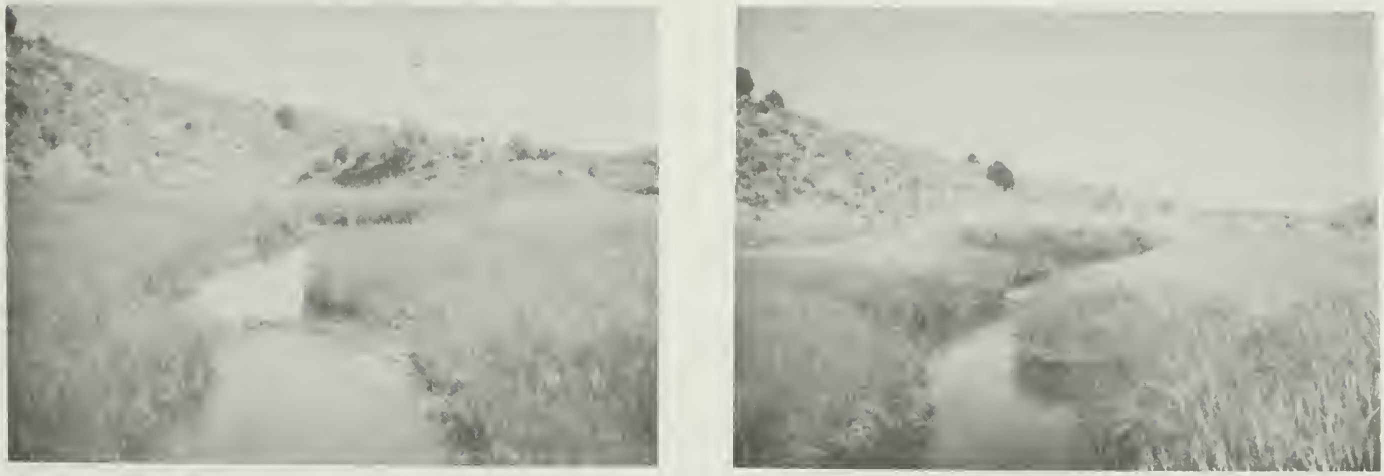


Figure 1.--Vegetation and channel responses during six years of three-pasture rest-rotation grazing. Left photo taken in August 1978, right photo taken in August 1984. Note continued improvement in sedge-rush-grass community.

Figure 2.--Channel widening and willow loss after seven years of three-pasture rest-rotation grazing. Left photo taken August 1977, right photo taken September 1986.

vegetation is important to a particular stream system.

Other grazing systems that are commonly used in Eastern Oregon include deferred (graze after seed ripe every year) and early or spring grazing. Deferred grazing every year can quickly remove small shrubs from a stream system because of heavy woody species utilization in the riparian zone, but it can also increase sedge and rush communities in wide, low gradient valley systems. Early or spring use every year can be beneficial to riparian system recovery, but many times this system can be detrimental to upland grasses if grazing always occurs during the critical part of the growing season (when flower stalks emerge from basal bud). It should be apparent that utilization of riparian vegetation is usually not a major concern unless it affects stream function. This situation occurs commonly with deferred grazing systems on sites where regrowth is limited and in the use of three pasture rest rotation where shrubs are needed for bank stability and sediment filtering.

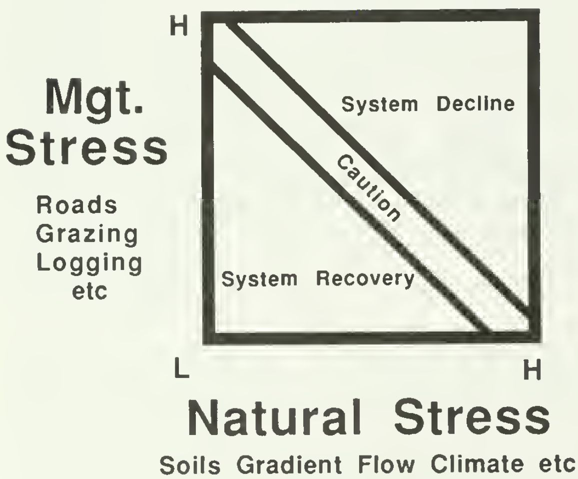


Figure 3.--Natural stress or sensitivity of streams vs management stress. Factors like soils, gradient, water column, climate, etc. must be considered when designing management strategies for system recovery.

Figure 3 is a simplified look at how we try to analyze our riparian systems and proposed management techniques. Every management strategy exerts a certain amount of stress on our riparian systems. The ability that each stream has to handle this stress depends on its own natural stress. Some streams with high natural stress (such as those with bentonite soils and high erosion potential) can stand little, if any, management stress (human influences). Others that are low gradient with sandy loam soils, for example, can withstand a much higher management stress. In our evaluation, "management stress" must not be confused with livestock numbers. Often, historically, livestock reduction was proposed as a solution for streams in poor condition, yet no recovery in the stream occurred. It is now clear that the numbers of livestock were not the problem, but that the management strategy was. For example, Bear Creek in the Prineville BLM District previously had 73 animal use months (forage needed to sustain a cow for one month) of grazing under a season-long grazing system. This system caused more management stress than over 300 animal use months now exerted with an early spring grazing system. As a result of decreased management stress, the creek is making significant improvement even though there has been a four fold increase in grazing use. There are many other examples of proper grazing in riparian areas in Oregon and throughout the Great Basin, as exhibited in research work by Bill Platts and others (Platts and Raleigh 84; Platts and Nelson 1985).

Exclusion of livestock is a management strategy that has been proven to work for initiating the recovery of riparian areas along many types of stream systems. However, it continues to receive a lot of criticism from many managers and users of the public lands for several reasons. These include: expense of fence construction and maintenance, wildlife concerns, and livestock water. However, if we look at many riparian areas in poor ecological condition they have become, in effect, upland exclosures. The attractant nature of streams and streamside areas to livestock during summer grazing periods often discourages livestock use on 90 to 95 percent of the adjacent upland areas. What we typically observe with streams in poor ecological condition are all of the negative values that result from improper grazing concentrated in one area. At the same time, we attain none of the positive results in the upland areas where grazing was intended. We are also, I believe, many times comparing exclusion of livestock to improper grazing and not comparing it to proper grazing.

CONCLUSION

We must begin to realize that we need to evaluate the requirements of riparian vegetation differently than in the past and that changes in grazing management can provide important opportunities to alter the ecological condition of stream systems. The benefits from those changes far outweigh the attributes of continuing with present practices and policies.

Furthermore, the watershed, not just the stream system, must be our focal point. As our energy and dollars focus on restoring degraded streams, we must continually look to the uplands. We cannot forget that the speed and clarity with which water comes off our uplands has a major impact on what happens in the stream system. If our goal is a higher quality and quantity of useable water, then the whole watershed must be a significant component of our riparian program.

We are at a critical time in the management of riparian areas and associated uplands. "Members of the livestock industry can provide leadership in understanding and solving coplex riparian questions"(Elmore and Bestcha 1987), but will they accept the responsibility? We must begin to look at both private and public lands because riparian areas do not respond to the differences in ownerships, only in management. If we don't change management, we will either lose the benefits of our natural resources or the flexibility to manage for multiple use. The American public is concerned about useable water quality and quantity as evidenced by the recent Congressional override vote on the President's veto of the Clean Water Act. The public will continue to demand more from the management of our natural resources and we must start now to meet those demands. It's obvious that you will never see a picture of a degraded riparian zone on a calendar so why should we have have them in our landscapes. Riparian management--full stream ahead.

LITERATURE CITED

Elmore, W., 1987. Riparian Management: Back to basics. The Public Lands During the Remainder of the 20th Century. Univ. of Colorado School of Law. June 8-10, 1987.

Elmore, W.; Beschta, R.S. 1987. Riparian areas: perceptions in management. Rangelands. 9 (6):260-265.

Platts, W.S. and Raleigh, R.F., 1984. Impacts of grazing on wetlands and riparian habitat, In: Developing Strategies for Rangeland Management. National Research Council/National Academy of Sciences. Boulder, CO: Westview Press. pp 1105-1117.

Platts, W.S. and Nelson, R.L. 1985. Impacts of rest-rotation grazing on streambanks in forested watersheds in Idaho. N. Amer. Jour. of Fisheries Management, 5:547-556.

Greenhouse Fish[1]

Douglas G. Fox[2] and William Moir[3]

The climate of the 21st century will be different from that of the 20th. Gases, especially CO_2 and methane, are increasing and either have or will reach concentrations high enough to affect the balance between solar radiation, earth, and atmosphere that drives our climate and in turn our global ecosystem. The global atmosphere will heat up. But we don't know if this means the Rocky Mountains will be hotter or colder, drier or wetter. We also don't know if climate extremes will become more or less common. We can do elegant theoretical analyses using sophisticated models of the coupled global ocean-atmosphere to provide guesses about the future, but these predicted futures are very uncertain. Even more uncertain is what climate change will do to our natural resources. In this paper we explore scientific areas of certainty and those of uncertainty in this issue.

INTRODUCTION

The year 1988 was a landmark year for us. We became particularly aware that things were not the way we wanted. Around Yellowstone unprecedented fires were raging. Suffering heat waves, commuting in the smoggy cities, or speculating about parched cornfields and forest dieback, we asked "What's happening?" As it turned out, the years 1981, 1987, and 1988 combined to make this decade the warmest of the past 100 years in the United States (Schneider 1989a).

A visitor to Yellowstone in 1974, when the first Wild Trout symposium was held, shared this beautiful Park resource with 28.6 million fewer U.S. citizens than there are today. During that 15-year period the global human population grew by over 1.1 billion people, as many people as the entire world held in 1850.

We are now impacting fundamental processes of our planet earth on a global scale. Our burning of fuel has altered global atmospheric chemistry. Tropical deforestation is eliminating species at a rate much faster than our ability to identify them. Smog in southern California and acid rain and smog in Europe and the eastern United States are affecting terrestrian and aquatic ecosystems on 1000km scales. Water pollution has reached beyond continental river systems, to estuaries, bays, gulfs, and even seas. Toxic waste clean up efforts strain even national economic systems. Emissions of chloroflurocarbons (CFC's) from spray cans and refrigeration systems have caused a hole in the stratospheric ozone layer over the poles of our planet.

In short, our globe is changing. It is changing in much the same way as it has changed over its 100-billion-year history, but humans are now significant agents in that change. Not only are we both accelerating and retarding natural global processes, but we are being dislocated by them. So-called natural disasters -- earthquakes, volcanoes, hurricanes, floods, and droughts -- generate global responses and environmental refugees. In much the same way that war disrupted the world over the past 100 years, Earth's response to our disrespect for her will occupy the activities and economies of people in the future century. Can we mobilize to this challenge? Major impediments exist. We are two worlds: an affluent, healthy, and energy-wasting industrially developed world, and a poor, unhealthy, unclothed and unfed underdeveloped world. Understanding global change requires that we recognize the inherent connectedness of environmental degradation, energy consumption, poverty, and population in our global community. It requires that we heighten our awareness and develop alternatives so we may continue to comfortably habitate earth. Every Earth citizen is part of the process of change, so every one of us has a responsibility to our common future.

---

[1]Paper given at Wild Trout IV Symposium, Yellowstone National Park, Wyoming, September 18-19, 1989.

[2]Douglas G. Fox is Project Leader on Effects of Atmospheric Change on Alpine and Subalpine Ecosystems, USDA Forest Service, Rocky Mountain Forest & Range Experiment Station, Ft Collins CO.

[3]W. Moir is Research Ecologist on that project.

At the essence of global change is the increasing awareness that we are altering our climate. In this paper we give briefly some of the evidence for climate change, suggest a few implications for resource managers, and then propose some ways we, as planetary citizens and fisheries enthusiasts, might respond.

EVIDENCE FOR GLOBAL CLIMATE CHANGE

Our Earth appears to be warming up. Thousands of thermometers around the globe give evidence of climate warming during the past century. Since about 1880 global temperatures have risen about 0.5° C. During the same period ocean levels have risen about 10 cm (fig. 1), attributed mostly to thermal expansion of ocean waters. Even when compensated for urban heat island effects, most meteorologists consider this warming trend significant.

Besides direct measurements of temperature, a variety of other observations indicate global warming. Tree ring evidence from different parts of the world also suggest recent warming (Graumlich and others 1989, Woodward 1987). Analyses of pollen deposits and plant macrofossils in pack-rat middens both indicate that present climate of the North American continent is about at the warmest of the past 12,000 years (Van Devender and Spaulding 1979, Neilson 1986, Woodward 1987). Corroboration of the present warming trend is found additionally from measurements from glacial ice cores (Dansgaard 1987), C-14 chronologies, measurements of fluctuating pluvial lakes, and other sources. The isolation and disjunction of both the Apache and Gila trout in the southwestern mountains of the United States is but one of many examples of plant and animal distributions suggesting that climates there were both cooler and wetter than they are today.

Taken in their entirety, these various sources of information from different parts of the world have convinced most scientists that an overall global warming trend has been taking place during the past century and will continue well into the next. But is this trend a result of natural solar terrestrial processes, or is it, in part, caused by people? To help answer this we briefly touch on the basic physics of how the sun energizes our planet.

THE GREENHOUSE EFFECT

The energy budget of Earth is driven by solar radiation heating up our planet and its atmosphere. This heating, coupled with the fact that the earth is rotating, causes a redistribution of energy that leads to the climate as we know it. We can analyze our climate by using principles of the conservation of energy, mass and momentum (in mathematical form) and applied over the globe. These so-called general circulation models (GCMs) start with the sun's radiation of the Earth and

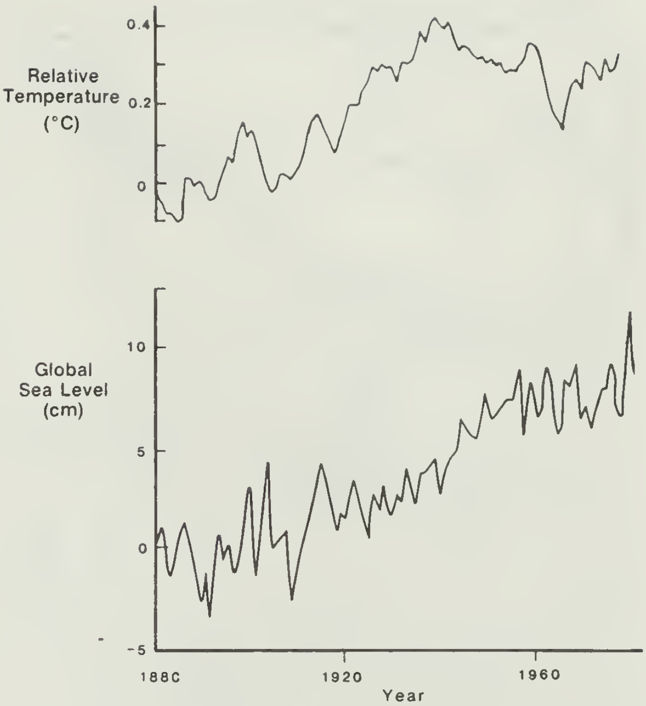
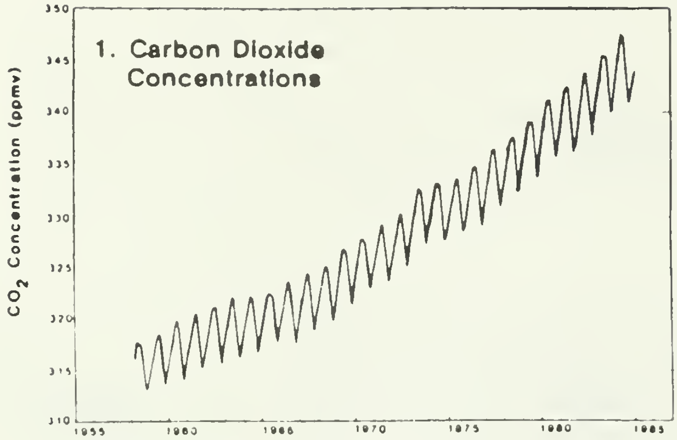


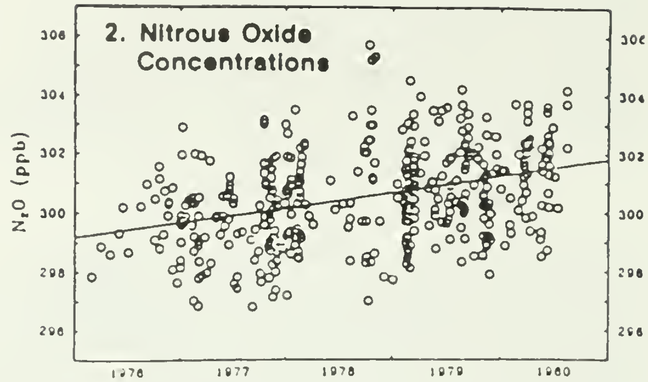
Figure 1. Global temperatures and sea level trends in the last century (Titus 1988).

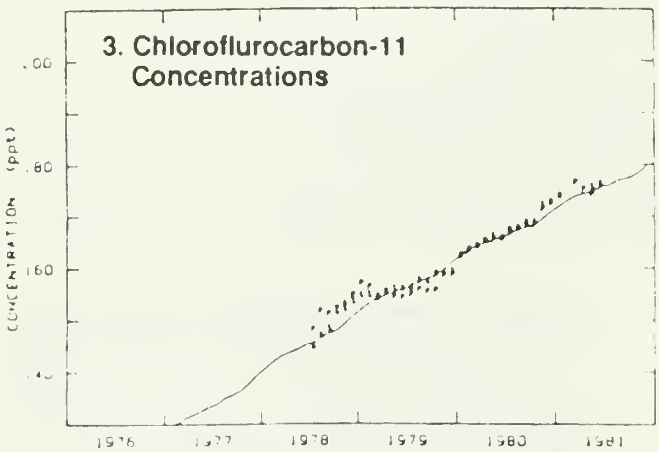
recognize the presence of atmospheric water and certain trace gases that affect that radiation (see, for example, Henderson-Sellers and McGuffie 1987).

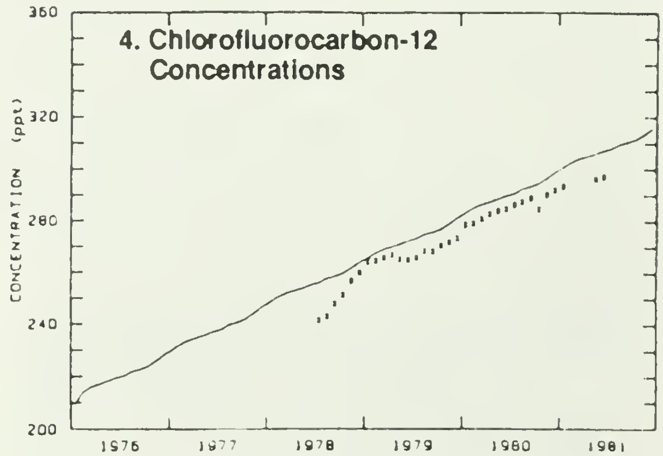
We are all aware of the "greenhouse effect", which results because the atmosphere is transparent to much of the sun's shortwave radiation passing through it. (Some of the ultraviolet frequencies are screened out by water vapor and stratospheric ozone). This solar energy heats the Earth's surface, which in turn radiates longwave energy upward or away from the Earth. Some of this re-radiation is absorbed by water, carbon dioxide, methane, and other "greenhouse" gases, causing them to heat and in turn re-emit a portion of this longwave or heat energy back to the surface. The greater the concentration of greenhouse gases, the more there is of this blanket effect to warm the surface. Presently about 88 watts/meter^2 of heat energy per square meter is re-radiated downward from greenhouse gases (including water vapor), and the Earth is about 33° C warmer than it would be without trapping (Schneider 1989a).

It appears that human activities are changing the composition of atmospheric gases (fig. 2). Human energy use and production contributes most to greenhouse gas buildup, but other activities include agricultural practices, land use modifications, release of chloroflurocarbons (CFCs), and miscellaneous industrial emissions. The United States produces about 1/4 of the









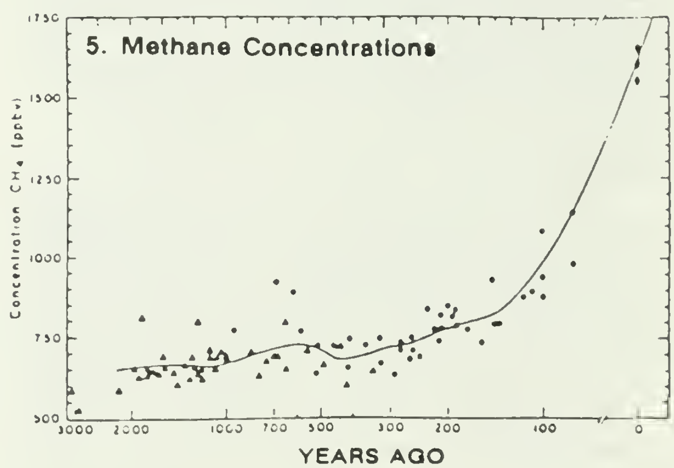


Figure 2. Concentrations of selected greenhouse gases over time (Titus 1988).

world's CO_2 emission. Industry contributes about 29% of this, followed by electric power generation (28%), transportation (27%), and home and business activities (16%). Developing countries plus mainland China and India produced about 20% of CO_2 emissions in 1980. The proportionate contribution of atmospheric CO_2 by these nations has been increasing since 1950 (Shepard 1988).

A recent blue-ribbon group of scientists and world leaders developed the scenarios of global warming indicated in figure 3. Most meteorologists and climatologists suggest that there is a better than even chance that future warming of this planet is within the range between the two lower dashed lines of figure 3; other scientists suggest the range between the upper two dashed lines as being a better than even chance. Human decisions about greenhouse gas emissions can alter these outcomes, although the lower curves would require dramatic reductions in current rates of increase in CO_2 and associated greenhouse gas emissions and increase in the global uptake of these gases (for example by oceans and the terrestrial biosphere.)

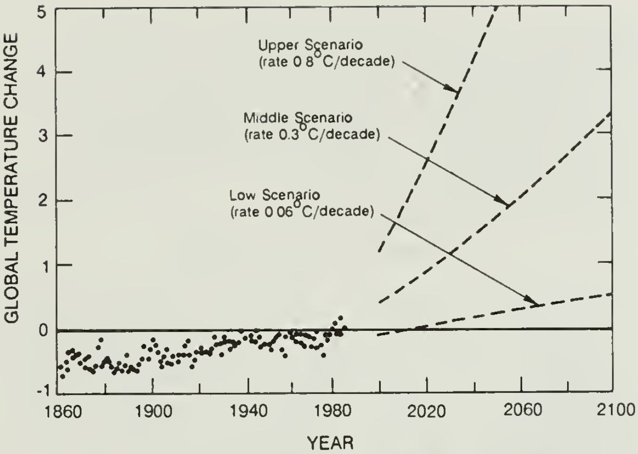


Figure 3. Globally averaged temperatures that might develop with continued emission of greenhouse gases (Jaeger 1988).

Exact predictions of the magnitude and rate of global warming are not possible because of limitations of GCM models, and because we are unsure of future social and political realities that will affect levels of greenhouse gases. In addition, GCMs produce only large scale predictions. The uneven distribution of surface heating, energy transformations, and convection around the globe cannot as yet be predicted for regional or local levels. But most GCMs seem to agree that a doubling of atmospheric CO_2 will produce some kind of warming effect over the continents. For example, a recent comparison of different models shows that each predicts a somewhat different pattern of precipitation in a local area (figure 4).

In addition to alterations in the mean state of the atmosphere, it is likely that we will experience major transient dislocation of climate -- that is, relatively large fluctuations from the mean state for relatively short time periods. These transients are largely unpredictable with our current technology. Warming of the global atmosphere will also add energy to instabilities in the global circulation that in turn give rise to major storm systems.

IMPLICATIONS

It is not yet possible to assess intensity and effects of climate changes likely to occur at regional and local scales because of global changes. The interactions of climate change across scales represent a major thrust of current research. Despite the uncertainties, some general themes emerge for resource managers to consider. We suggest now some of the major implications.

With more energy in the atmosphere, we can expect an overall increase of storm intensities. Coastal areas are particularly vulnerable, even more so in light of rising sea levels. But interior arid and semiarid regions

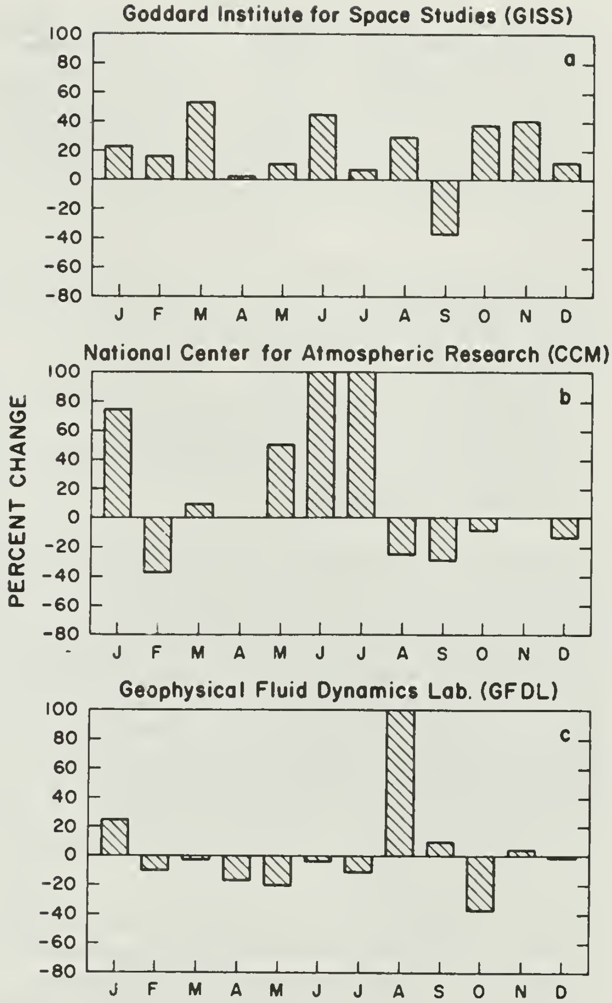


Figure 4. Changes in monthly precipitation in northern California from doubling of CO_2 as predicted by three GCM models (Gleick 1988, reprinted by permission of Westview Press).

become more vulnerable to soil erosion (most models of soil loss incorporate rainfall intensity as a driving force). Implications for fisheries in affected regions might involve more variable hydrographs and peak discharges from streams, possibly with additional sediment loads from runoff.

Somewhat increased groundwater temperatures would cause a limited retreat of cold-water habitat northward or upward in elevation. Watersheds in ecologically healthy conditions (where runoff channels are performing adequately within the amplitudes of present day climate variability) are doubtless our best buffers for adverse climate change. Good watershed management is the best gambit for us to enter into future uncertainties.

Global warming will be accompanied by greater evaporation from land surfaces and vegetation.

A scenario of mid-continental soil drought with increasing atmospheric CO_2 is given by Manabe and Wetherald (1986). Probabilities for water shortages in some regions will increase, with increasingly competitive demand for dwindling water supplies. Trout fisheries will compete for maintenance of instream flows with municipal, agricultural, hydropower, and other demands.

Maintenance of high river flow can become a major necessity to maintain freshwater aquifers against saltwater intrusion along seacoasts. Fisheries planners would be well advised to develop low flow and drought strategies to enhance the long term sustainability of fish populations in critical river and stream stretches (Gleick 1989). Identification and protection of refugial areas and their water rights may be necessary.

Increased global temperatures will also increase biological respiration and photosynthesis. The resulting net effects on warming are not yet known. Measures of global biomass that might be "liquidated" through increased respiration are crude, and we have little knowledge about compensatory effects of increased plant productivity and biological storage of carbon dioxide. Some suggest that stressed plant and animal populations will be found mostly at ecotones of the major biomes, and that here the numerous interactions between organisms - signified by the phrase "displacement ecology" - will be most apparent.

Fisheries managers may want to take another look at the river or stream continuum in the transition zone between "cold" and "warm" waters. For example, management that maintains or enhances streambank vegetation (which influences water temperature) would seem to be a useful tactic to buffer this zone against climatic warming. Another tactic would be to review fish harvest regulations for such stretches.

Although it always sounds somewhat self serving, research looms as an increasing need. A key to survival in a greenhouse altered climate will be flexibility: flexibility in the definition of alternatives, and flexibility in the face of an increasing public demand for natural resources. In recognition of this need, the scientific community has been getting together in unprecedented cooperation. One major indicator of this cooperation is the US Global Change Research Program prepared by the Committee on Earth Sciences (CES) of the Federal Coordinating Council on Science, Engineering and Technology (FCCSET) of the President's Office of Science and Technology Policy. This committee, recognizing the multi disciplinary challenges, is coordinating the Federal government's research plans. Agencies that normally have no communication of plans and budgets are sharing their approaches to this problem. In July 1989 the CES released "Our Changing Planet: The FY90 Research Plan" (CES 1989), which lays out a prioritized research effort (fig. 5). The budget proposal for this effort in FY90 is $191.5 million. While this program does not promise any total answers to global change, it does represent a reasonable start toward marshalling some of the resourcefulness and creativity of our society in attempting to cope with global change.

LIVING IN THE GREENHOUSE

Some climatologists suggest that the year 2000 may begin in earnest the global greenhouse century (Schneider 1989b). Although the human species has already demonstrated its capability to thrive in a wide variety of climates, this does not diminish the necessity to make adjustments, many of which may prove to be costly and painful. The global experiment with our atmosphere, begun about 100 years ago with industrialization and the exponential rise in human population, may be yielding its result, and we have no choice but to live with it.

To a limited extent we can mitigate the severity of global warming by improving human consumptive efficiencies, reducing per capita demand for energy and commodities, and increasing the supply of assimilative ecosystems such as forests, estuaries, coral reefs, and riparian areas. Our experiment with Earth's atmosphere has given us convincing evidence that, by **not** doing these things, we contribute to global warming as well as numerous other unwanted environmental consequences.

Adaptive strategies may well be forced upon us because atmospheric trends and greenhouse effects are projected well into the next century no matter how extreme the measures that societies might adopt today. But land managers can also pursue some elective strategies ahead of any crunch that might visit us in the next century. Among these elective options, the foremost would seem to be to adjust land management practices. Rates of conversion from high biomass to low biomass ecosystems can be slowed down or even reversed. Desertification must be drastically slowed down. Numerous other ecologically based, cultural land and watershed practices have been suggested, and need to be taken seriously (see Altierier 1983, Maser 1988, Crosson and Rosenberg 1989, Jackson and others 1984, Green 1987).

Another strategy for adjusting to future uncertainties is to manage for genetic diversity. Populations with a broad genetic base have greater odds to endure environmental adversity than those with a narrow base. Species with broad ecological amplitude (more ecotypes) will generally fare better in tomorrow's world than those of narrow amplitude. This concept of managing for diversity can be extended to community and landscape levels. Diversity represents opportunity, and more options in the uncertain future. Good resource managers help to insure future choices instead of narrowing them.

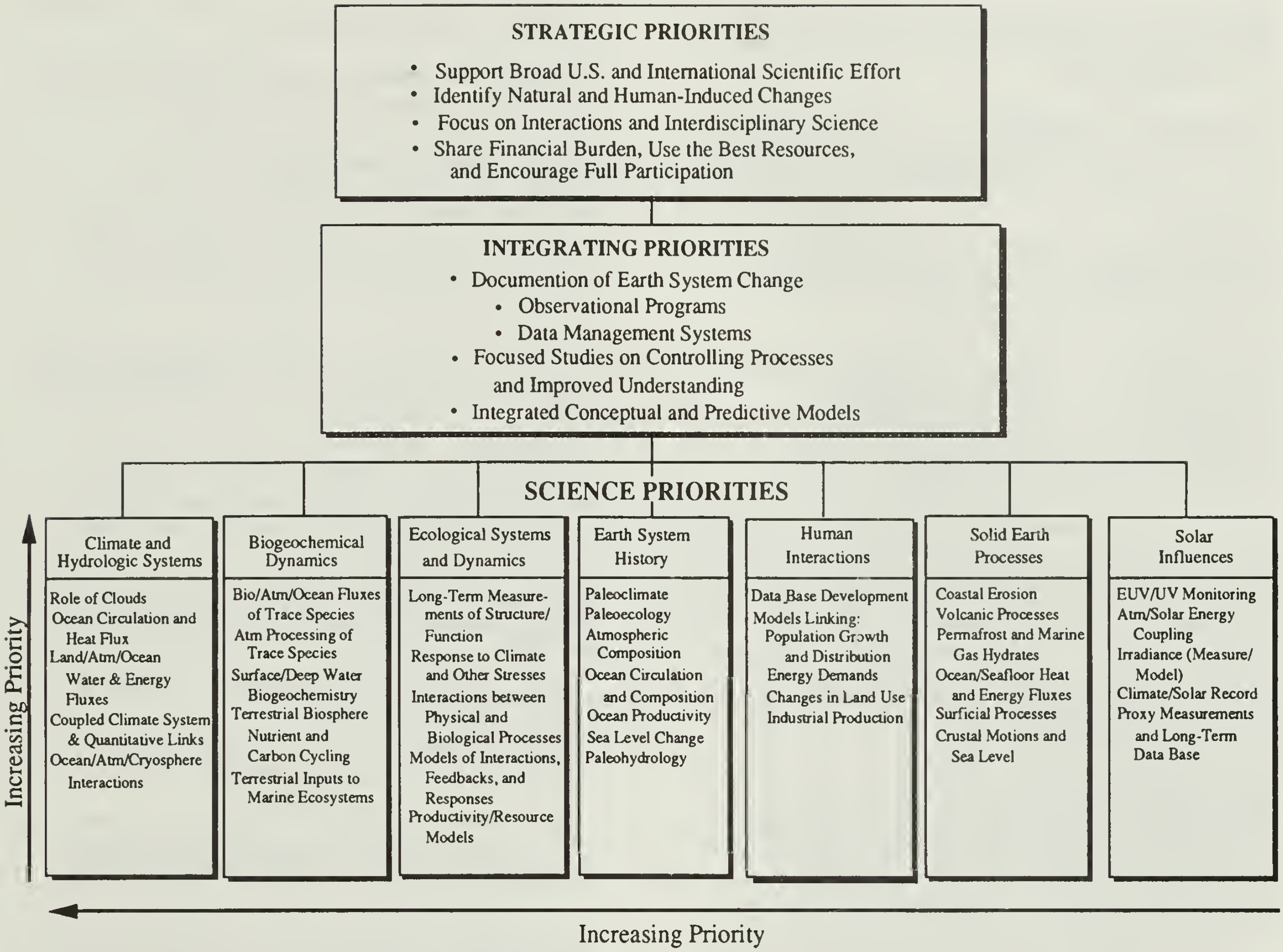


Figure 5. A priority framework for U.S. global change research (CES 1989).

The 21st century will be affected by the the cumulative activities of over 5.1 billion people inhabiting our planet today. People in developed nations can gradually shift to low environmental impact products (for example bicycles or mass transit rather than automobiles for commuting) or biodegradable wastes, or refrigerants that do not release CFCs to the atmosphere. Finally, industry might find that environmentally sound products and practices can be good business. New industries will center along principles of better caring for the Earth, and not, as Garrett Hardin puts it, "Privatizing profits and commonizing costs" (Hardin 1985).

It's hard to know what the fate of wild trout fisheries will be in the "Greenhouse Century". Some regions will be impacted more than others. Competition for water uses will be increased nearly everywhere. Better watershed management will be an imperative for successful adaptation, which will be an advantage to fisheries in general. In areas where aquatic diversity is low, or where mountain ranges do not attain sufficient elevation, cold-water fisheries may be replaced by warm water fisheries.

For sure, there will be greater appreciation and valuation for wild trout and other salmonid resources in their remaining locations. New genetic strains of fish may become more tolerant to low flow and drought conditions, acid pulses, and other seasonal adversities of flowing waters. Fishing privileges may become rationed among users. And fisheries managers will be greatly challenged to continue to manage for excellence this prized resource of high demand but ever more limited supply.

REFERENCES

ALTIERIER, MIGUEL A. 1983. Agroecology - the scientific basis of alternative agriculture. Univ. California Press, Berkeley.

COMMITTEE ON EARTH SCIENCES (CES). 1989. Our changing planet: The FY 1990 research plan.

Federal Coordinating Council for Science, Engineering, and Technology, Office of Science and Technology Policy, Washington D.C., xiii, 118 p.+ appendices.

CROSSOM, P.R., ROSENBERG, N.J. 1989. Strategies for agriculture. IN: Managing Planet Earth, Sci. Amer. 261 (September): 128-135.

DANSGAARD, W. 1987. Ice core evidence of abrupt climatic changes. Proceedings NATO Advanced Workshop on Abrupt Climatic Change, Dordrecht, Holland, p 223-233 (NATO ASI Series, Series C, v 216, QC981.8.C5N38)

GLEICK, PETER H. 1988. Climate change and California: past, present, and future vulnerabilities. Pp 307-327 IN: Michael H. Glantz (Ed.) Societal responses to regional climatic change, Forecasting by analogy. Westview Press, Boulder CO, 428 p.

------. 1989. Vulnerability of United States water systems to climate change. Proc. 2nd North American Conf. on Preparing for Climate Change: 327-336, Climate Institute, Washington D.C., June 1989, xi, 696 p + appendix

GRAUMLICH, LISA J., LINDA B. BRUBAKER, & CHARLES C. GRIER. 1989. Long-term trends in forest net primary productivity: Cascade Mountains, Washington. Ecology 70: 405-410.

GREEN, CHAMPE 1987. A strategy for reversing desertification. Pp 131-137 IN: In: Strategies for classification and management of native vegetation for food production in arid zones. U.S.D.A. Forest Serv. Gen. Tech. Rep. RM-150, Rocky Mountain Forest & and Range Experiement Station, Ft Collin CO, vii, 257 p.

HARDIN, GARRETT 1985 Filters against folly. Viking Penguin Inc., New York, x, 240 p.

HENDERSON-SELLERS, A & K. McGUFFIE. 1987. General circulation climate models. Pp 134-184 in their: A Climate Modelling Primer, John Wiley & Sons, New York, NY, xv, 217 p.

JACKSON, WES, WENDELL BARRY, BRUCE COLEMAN. 1984 Meeting the expectations of the land. North Point Press, San Francisco CA, 250 pp.

JAEGER, J. 1988. Developing policies for responding to climate change. P. 109 IN: Committee on Global Change, Toward an understanding of global change, Initial priorities for U.S. contributions to the International Geosphere-Biosphere program, National Acad. Press, Washington D.C., x,213 p.

MANABE AND WETHERALD. 1986. Reduction in summer soil wetness induced by an increase in atmospheric carbon dioxide. Science 232:626-628.

MASER, CHRIS. 1988. The Redesigned Forest. R&E Miles Press, San Pedro CA, xx, 234 pp.

NEILSON, RONALD P. 1986. High resolution climatic analysis and Southwest biogeography. Science 232: 27-34.

SCHNEIDER, STEPHEN H. 1989a. The greenhouse effect: science and policy. Science 243: 771-781.

_______ 1989b. Global Warming. Sierra Club Books, San Francisco CA.

SHEPARD, MICHAEL. 1988. The politics of climate. EPRI Journal 13: 4-15.

TITUS, JAMES G. (Editor) 1988. Greenhouse effect, sea level rise, and coastal wetlands. U.S. Environmental Protection Agency EPA-230-05-86-013, v, 152 p.

VAN DEVENDER, T.R. AND W.G. SPAULDING. 1979. Development of vegetation and climate in the Southwestern United States. Science 204:701-710

WOODWARD, F.I. 1987. Climate and plant distribution, Cambridge Univ. Press, Cambridge, London & New York, xi, 174 p.

Acidification and Fishery Resources in Maryland[1]

Douglas L. Britt[2] and W. Peter Saunders, Jr.[3]

Abstract.--A stream chemistry survey was designed and implemented to estimate the number and extent of stream reaches affected by, or at risk from, atmospheric acid deposition in Maryland. Statewide, 4,169 km of streams in the target populations (total=12,499 km) were found to be sensitive to acidification. Approximately 2,258 km of streams had pH values considered to be potentially detrimental to fish populations. The greatest percentages of potentially affected streams were located in the North and South Coastal Plains and the Appalachian Plateau physiographic provinces. These results have been used to develop a long-term monitoring program to detect future water quality changes and to identify potential risks to important fishery resources.

INTRODUCTION

Atmospheric acid deposition and its potential effects on aquatic biota, particularly fish, are now well recognized phenomena. Our understanding of the present extent and future risks of damage from acidification to aquatic resources, however, remains uncertain, especially with regard to lotic environments.

The National Stream Survey conducted in 1986 by the U.S. Environmental Protection Agency suggested that the Northern Appalachian, Valley and Ridge, and Middle Atlantic Coastal Plain physiographic provinces contain a greater percentage of streams with low pH and/or low acid neutralizing capacity (ANC) than other Mid-Atlantic and Southeast regions sampled, excluding Florida (U.S. Environmental Protection Agency 1988). Several other recent studies conducted in Maryland have indicated that precipitation events depress pH values in some streams, especially in the Coastal Plain Province (Janicki and Cummins 1983; Hall et. al. 1985; Campbell et. al. 1987; Greening et. al. 1987). Furthermore, pH values in several of these Maryland streams were observed to be lower than values reported to impair recruitment and survival of fish species found in Maryland waters (fig. 1). Aluminum concentrations also have been reported above potentially toxic levels in several Maryland streams exhibiting low pH during critically important spawning seasons (Hall 1987, Correll et. al. 1987).

Results of these and other similar studies suggested the need for a standardized statewide survey to quantify the number and extent of streams that are affected by, or sensitive to, acidification in Maryland. To this end, International Science & Technology, Inc. (IS&T) was contracted by the Maryland Department of Natural Resources to design and implement a Maryland Synoptic Stream Chemistry Survey (MSSCS).

The following objectives were established for the MSSCS:

- Design a survey that will allow the estimation of resources presently affected by, or at risk from acidification;
- Implement the survey design;

---

[1]Paper presented at the Wild Trout IV Symposium [Yellowstone National Park, Mammoth, Wyoming, September 18-19, 1989].

[2]Douglas L. Britt is President, International Science & Technology, Inc. (IS&T), Reston, VA.

[3]W. Peter Saunders, Jr. is Senior Biologist, Public Services Company of New Hampshire, Manchester, NH.

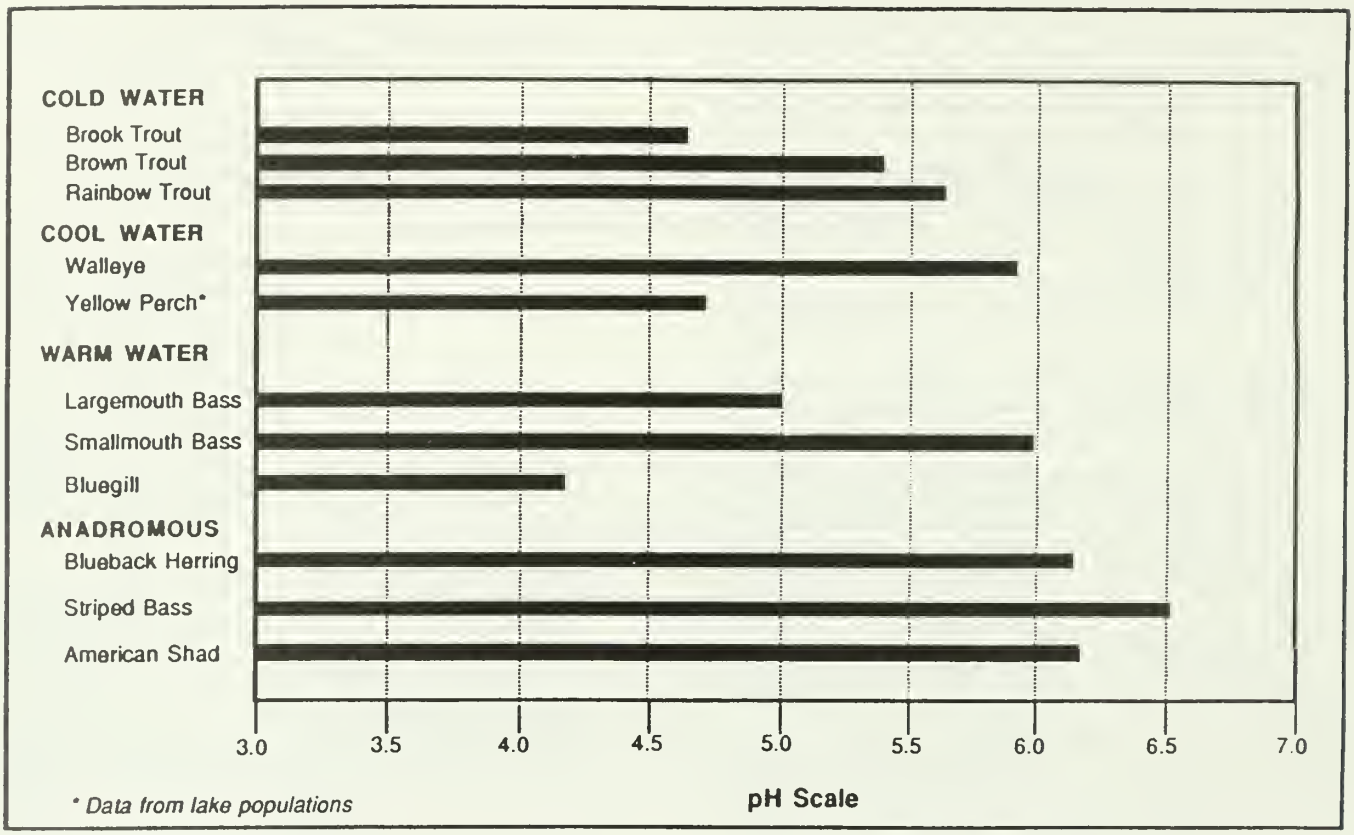


Figure 1. Critical pH Values, (i.e., those causing mortality in some part of the life cycle), For Some Common Maryland Game Fishes (from Maryland Power Plant Research Program, 1988). *Sources: Haines 1981; Baker 1982; Wood and McDonald 1982: Klauda and Palmer 1986; Mehrle et al. 1984, 1985; Hall et al., 1985.*

- Analyze the data collected to produce statistically valid population estimates of resources at risk; and,
- Design a long-term monitoring program to detect changes in stream chemistry related to acidic deposition.

SURVEY DESIGN

The MSSCS was designed to optimize the distribution of a fixed level of sampling effort to produce minimum variance estimates of the population of resources at risk. A stratified random sampling design was developed for the population of Maryland non-tidal stream reaches[4]. This population included streams with significant biological resource potential.

[4]A stream reach is defined for this purpose as a blue-line drainage feature segment on a U.S. Geological Survey (USGS) 1:250,000-scale topographic map. The boundaries of a reach can be its intersection with two other blue lines, with an impoundment, or with the upstream terminus of the line.

Because of the project's focus on streams that may have a high probability of being sensitive to atmospheric acid deposition, all freely flowing stream reaches with drainage areas less than 100 km^2 and having no known sources of industrial pollutants or acidic mine drainage were included in the population of interest. Statewide, the estimated population of interests comprised 5411 reaches with a total length of 12,499 km.

Six sampling strata, reflecting regional patterns in potential sensitivity of surface waters to acidification, were defined: Appalachian Plateau, Valley and Ridge, Blue Ridge, Piedmont, North Coastal Plain, and South Coastal Plain (fig. 2). The strata were based on the physiographic provinces of Maryland with modification of some boundaries to provide for consideration of geology and soils in the stratification scheme.

A single water chemistry sample was collected from each of 559 randomly selected stream reaches within the population of interest (fig. 3) during spring of 1987. An additional 71 previously selected reaches of special

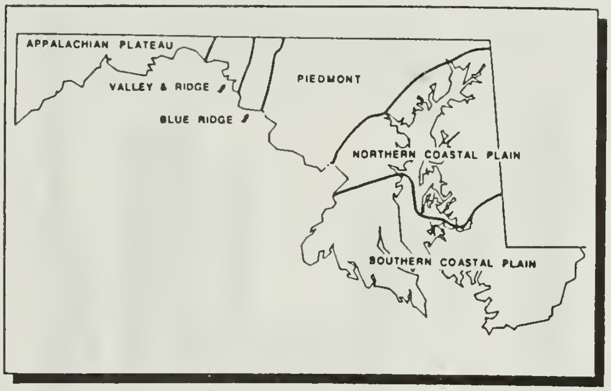


Figure 2. Sampling regions from the Maryland Synoptic Stream Chemistry Survey. *Source: Knapp et al. (1988a).*

interest to the state were also sampled as part of this survey. The individual samples from each reach represented indices of stream chemistry in all reaches in the region sampled on a specific sampling date. These index values were used to construct population estimates that reflect synoptic stream chemistry during relatively constant spring phenological conditions. To sample all streams during similar conditions (i.e., early spring base flow), sampling commenced in the South Coastal Plain on March 7th, and progressed northward and westward, concluding in the Appalachian Plateau on May 9th.

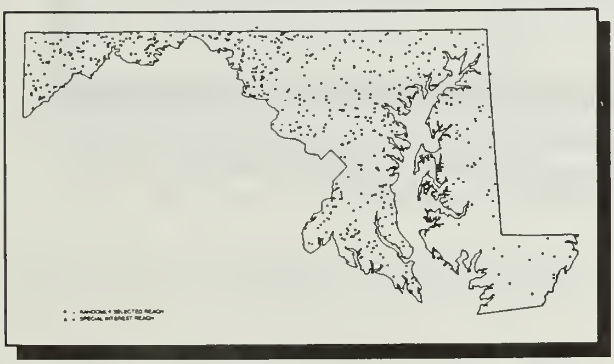


Figure 3. Geographic Distribution of Reeches Sampled in the MSSCS.

Representatives of the Maryland Forest, Park, and Wildlife Service assisted in obtaining site access permission for sample collection prior to initiation of water sampling. A central feature of the survey was the use of volunteers in the collection of samples. These volunteers were recruited from conservation organizations and the general public. Sampling was coordinated on Saturdays from regional field headquarters, where the volunteers assembled to be trained in sample collection protocols, received stream sampling assignments, and returned with collected samples. The field headquarters facilities were staffed at all times when volunteers were in the field, for safety reasons and to provide communications. All samples were returned to the regional field headquarters and then to the analytical laboratory on the same day as they were collected.

Six water chemistry parameters were measured for all streams sampled: pH, ANC, dissolved inorganic carbon, dissolved organic carbon, conductivity, and color. In addition, mineral acidity titrations were performed for samples with pH values less than 4.5, to assess the potential influence of acidic industrial or mine discharges. Quality assurance and quality control (QA/QC) sampling involved collection of field duplicates (13.5 percent of reaches sampled) to assess sampling system variability; laboratory duplicates (6.5 percent of field samples) to assess analytical precision; and laboratory audits (6.5 percent of field samples) to assess analytical accuracy. In addition field performance audits were conducted at 11.5% of the stream sites sampled by volunteers, to document the accuracy with which volunteers adhered to the prescribed sampling protocols.

Further details of the MSSCS design have been described by Knapp and Saunders (1987).

RESULTS AND DISCUSSION

A detailed description and interpretation of the results of the MSSCS have been recently documented (Knapp et. al. 1988a). This paper summarizes only the regional differences in pH and ANC, and suggests the implications of the differences with regard to important fishery resources.

Figure 4 illustrates the distribution of stream reaches by pH classes for each of the sampling strata. A similar graphical representation for ANC classes is presented in figure 5. Low pH and low ANC reaches occur in all strata except the Valley and Ridge. The absence of low pH and low ANC waters in the Valley and Ridge Province is not surprising considering its predominantly limestone geology.

The MSSCS data also indicate that, compared to other regions of the state, larger proportions of streams in the Coastal Plain and western Maryland exhibited relatively low pH and ANC values. These data also suggest that, during spring, several drainage systems in Maryland contain streams with water quality that may be detrimental to resident or anadromous fish populations (refer to fig. 1). In the North and South Coastal Plain, where the most acid-sensitive anadromous fish spawn, a pH of 6.5 or less was selected to indicate potentially affected biological resources. In the upland areas of the state (i.e., Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau) a pH threshold of 6.0 was used to indicate water quality that may impair important resident and stocked fish populations (e.g., trout, walleye, bass).

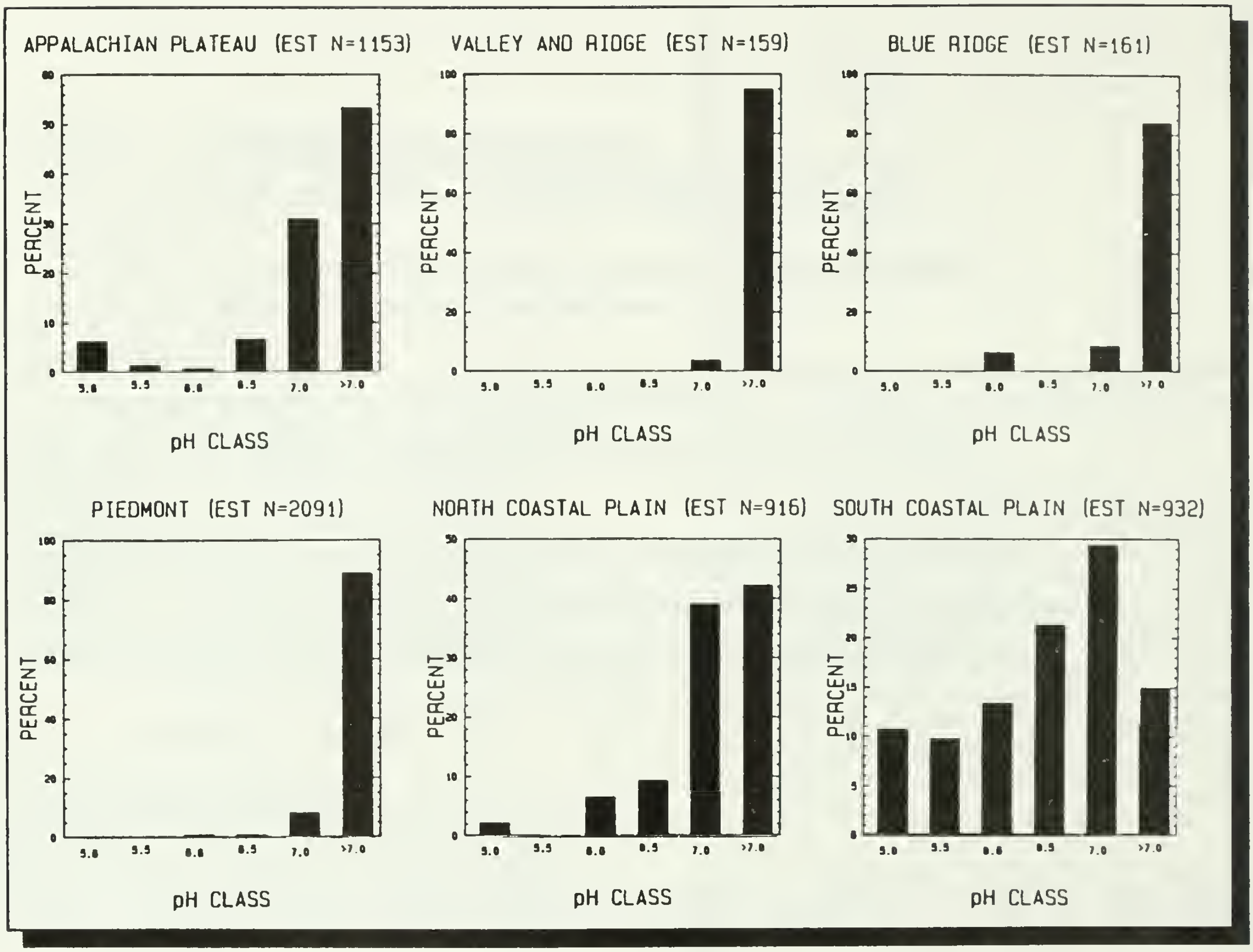


Figure 4. Sampling Stratum Relative Frequencies for the Estimated Number of Reaches in the Population of Interest Within Each of Six pH Classes. Numbers on the x-axis indicate the upper boundary of each pH class. "N" is the estimated total length of streams, in kilometers, in each strata.

Figure 6 illustrates the estimated percentage of stream kilometers for three classes of stream pH (less than 6.0, 6-6.5, greater than 6.5) in each of the sampling strata. Employing the sensitivity thresholds defined above, an estimated 2,258 km (1,400 miles) of streams in the statewide target population (total=12,499 km) had pH values indicative of possible adverse effects on fish populations. The South Coastal Plain, North Coastal Plain, and Appalachian Plateau had the largest percentages of potentially affected stream reaches (58.0%, 19.3%, and 11.6% of the total stream kilometers in each region, respectively).

Within the Coastal Plain, the anadromous fishes of the Chesapeake Bay drainage may be most affected. During the past few years, anadromous fish stocks have reached or approached historically low levels in the Chesapeake Bay. Although acid deposition has not been shown to be a direct causal mechanism in these declines, acidification of spawning habitat represents a potential obstacle to the recovery of affected stocks.

Within the Appalachian Plateau, the most important resources with respect to fisheries management are salmonid populations, especially self-sustaining populations of brook trout, Salvelinus frontinalis, which inhabit over 240 km of streams (approximately 22% of the total length of streams) in this province (Steinfelt 1985). This is the most important region in the state for wild trout management.

The ANC of streams is often used to assess their sensitivities to acidification. An ANC of less than 200 eq/l was used in the present study to indicate sensitivity to chronic acidification in the long-term, as well as present susceptibility to episodic acidification associated with acid pulses from precipitation events and snowmelt. This threshold has been frequently used by others as a stream sensitivity criterion for acidification (Norton et. al. 1982). Based on this criterion, 4,169

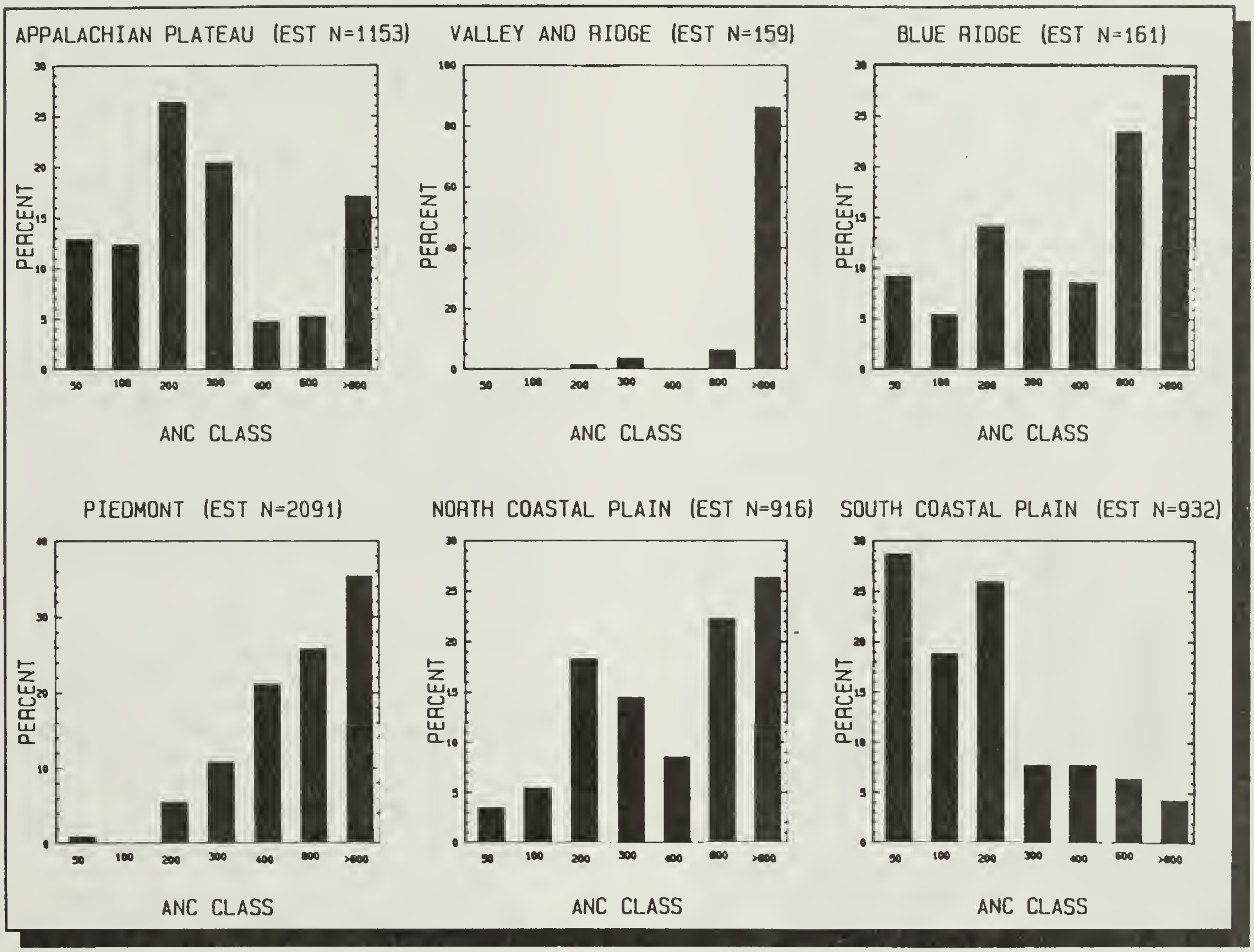


Figure 5. Sampling Stratum Relative Frequencies for the Estimated Number of Reaches in the Population of Interest Within Each of Seven ANC Classes. Numbers on the x-axis indicate the upper boundary of each ANC class. "N" is the estimated total length of streams, in kilometers, in each strata.

km (2,585 miles) of streams, corresponding to 33.4% of the target population, are estimated to be sensitive to acidification.

Figure 7 illustrates the distribution of stream kilometers by sampling strata for three ANC classes: $\leq$ 50 μeq/l, $\geq$ 50 $\leq$ 200 μeq/l, $\geq$ 200 μeq/l. Using the 200 μeq/l threshold, the Piedmont and Valley and Ridge Provinces have relatively low percentages of potentially sensitive streams (less than 10%). The North Coastal Plain and Blue Ridge Provinces have moderate percentages of potentially sensitive streams (28.3% and 26.0%, respectively), while the South Coastal Plain and Appalachian Plateau regions have relatively high percentages of potentially sensitive streams (74.4% and 53.3%, respectively).

The MSSCS was conducted during spring conditions, which likely reflect lower pH conditions than in other seasons owing to the influence of the annual hydrological cycle (Messer, et. al. 1986). The survey, however,

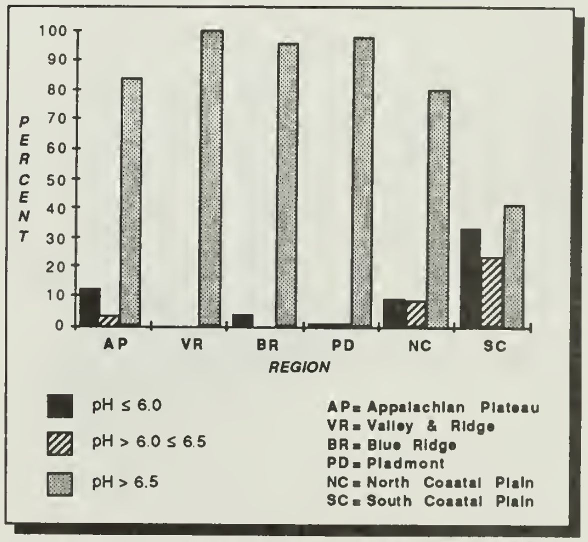


Figure 6. pH Data (percentage of stream kilometers) From the Maryland Synoptic Stream Chemistry Survey.
Source: Knapp et al. (1988a).

does not capture worst-case conditions, because pH minima typically occur during major hydrological events. This raises concerns that many Coastal Plain and Appalachian Plateau streams having low ANC may be subject to critical pH depressions during episodic events, or from continued chronic exposure to atmospheric acid deposition. That episodic events associated with spring rains often coincide with the spawning runs of anadromous fish is a serious issue for the tidewater regions of the state. With respect to Maryland's cold water fisheries management, the potential impacts of episodic hydrologic events associated with storms and snowmelt on the native trout populations of Western Maryland are deserving of immediate attention.

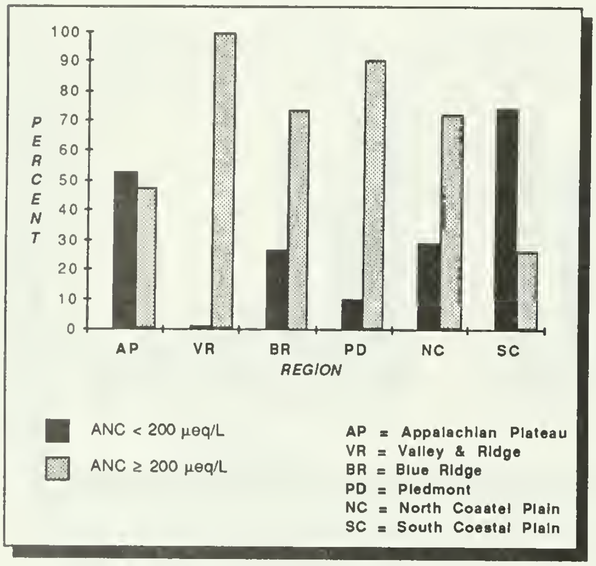


Figure 7. ANC Data (percentage of stream kilometers) From the Maryland Synoptic Stream Chemistry Survey.
Source: Knapp et al. (1988a).

CONCLUSIONS

The Maryland Synoptic Stream Chemistry Survey represents a significant effort in the monitoring of acidification effects on aquatic resources. The MSSCS provided a statistically valid sample from a population comprising the majority of stream resources in the state. In addition, the volunteer component of the MSSCS fostered public involvement and concern while providing a very cost-effective approach to sample collection. The MSSCS successfully provided a comprehensive "snapshot" of the stream resources potentially at risk from acidification; and the MSSCS results are playing a role in the ongoing monitoring of acidification effects on Maryland streams. The MSSCS survey design has also provided the statistical framework for a long term monitoring program in Maryland (Knapp et. al. 1988b).

The MSSCS provides a reliable indication of those areas where a substantial proportion of the fisheries resources may be at risk due to acidification. The general conclusions are that appreciable fisheries resources may be at risk from acidification in the Coastal Plain and Appalachian Plateau of Maryland. Although acidification effects on those resources have not been demonstrated by the MSSCS, the survey results have delineated the magnitude of the potential problem and have helped to focus the attention of resource management agencies on the areas of concern.

Trout Unlimited volunteers played an important role in the MSSCS sampling effort. Because of the success of this program, Trout Unlimited is encouraging more states to conduct their own statewide synoptic surveys of streams to determine their sensitivity to acidification. As part of this effort, Trout Unlimited is offering to assist in the recruitment and organization of volunteers, and is soliciting donations to fund and conduct such surveys in states having cold water resources.

LITERATURE CITED

Baker, J.P. 1982. Effects on fish of metals associated with acidification. In: Acid rain/fisheries, 165-176. T.H. Haines and R.E. Johnson, eds. American Fisheries Society, Bethesda, MD.

Campbell, S., J. Bartoshesky, D. Heimbuch, A. Janicki, and H. Petrmoulx. 1987. Relationships between acid deposition, watershed characteristics and stream chemistry in Maryland coastal streams. Prepared for the Maryland Power Plant Research Program. Report No. AD-87-8.

Correll, D.L., J.J. Miklas, A.H. Hines, and J.J. Schaffer. 1987. Chemical and biological trends associated with acidic atmospheric deposition in the Rhode River watershed and estuary. Water, Air, and Soil Pollution 35:63-87.

Greening, H., A. Janicki, and W.P. Saunders. 1987. An evaluation of stream liming effects on water quality and yellow perch spawning in Maryland Coastal Plain streams. Prepared by International Science and Technology, Inc. Reston, VA, for Maryland Department of Natural Resources, Tidewater Administration, Annapolis, MD. Final report.

Haines, T.A. 1981. Acidic precipitation and its consequences for aquatic ecosystems: a review. Trans. Amer. Fish. Soc. 110:669-707.

Hall, L.W., Jr. 1987. Acidification effects on larval striped bass, Morone saxatilis in Chesapeake Bay tributaries: a review. Water, Air, and Soil Pollution 35:87-96.

Hall, L.W. Jr., A.E. Pinkney, and L.O. Horseman, 1985. Mortality of striped bass larvae in relation to contaminants and water quality in a Chesapeake Bay tributary. Trans. Amer. Fish. Soc. 114:861-868.

Janicki, A. and R. Cummins. 1983. An analysis of survey data on the chemistry of twenty-three streams in the Chesapeake Bay watershed: some implications of the impact of acid deposition. Prepared for the Maryland Power Plant Research Program. Report No. AD-87-11.

Klauda, R.J., and R.E. Palmer. 1986. Laboratory and field bioassay experiments with blueback herring from Maryland Coastal streams. Prepared by the Johns Hopkins University, Applied Physics Laboratory, Laurel, MD, for the Maryland Department of Natural Resources, Power Plant Research Program, Annapolis, MD. PPRP-AD-15. NTIS No. PB86/209541/AS. 228 pp.

Knapp, C.M., G.J. Filbin, and M.B. Bonoff. 1986. Maryland Long-Term Stream Chemistry Monitoring Program. Prepared by International Science & Technology, Inc., Reston, VA, for Maryland Department of Natural Resources, Power Plant Research Program. Annapolis, MD. Report No. AD-88-3.

Knapp, C.M. and W.P. Saunders. 1987. Maryland Synoptic Stream Chemistry Survey design report. Prepared by International Science & Technology, Inc. for Maryland Department of Natural Resources, Power Plant Research Program. Annapolis, MD. Report No. AD-87-5.

Knapp, C.M., W.P. Saunders, D.G. Heimbuch, H.S. Greening, and G.J. Filbin. 1988a. Maryland Synoptic Stream Chemistry Survey. Estimating the Number and Distribution of Streams Affected by or at Risk from Acidification. Prepared for the Maryland Power Plant Research Program. Report No. AD-88-2.

Mehrle, P.M., D. Buckler, S. Finger, and L. Ludke. 1984. Impact of contaminants on striped bass. Interim report. U.S. Fish and Wildlife Service, Columbia National Fisheries Research Laboratory, Columbia, MO.

Norton, S.A., J.J. Akielaszek, T.A. Haines, K.L. Stomber, and J.R. Longcore. 1982. Bedrock geologic control of sensitivity of aquatic ecosystems in the United States to acidic deposition. Fish and Wildlife Service, Patuxent Wildlife Research Center, Laurel, Maryland.

Steinfelt, H.J., S.E. Rivers, C.R. Gougeon, and D.E. Woronecki. 1985. Final report for federal aid project F-36-R survey, inventory, and management of Maryland's cold water fishery resource. Maryland Tidewater Administration, Department of Natural Resource, Cold Water Fisheries Program, Annapolis, MD.

U.S. Environmental Protection Agency. 1988. Chemical characteristics of streams in the mid-Atlantic and southeast United States (National Stream Survey); Volume I: Population descriptions and physico-chemical relationships. U.S. EPA, Washington, D.C., EPA/600/3-88/02/a,b.

Wood, C.M., and D.G. McDonald. 1982. Physiological mechanisms of acid toxicity to fish, In: Acid rain/fisheries, 197-226. T.A. Haines and R.E. Johnson, eds. American Fisheries Society, Bethesda, MD.

Strengthening the Partnership Between Water Quality Management and Fisheries Protection[1]

Rebecca Hanmer[2]

Abstract.--The Section 404 program offers many opportunities for water quality and fishery habitat concerns to join. The State nonpoint source management programs are being encouraged by Federal policy to target streams and other water areas of great natural value, and they are also being encouraged to form partnerships with State fish and game agencies. The U.S. Environmental Protection Agency, which has traditionally used salmonid species in developing water quality criteria levels of protection, is increasing attention to biocriteria and sediment quality, which should benefit protection of trout fisheries. With Federal funding for municipal water pollution control disappearing, the 1990s offer a time for "breakdown" or "breakthrough" in water quality management that is already stimulating innovative thinking about water conservation, local land use, and growth management and system rehabilitation. However, citizens' willingness to pay for water quality will be strongly tested, and the link between quality and benefits such as fisheries and recreation will be a crucial factor.

My background is in environmental pollution control, a movement that has grown largely out of what I call "the Sanitarian tradition" -- one which pervades public health administration. Standing here in Yellowstone, I am reminded of another tradition that has lent its support especially to water pollution control--the "Nature Conservation tradition." I feel very privileged to be among so many fishermen and fishery managers who embody that pre-eminently American tradition and are perhaps its strongest members.

These two traditions of water quality management have not always reinforced each other; you as well as I can cite many examples of outright conflict and even more of failure to communicate. Linking water quality programs with their fish and wildlife brethren is something EPA sees as urgent, and I'd like to tell you this morning where we are in several Clean Water Act programs that offer opportunities, especially relevant to trout stream protection: Section 404 permitting, State nonpoint source programs, and taking water quality standards "up the banks" to link with wetlands as well as "to the bottoms" to deal with sediments.

I'd also like to mention briefly an interesting opportunity the global warming concerns offer for reforestation. I want to alert you to a great breakdown in water pollution control funding that offers both perils and opportunities for the 90s.

Finally, and most importantly, I'd like to listen to you. We're in the middle of four-year strategic planning and Administrator Bill Reilly has stressed his support for EPA's ecological protection programs, his willingness to exert leadership in natural resource protection, and his support for partnerships of all kinds. We're at a crossroads and open to the paths you might lay out for us.

---

[1]Paper presented at Wild Trout IV, Sept. 18-19, 1989, Yellowstone National Park, Wyoming.

[2]Acting Assistant Administrator for Water, U.S. Environmental Protection Agency, Washington, DC.

CLEAN WATER ACT PROGRAMS

Section 101 of the Act states an overall goal of the law to restore and maintain the chemical, physical and biological integrity of the Nation's waters. Our water pollution control program has emphasized chemical integrity and we, as a society, have probably spent in excess of $200 billion over the last 20 years to attain this objective in areas affected by municipal and industrial discharges. Now there's a growing recognition that we've wasted our money if we're not also protecting aquatic habitat and the beach and lake recreation areas. Everywhere we look, habitat losses and beach degradation are alarming so we're turning increasing attention to these issues.

SECTION 404

One section of the law that is overtly habitat oriented is Section 404, which regulates disposal of dredged or fill material in waters of the U.S. The Clean Water Act jurisdiction covers essentially all natural waters and many manmade waterbodies as well, and includes wetlands. Thus 404 issues frequently get right to the heart of water resource use and land management. As you're aware, no doubt, the Army Corps of Engineers is responsible for issuing Federal 404 permits but EPA has major responsibilities for standards-setting, enforcement and permit review, and the Interior and Commerce fisheries programs are daily involved in commenting on permits and working out issues.

Early in the Reagan Administration, the 404 program was slated for major rollback due to a number of land and water use controversies around the country. EPA was directed to review and reform its 404(b)(1) Guidelines, especially their reliance on evaluation of alternatives to filling and the water dependency test. But 404 and the Guidelines survived. In the last few years we're taking enforcement actions against illegal dischargers that have had strong local public support and we've taken some key permit veto actions under 404(c). Wetlands protection is the most often mentioned feature of 404 because wetlands are especially vulnerable to the type of physical destruction that 404 covers; however, we pay attention to all aquatic resources and some of our recent actions have focused on protection of trout waters.

In the Rocky Mountain States especially, the vast majority of 404 permit applicants are concerned with rivers and streams, not wetlands.

Recent enforcement actions by EPA protected trout waters threatened by unauthorized dredging and filling occurred on the Little Bighorn River and Yellowstone Rivers, Montana, and Roaring Fork River, Colorado. The fisheries habitat and riparian areas in Little Bighorn River were restored as required by an EPA-issued Administrative Order (AO). EPA AO's commonly require restoration and may impose administrative penalties. As a result of the February 1987 amendments to the CWA, EPA has authority to issue administrative penalties. (Class I penalties - up to $5,000 per day not to exceed $25,000 and Class II penalties - up to $25,000/day not to exceed $125,000.)

EPA can also refer 404 violations to DOJ who can seek court penalties in addition to EPA AO requirements for environmental restoration. For example, in the case of the Little Bighorn River violation, a civil penalty (fine) is being sought by DOJ through Federal court. Also. criminal actions can be referred to DOJ, when warranted.

To minimize impacts from annual maintenance in and around irrigation diversion structures on Montana trout streams and rivers, EPA is working with and through the Montana Association of Conservation Districts (MACD) to get information to water users regarding 404 permit requirements. EPA has provided funds to MACD to develop and distribute a plain language brochure, and we will use this as a model for similar activities in other western states. (MACD was brought into this program by two recent EPA AO's in Montana concerning unauthorized discharges in and around irrigation diversion structures on the Yellowstone River.)

EPA's use of 404(C) veto authority has increased and an outstanding example is the Two Forks water project in Colorado. Adverse impact to an outstanding aquatic resource (Gold Medal trout water) is a main reason for the "Proposed Determination" that this project would result in an unsatisfactory impact on fish and wildlife under the Act. (We've just entered the formal comment period on this determination and will hold hearings in Colorado and Nebraska in October.)

404 is a valuable tool for linking water quality and fisheries protection, although it does not offer a comprehensive way of forging the links. It cannot deal with drainage, for example, which is the principal cause of wetlands loss. Minimum stream flows can be a condition of 404 permits, but there are difficulties. Section 404 controversies have spawned a number of planning efforts, but there needs to be a broader framework. Thus, I'll go on to talk about State nonpoint source control program and water quality standards which might offer such a framework.

NONPOINT SOURCE POLLUTION CONTROL

The term "nonpoint source pollution control" (NPS) covers all sources of pollution not caused by municipal, industrial, agricultural and commercial discharges through pipes, and thus refers to a large array of practices. Only about 20% of the waters of the U.S. are estimated to be affected by point sources; thus, whatever is causing pollution in the other 80% is by definition nonpoint source in origin. Many of the remaining water quality problems in the point source areas are due not to these controlled discharges but to the uncontrolled runoff, accidents, seepage from septic tanks and other sources of groundwater contamination and atmospheric deposition.

Congress did not give EPA strong authority over nonpoint source pollution. Recognizing that land and water management practices were at the heart of the matter, Congress mandated the States, in 1987, to perform problem assessments and develop nonpoint source management programs by August 1988.

Congress asked a lot from the State water quality (WQ) agencies in a short time, and not surprisingly, the work isn't finished in a number of states. In EPA's guidelines for the program, we emphasized some pragmatic objectives and especially stressed the need for partnership at the state level with fish and wildlife agencies. Specifically:

- We urged the State WQ agencies to gather available information from the state counterparts in fish and wildlife, agriculture and forestry and health.

- What a WQ "problem" is needed to be related to what uses were impaired. We also asked states to identify high quality areas that were threatened by land use changes which might lead to quality problems.

- Assuming money constraints, we asked states to target NPS program activities to areas of highest resource value, using conservationist and other agency advice and seek to leverage money from other agencies and local public support.

- Since trout streams, particularly wild trout, have been a traditional indicator of high water quality, we are expecting states especially to identify these streams and focus on them if there's a pollution threat. Given the "physical, chemical, biological integrity" goal, a threat can be defined very broadly. Prevention and remediation actions, called "best management practices" are similarly a very broad range of actions. Some states have moved out strongly on NPS but in most places we have work to do. Resources have been a major issue and they are admittedly limited. However, states may use funds from the new State Water Pollution Control Revolving Loan Funds to make loans for nonpoint source projects, and I believe Congress will begin to fund NPS grants this coming fiscal year.

- This program is rich with possibilities for connecting water quality and habitat protection practices. In this region, for example, EPA is jointly funding preparation of a best management practice manual to address livestock grazing impacts. We will provide funding for a technical publication for livestock owners, land managers and state personnel which will provide detailed guidance for developing grazing strategies to restore and protect riparian areas.

In Headquarters, we are using this program to work with the U.S. Department of Agriculture (USDA) on a broad Water Quality Initiative. Key features for us will be use of the existing USDA and NPS programs to foster "low input" agricultural practices and further strengthening of conservation practices for water quality protection in the 1990 Farm Bill.

WATER QUALITY STANDARDS

This is the central Clean Water Act program which will increasingly drive priorities and actions in both point and nonpoint source controls. There are two facets I'd like to note: antidegradation policies required in each state standards program, and recent emphasis in criteria development.

EPA's Water Quality Standards (WGS) regulations require that:

- Each state develop and adopt a statewide antidegradation policy and identify methods for implementing such a policy.

- The purpose is to protect and maintain existing uses to support propagation of fish, shellfish, wildlife, recreation and water supply.

- Where high quality waters constitute an outstanding national resource, such as waters of National and State parks and wildlife refuges and waters of exceptional recreational or ecological significance, these waters shall be maintained and protected in their present high quality.

- For example: the state of Wyoming has designated all surface waters within the boundary of Yellowstone National Park to be Class I waters (e.g., outstanding natural resource waters). In addition, all Congressionally designated wilderness areas in Wyoming are designated Class I waters. Other western states have designated outstanding natural resource waters similar to these designated in Wyoming through the EPA water quality standards regulation, thereby protecting trout waters.

- States can be petitioned by the public to designate "outstanding natural resource waters." EPA is aware that a number of western state fish and game departments have classified their state rivers and streams as being "blue ribbon" or "gold medal" to protect valuable trout fishery waters.

• State fish and game departments and interest groups such as Trout Unlimited should work closely with state water quality agencies in protecting water quality for fishery resources.

The antidegradation requirement has been on the books since 1967, and still many high quality waters have been lost. What's new is that Congress renewed and emphasized the mandate in 1987, and we and the environmental community have made it a high priority.

In water quality criteria development we have long placed a high priority on the protection of sport fish, such as salmon and trout. We have developed approximately 40 criteria to protect aquatic life. The guidelines for developing water quality criteria require tests be done on at least two fish, one of which must be of the salmonid (salmon or trout) family. In practice, we usually test additional fish. We are also evaluating whether our present methodology could be improved in the area of protection of wildlife.

In recent years, we've added whole effluent toxicity testing and control to our point source program, using biological tests for both acute and chronic toxicity. Now we are engaged in the development of biocriteria, which will evaluate the health of ecosystems as a unit. This will enable us to identify environmental problems directly, avoiding the pitfalls of overlooking a specific problem chemical, or of inadequate knowledge about a specific chemical. Biocriteria should be helpful in nonpoint source program implementation especially.

In addition, we are looking at ways to strengthen the WQS to protect wetlands. At this point, we're in an early exploratory stage examining a number of mechanisms from sediment criteria to vegetative parameters. In this way, we're taking WQS "up the banks" and "to the bottoms." Several states spoke at our December WQS workshop about their work on sediment criteria. Renewed attention to sediments should be especially helpful to trout stream protection, and would be used in evaluating forestry and agricultural practices.

REFORESTATION

An interagency group, involving USDA, Energy, Interior and EPA staff, is currently working on a proposed Administration initiative called "Trees for U.S." In EPA, Administrator Reilly is following development of this proposal personally as part of his overall Clean Air Act/ Global Warming response. There are some interesting statistics in the early draft I read: historically there were over a billion acres of forestland, which had declined to 751 million by 1920. In the succeeding 50 years, to 1970, we restored some of this decrease but now the acreage is declining again. The community forest land situation is especially variable with an estimated current replacement of lost trees at only one for four.

In looking at global warming response, some studies have been done of methods for slowing CO_2 buildup in the atmosphere which show tree planting--especially in or near urban areas--could be very cost effective compared to other options. Very preliminary but interesting cost figures indicate a cost of $6-25 for planting urban trees, per ton of carbon conserved. By contrast, more efficient electric appliances were costed at $50 per ton and more fuel-efficient cars at $200 per ton. I'm not sure these costs will hold up in absolute terms but they present very interesting possibilities for forestry management.

In terms of CO_2 conservation alone, preservation of forests in the headwaters for water quality and fisheries protection might not be considered very important. But surely, there's a way to link the two concerns, while the Administration is focusing in a long-term way on some very important forestry concerns.

According to the draft plan I saw, the reforestation proposal will be built into the debate over the 1990 Farm Bill reauthorization. For example, tree planting initiatives could be included in the Conservation Reserve program. This summer and fall, a variety of analyses are being done and the policy debate is scheduled for the January to March 1990 timeframe. EPA is also entering into its own cooperative program with the American Forestry Association to study forestry opportunities in the U.S. to mitigate the effects of global warming.

In closing, I have to sound one discordant note. After 20 years, the huge Federal grant program that supported towns and cities in cleaning up their water pollution problems is disappearing. During the transition to state and local self-sufficient financing, the Federal capitalization grants will offer five years of funding to State Revolving Loan Funds. The good news is that the states can run their loan programs without many of the Federal requirements that were costly, and can fund a broad range of pollution control projects, including nonpoint source. Less Federal money should stimulate creativity about less costly and non-structural ways to achieve water quality objectives and it will definitely stimulate cost-sharing partnerships. We see many instances of local interest in water conservation and better land and growth management.

The concern is that most of the inherent water pollution we had is still there - we've just built dykes and pumping systems and treatment basins between ourselves and the deluge. Urban systems are aging and need constant maintenance and replacement. This will lead at a minimum to greatly increased local costs and put water quality issues on the agenda in every state legislature. A change this big is like going over Niagara Falls in a barrel. Citizens' willingness to pay for water quality will be strongly tested, and the link between quality and benefits such as fisheries and recreation will be a crucial factor.

These opportunities, brought by our increasing knowledge, and this challenge mean exciting times ahead for water quality managers. Never more than now do we appreciate who our friends are, and fishermen are our friends. I look forward to your reaction, and to a future of cooperative endeavors.

Atlantic Salmon Fixes[1]

Alex T. Bielak[2]

Abstract. A decade ago many wild Canadian Atlantic salmon stocks had dwindled to the point where draconian measures were needed to reverse the declines. This paper details the often innovative steps taken to begin restoring the resource, as well as unforseen factors which played a role in the process. It reports on some of the results of actions taken to date, and concludes with a prognosis for the future.

INTRODUCTION

The Atlantic salmon, Salmo salar L., continues to inspire, challenge and fascinate mankind. Many of the reasons for the continuing reverence for the species remain the same as may be found in any number of popular writings: The salmon is a remarkable leaper, does travel incredible distances, and does perform remarkably at the end of a fisherman's line. Perhaps most importantly it continues to serve as an indicator of healthy environments, as well as remaining a culinary delight.

However, some new items can be added to the above list. Despite local extinctions and a general decline in stocks, the species has proven a good deal tougher and resilient than many observers thought: despite all man's efforts to the contrary, salmon have managed to survive into the late twentieth century. Recreational fisheries for Atlantic salmon have become increasingly important from an economic standpoint, and particularly so in the often economically disadvantaged regions where salmon rivers frequently occur.

Perhaps most remarkably, worldwide harvest of Atlantic salmon has increased twenty-two fold, from about 8000 tonnes in the 1970s to somewhere in the region of 175,000 tonnes in 1989 - And there-in lies the rub, because now the vast majority of those fish come to market from sea-farming operations, and are about as wild as beef cattle.

Consequently it has become more important than ever to preserve wild strains of salmon, and this paper details some of the innovative measures taken by Canadian federal and provincial governments, as well as by private sector groups such as the Atlantic Salmon Federation and its affiliates, to secure the Atlantic salmon's future.

THE ATLANTIC SALMON RESOURCE IN CANADA

Although the aboriginal range and productive capacity of many Canadian salmon rivers has been reduced significantly (Watt 1988), Canada still boasts 400 - 500 salmon rivers ranging in size from small streams producing less than 100 returning fish a year, to New Brunswick's mighty Miramichi with a run of over 100,000 salmon returning to its many branches. Chadwick (1985) estimated that about a third of the 268 rivers in the Atlantic provinces (the eastern provinces excluding Quebec, i.e. Nova Scotia, Newfoundland and Labrador, New Brunswick and Prince Edward Island), where catches were recorded, had angling catches exceeding 100 fish, while captures were not monitored in a further eighty or so - presumably minor - rivers.

User groups in order of importance of catch are commercial, recreational and native fishers. An appreciable component of the total catch has additionally been taken as by-catch in commercial gear set for other species (Muir 1986). Commercial and native fishermen use trap nets and fixed and drift gill-nets while anglers are almost entirely restricted to fly-fishing in freshwater with unweighted artificial flies.

Commercial and sports fishery catches averaged around 2000 tonnes per year between 1970 to 1985 with 60% of the catch being multi-sea-winter fish (ranging from about 4-20+ kg), and 90% of the catch (by weight) landed in the commercial fisheries (Marshall 1988). Salmon landings by anglers averaged, with little variation, 98,000 between 1965 and 1983. Native food fisheries, although sometimes locally significant, accounted for just 1.3% of landings by weight (Anon 1988a).

---

[1]Paper presented at Wild Trout IV. (Yellowstone National Park, Mammoth, Wyoming, September 18-19, 1989).

[2]Dr. Alex Bielak is Executive Director (Canada) of the Atlantic Salmon Federation, Montreal, Quebec.

In 1985 the wholly attributable investment and expenditures by 54,000 salmon anglers were calculated at almost 84 million dollars (Tuomi 1987). The recreational fishery created over 2000 person years of employment for cooks, guides and river guardians, and took only 29% of the catch. The commercial sector, which accounted for 71% of the fish captured, created just 163 person years of employment, and generated only $6.5 million (7%) of economic activity, largely in the same areas where the sports fishery was also creating employment opportunities.

In 1987, 86.1%, by weight, of the Canadian catch of 815 tonnes of grilse (one-sea-winter salmon weighing about 2 kg) and 916 tonnes of multi-sea-winter salmon (423,698 and 193,168 fish respectively) were captured in Newfoundland and Labrador. Of this the lion's share (96.8%) was taken by the approximately 3,400 commercial netsmen licensed to fish that province's coastal waters, the balance being harvested by the 19,721 anglers licensed to fish there. Quebec accounted for 9.3% of the total landings (60.3% to the 197 netsmen actually permitted to fish, 39.7% to 14,831 anglers), and the other provinces for 3.3% (100% to the 20,502, 7188 and 461 licensed anglers in New Brunswick, Nova Scotia and Prince Edward Island respectively). Native fishermen accounted for he remaining 1.3% of landings. In sum recreational and commercial fishermen took 9.6% and 88.9% of the catch respectively.

A much more complete profile of the fisheries prosecuted in each province, as well as breakdowns of landings by province, user group and year can be found in the historical overview of recent Atlantic salmon fisheries prepared for an Atlantic Salmon Management Workshop held in 1989, and from which the data in the above paragraph have been extracted (Vezina 1988).

Ultimate jurisdiction over the salmon fisheries is exercised federally through the Department of Fisheries and Oceans (DFO) although management responsibilities have been devolved to the provinces to varying extents. All provincial governments may legislate on such matters as property leases in non-tidal waters and fishing licenses, but Quebec, via a 1922 delegation of authority, plays the primary role in regulation, research, enforcement and enhancement activities within its provincial boundaries.

For about the last 10 years the status of Canadian Atlantic salmon stocks has been monitored and documented via the Canadian Atlantic Fisheries Scientific Committee (CAFSAC) process. The highly-regarded CAFSAC reports and advice have provided a rational basis for discussion of management options.

Thirty four management zones (of which 11 have been defined by Quebec) have been set-up to allow differential harvesting according to local conditions. Zone Advisory Committees in the Atlantic provinces allow for user-group input to the management process at a local level, and a federal Atlantic Salmon Advisory Board is nominally supposed to provide the minister with advice on salmon policy.

Whilst doubtless set up with the best of intentions, neither level of body appears to accomplish very much except for providing a forum for pro-forma posturing by user groups with different axes to grind. Meetings are often called at the last minute, up-to-date information on stock status is sometimes unavailable and recommendations are ignored or not transmitted through a system viewed by many as institutionalised, cumbersome, unresponsive and often a sheer waste of time. What participants do appear to agree on is that the advisory system is long overdue for a complete overhaul.

OVER A CENTURY OF DECLINE

In Canada, the earliest users of the Atlantic salmon were native peoples who fished for subsistence. The advent of white settlers brought trade in salmon, with a single commercial netter, based near New Brunswick's famous Restigouche river, responsible for the export of well over 100 tonnes of pickled fish in the last decade of the eighteenth century (Dunfield 1985).

Commercial catches in insular Newfoundland exceeded 2700 tonnes in 1930 (Taylor 1985), by which time salmon runs in the Jacques Cartier river, near Quebec City, had been extinguished for almost half a century by over-fishing and habitat degradation.

Serious calls to preserve the resource began as early as the mid-nineteenth century (Nettle 1857), and a voluminous literature on the status of salmon stocks built up over the next 125 years or so (eg. Belding and Prefontaine 1938, Nobbs 1949, Menzies 1951, Wulff 1958, Carter 1968, Netboy 1968, Government of Quebec 1977, 1979, Atlantic Salmon Review Task Force 1979, Muir 1983.)

The development, in the 1930s, of the Port aux Basques drift net fishery off Newfoundland, and the blossoming of the Greenland fishery in the 1960s were particularly significant in the chronology of the salmon's decline. The former contributed significantly to all-time record Canadian landings in 1930 of 6,101 tonnes, while the latter, in which about 50% of the catch was Canadian in origin, peaked in 1971 at 2,689 tonnes or over 750,000 fish. More recently acid precipitation has led to the extinction of salmon from thirteen Nova Scotian rivers and threatens many more (Watt et al 1983). It was recently conservatively estimated that the loss of salmon production to acidification has been 8,870 adult fish per year since 1950 (Anon 1989).

The period between 1972 and 1984 can best be characterised as one of "all words and little effective action". Reams of discussion, position and policy papers, including the massive multi-volume Federal/Provincial Atlantic Salmon Review (Atlantic Salmon Review Task Force 1979), were produced during this time frame, but there seemed little will to actually act decisively. Despite a series of piecemeal management initiatives (for details see review by Vezina 1988), beginning with the closures in 1972 of certain commercial salmon fisheries, no cohesive strategy was to emerge to deal with the problems facing the salmon until over a decade later.

By 1983 the situation had become so critical that returns to the rivers of Quebec's Gaspé region amounted to only 32% of the 20,000 fish target spawning requirement (Vezina 1988). Also in 1983 egg deposition in the normally very productive Restigouche river fell as low as 10% of that required for adequate spawning -- down from an average of only 25% for the previous decade -- and the river was described as "critically depressed" by government scientists charged with monitoring the stock (Randall and Pickard 1983). The Atlantic Salmon Federation, the world's largest private salmon conservation organisation, issued a statement to governments of Atlantic salmon producing countries, and to commissioners of the newly-formed North Atlantic Salmon Conservation (NASCO), regarding "A crisis in the conservation and management of the Atlantic salmon" (Cullman and Rolland 1983).

THE 1984 - 1988 ATLANTIC SALMON MANAGEMENT PLAN

While overfishing at sea constituted the main threat to salmon stocks, increasing angler effort put additional pressure on the fish which were actually making it back to their natal streams. What was needed was political courage coupled with a long-term plan to restore runs, while attempting to maintain economic returns generated by the resource. In other words, sacrifice shared among all the various user groups was required in the spirit of "short term pain for long term gain."

The emergence of a new breed of fisheries minister, able to recognise that, because of its economic value, the recreational fishery ought to be given due consideration in allocation debates, coincided with the crisis calls in 1983. During the course of the plan which was eventually instituted, federal policy was changed to allocate the resource on the basis of maximising the generation of socio-economic benefits (after initial allowances for spawning escapement and native food fisheries.) In the Maritime provinces (Nova Scotia, P.E.I. and New Brunswick) this, de facto, moved the recreational fishery ahead of the commercial, while in Newfoundland and Labrador the balance remained largely in favour of the netsmen.

The Government of Quebec implicitly recognised that recreational fisheries generated greater benefits than the commercial fishery by allocating stocks first to spawning, second to native food fisheries, third to recreational and fourth to commercial fisheries.

At the same time as stocks of wild Atlantic salmon were reaching their nadir, the fledgling Bay of Fundy Atlantic salmon aquaculture industry was poised to take off in an exponential growth phase. Production levels of 68 tonnes from 5 farms in 1983 became an estimated 4,500 tonnes from 42 farms by 1989 (Anderson 1989). Total Canadian landings of "wild" fish (i.e. including hatchery releases) averaged 1,392 tonnes for the period 1983 to 1987.

World wide farmed fish production levels rose from 20,213 to about 165,000 tonnes, between 1983 and 1989, with no signs of the growth curve plateauing (Anderson 1989). The ready availability, at competitive prices, of excellent quality farmed salmon has raised doubts about the long-term viability of the remaining commercial netters (Anderson 1988, Côté in press), although the market might simply expand in response to the increased availability of farmed fish (Anon 1988b).

As important as the above factors was the recognition, by government, that any plan should be long term in nature. The 1984-1988 conservation strategies introduced by the federal and Quebec governments, and strongly supported by conservation groups such as ASF, were based on an "average" salmon's life cycle of five years. They aimed principally at attaining target spawning levels through reductions in interception of fish originating in other provinces, and pressure in the rivers of origin, on the (predominantly female) multi-sea-winter salmon.

During the five-year period the plan included the following major measures:

* International negotiations through NASCO to reduce catch of Canadian salmon in Greenland.

* A two and a half week delay (to June 5th) in the opening of the commercial fishing season in Newfoundland and Labrador, and closure no later than October 15 (versus a historical closure date of 31 December).

* Permanent closure of the very effective, South West Coast of Newfoundland, interceptory fishery (area J2), with a mandatory buy-back of commercial fishing licenses.

* Voluntary and compulsory license buy-backs in the Atlantic provinces including cancellation of all part-time commercial licenses in Newfoundland. (These measures, costing $12 million, led to a 29% reduction in licenses in Newfoundland and Labrador,and an 80% reduction in the Maritimes.)

* Closure of commercial fisheries in the Maritimes and Gaspé.

* Prohibition of retention of salmon captured "accidentally" in non-salmon gear.

* Introduction of mandatory tagging for all salmon harvested.

* Prohibition of retention of large salmon (equal to or greater than 63cm) in recreational fisheries everywhere except Quebec and Labrador (i.e. mandatory catch and release of multi-sea-winter fish.)

* Reduced season and daily bag limits for recreational fishermen.

* Recreational fishing season opening delayed by 10 days on Gaspé rivers with a possibility of mid-season closures if spawning targets were not attained.

* Closure to angling of 13 Quebec salmon rivers.

A complete listing of the conservation actions introduced by DFO between 1972 and 1988 can be found in Vezina (1988). Two of the above mentioned measures, the imposition of catch and release, and tagging, deserve special comment, as do some parallel developments which proved positive in assisting the plan's objectives.

Catch and Release of Atlantic salmon

Given the traditional lexicon of salmon fishing, the concept of not "killing" a fish was somewhat revolutionary at the time it was imposed on salmon anglers in the Atlantic provinces.

The task of educating anglers on proper release procedures, and of changing the mindset that "all released fish died anyway" fell largely to the Atlantic Salmon Federation. With financial assistance from DFO, the Federation mounted two consecutive public information campaigns featuring a "Catch and Release Club." These public information initiatives, coupled with evidence of recovery in stock levels (ie more fish being seen in the rivers) proved successful in changing a marked resistance to the regulation to more enthusiastic compliance. The number of anglers who have actually joined the club to date, represents just over 2% of an average angling population, between 1984-1987, of 59,337 fishers. (For comprehensive details of the programs see Bielak 1988, 1989.)

The only place where it proved difficult to make any headway whatsoever in selling this particular conservation technique was Quebec, which, partly because of the diverse fisheries to be found in the province - ranging from relatively healthy northern stocks to the depressed ones of the Gaspé - had opted for a different management strategy to the federal one. Even now there is a great deal of fear among Quebec anglers that mandatory catch and release might be thrust upon them. Although it is considered by many as a valid <u>personal</u> conservation gesture, many Quebecers see no reason to submit to it while commercial fisheries in Newfoundland continue to intercept an important proportion (approaching 50%[3] in the early 1980s) of fish produced in Quebec rivers.

Tagging

In the vanguard of the new style of fisheries leadership was the New Brunswick Minister of Natural Resources, J.W. "Bud" Bird, who introduced salmon tagging in the New Brunswick recreational fishery as early as 1981, and ended up by proving, to a doubting salmon world, that mandatory tagging was an indispensible tool in controlling illegal catches, as well as providing a tangible reminder of the need for, and existence of, season bag limits for anglers.

These plastic devices are designed to be secured through a hole in the tail, or through the mouth and gills of a dead salmon. Each provincial salmon angling license is issued with a set number of tags bearing the license number attributed to its holder. Different colour tags are issued to anglers, cage farmers and native and commercial netsmen, and possession of an untagged salmon can lead to the prosecution of its possessor. A pre-determined number of tags (in effect a quota) has been issued in recent years to individual commercial netsmen and native bands in Quebec. Only commercially caught or cage reared salmon may be sold, and there is little doubt that the system can be an effective deterrent to poaching (Anderson 1986.)

Unfortunately the issuance of unlimited numbers of tags to commercial netsmen in Newfoundland, and anomalies regarding the importation of Atlantic salmon from west coast salmon farms to Quebec (and possibly the other eastern provinces) are opening the system up for abuse. For example there were reliable reports of a shipment of 1500 Restigouche salmon, taken in excess of the quota by natives, and intercepted en route for Montreal. Each fish bore a Newfoundland commercial tag, apparently obtained from fishermen visiting the Gaspé in exchange for (duty-free) cigarettes.

Interestingly enough, an attempted transfer of this management technique to the west coast failed miserably. Tagging was imposed in 1988 for depleted Strait of Georgia chinook salmon, but was opposed so vigorously as unworkable by user groups that the idea was dropped after only a single year. One of the differences between the two situations was that tagging was imposed on the west coast without very much consultation with the user-groups who would be affected by the measure, while on the east coast angling groups had actively lobbied for universal tagging for all Atlantic salmon harvested.

Other Elements

Involvement of Private Sector Groups

With the growing acknowledgement of the economic importance of the recreational fisheries sector, the increased implication of sports fishing groups in any number of enhancement projects and their consequent desire for input into management decisions, and cuts in government spending, it has been inevitable that governments have solicited a growing involvement of user groups in consultative processes and solicited their participation in projects of various kinds.

The Deputy Minister of DFO, Peter Meyboom (1989) commented on building a partnership between government and volunteers by saying "an essential part of the long-

---

[3] 1989. Coté, Y. Personal communication. Ministry of Leisure, Hunting and Fishing, Quebec City, Quebec.

term re-building of Atlantic salmon stocks is team work. Together, the Federal and Provincial governments, and associations interested in salmon conservation can be innovative, (and) make every dollar count." The jury is still out on whether such a new arrangement can be made to work effectively. The concept is a relatively new one in the Atlantic salmon world, and it remains to be seen whether governments will trust the private sector enough to enable it to become an equal partner in salmon management.

Perhaps one of the brightest indications that the system can work is Quebec's Controlled Exploitation Zone (ZEC) system first introduced in 1978. Côté (in press) described the evolution of public participation in fisheries management in Quebec, and described a ZEC as "a piece of crown land where fishing and hunting rights, as well as right of access are controlled by a local management group for the benefit of the general public." There are nine salmon ZEC's controlling 674 km along 9 rivers. Payment of a modest daily fee (ranging between $15 and $75) guarantees access to fishing provided the river has not been closed for conservation reasons. However certain sectors may be limited as to the number of rods, and access to these is dictated via telephone or mail-in lotteries. The cost for such fishing may also be somewhat higher than in the general access sectors. Within the provincial regulations the democratically elected boards which manage the ZEC's are free to determine their own policies governing fishing, protection, finance and administration (Côté in press).

Native Food Fisheries

Some of the most bitter conflicts and most difficult situations in recent salmon management history have arisen between native groups exercising what they consider ancestral netting rights within rivers, and other user groups concerned with conservation. Hazell (1988) described the continuing troublesome situation on the Restigouche river, and suffice it to say that the early 1980s saw numerous instances of similar confrontations. There are encouraging signs however that certain native bands have decided to trade their nets for jobs in the sports fishing industry (Taylor 1989, Davis 1989), having concluded that interim arrangements do not necessarily compromise any longer-term land settlement claims.

The formation, in 1982 by the provincial government, of a joint management Society - involving private salmon camp owners, a local native band and local anglers - on Quebec's world-renowned Grand Cascapedia river was perhaps instrumental in serving as an example to other east coast native bands that long-term economic benefits could accrue to all band members by entering into such agreements, rather than the short-term benefits to a few individuals associated, in the old regime, with salmon netting.

The example of the "Societé Cascapedia", where half the management board are native indians, and many seasonal guiding and protection jobs have been created for both natives and non-natives, has been cited as a model for other governments and native bands across Canada to follow (Pearse 1988). There is little doubt that continued positive developments - such as the near-elimination of netting in the river in 1989 - have contributed to the creation and maintenance of one of the premier Atlantic salmon fisheries in the world.

Innovative Management Techniques

Small scale technology, employed by local conservation groups, including black salmon (kelt) reconditioning techniques coupled with the use of incubation boxes has proven effective in increasing seeding of certain headwater streams (Côté in press). The installation of counting fences and barrier pools to evaluate and protect salmon returns have been instrumental in providing better data for management purposes and deterring poaching. (Parsons 1988). "Crimestoppers"-type programs have also proven somewhat effective in combatting the illegal harvest and sale of salmon (Silverstone 1989).

A network of index rivers across Eastern Canada now provide the basis for better management decisions. Experimental techniques such as the liming of rivers to mitigate the effects of acid rain, and restocking of rivers where salmon have disappeared, with adult wild or hatchery-reared fish, with certain desirable characteristics, have also been explored for their potential in assisting restoration efforts. An interesting Quebec initiative has been the stocking, by displaced netsmen, of fry in headwater streams, normally inaccessible to the salmon, using artisanal, transportable mini-hatcheries, and instream incubation techniques.

ASSESSING THE 1984-1988 MANAGEMENT PLAN

Information used to assess the success of the plan included measures of egg deposition, juvenile density, the proportion of large salmon surviving to spawn after returning to the vicinity of the river mouth, and harvest levels. Also taken into account were indicators of decreased interception of migrating stocks (Anon 1988c).

The results of these recent DFO and provincial studies have been encouraging. In essence, and despite difficulties in interpretation of the data, they indicate that more and bigger salmon have made it back to the headwaters, resulting in more young fish on the nursery grounds. A CAFSAC evaluation of the plan showed that there had been a reduction in catches of large salmon relative to grilse of the same smolt year (Anon 1988c).

Estimates of the proportion of large salmon which returned and subsequently survived to spawn on the Restigouche, Miramichi, Saint John and La Have rivers show up to twofold increases, consistent with the objectives of the management plan.

Target egg deposition levels were met on the Miramichi in four of the five plan years. However in three of those years the contribution of grilse rather than large salmon helped the targets to be met. In contrast, although egg deposition levels on the Restigouche increased over the plan period, spawning requirements were not achieved between 1984-1988. (Previously CAFSAC scientists had felt that target levels had been achieved in 1986, but the methodology used in the previous assessments has since been re-evaluated (Randall et al 1989). The reason for the shortfall was partly, at least, elevated native harvest levels and the lack of mandatory catch and release of large salmon in Quebec (the Restigouche river constitutes part of the boundary between the province of Quebec and New Brunswick).

Data from three other rivers, the Saint John, the Margaree and the La Have, also show some signs of recovery of stocks (Anon 1988c,d), although the relatively small number of large salmon returning to the Saint John in 1988 meant that spawning escapement was well below target levels on that river (Anon 1988d). In Quebec - though it is generally acknowledged that the rate of stock recovery has not matched that in the rest of Atlantic Canada due to the different management approach taken - spawner counts on Gaspé rivers indicated that the 1988 runs had been the highest on record since 1972.

Densities of young of the year have increased on both the Restigouche and Miramichi over pre-plan years confirming the recent increases in spawning levels (Anon 1988c,d, Randall et al 1989).

Although most of the indicators were encouraging and suggested that the plan was indeed taking effect, it was nevertheless quite clear that further conservation measures were necessary to consolidate gains made to date. Also, because of the five-year average life cycle of Canadian salmon, 1989 was the first year one could expect to see fish returning as a consequence of the conservation measures taken since 1984.

In addition, despite the reduced number of Newfoundland netsmen, the commercial catch of salmon there actually increased steadily between 1984 and 1987 (821 tonnes in 1984, 863 in 1985, 1230 in 1986 and 1473 in 1987) falling back somewhat in 1988 to 935 tonnes[4]. There were also indications from reliable Newfoundland sources that some insular stocks were facing very serious depletion[5]. Estimates of 1988 angling licence sales showed a 20-30% increase over 1985 figures (Anon 1988e), indicating that anglers, hearing that fish were apparently more plentiful, were also returning to the rivers and increasing the pressures on the resource.

In the light of the above, in January 1989, DFO convened a major workshop involving all the provinces and user groups with an interest in the resource. Its aim was to discuss elements of a second plan.

---

[4]Anon. 1989. Data presented to Atlantic Salmon Board 8 March 1989.

[5]Felt, Larry. 1989 Personal communication. Salmon Association of Eastern Newfoundland, St. Johns, Newfoundland.

At that meeting the ASF presented a major brief entitled "Securing the Atlantic Salmon's Future - A long-term Management Policy for the Atlantic salmon (Anon 1988f)." The central thrust of this document, which received wide-ranging support both prior to, and at the workshop, was that long-term planning continued to be essential to recovery, and that most effective management could only be achieved if salmon were harvested within their natal river or estuary. The Federation also called for a quota to be imposed on the Newfoundland fishery on an interim basis, until watershed management could be established throughout eastern Canada.

Some consensus emerged at the workshop, which proved particularly harmonious given the usually entrenched positions of the participants. DFO was sent a clear message that watershed/zone management was desired by one and all, and that, with the obvious exception (i.e. that of some of the Newfoundland commercial representatives), the time had come for quotas on catches in Newfoundland.

On May 5 1989, DFO announced the implementation of a new five-year Atlantic Salmon Management plan with conservation as its number one priority. It maintained the closure of the commercial fisheries in the Maritimes and mandatory catch and release for recreational fishermen, and introduced the somewhat nebulous concept of zonal "allowances" totalling 1300 tonnes for the province of Newfoundland and Labrador's commercial fishery. It also promised that the department would try to identify areas where zone/river management might be implemented on a trial basis in 1990. Quebec, with some minor changes made at the request of ASF's Quebec council, the Fédération Québécoise pour le Saumon Atlantique, also basically maintained the status quo.

MANAGEMENT PLAN II - THE SEQUEL

If conservation groups like ASF were pleased with the way the first plan ended, they are hating the first year of the 1989-1993 federal plan. In the words of ASF President David Clark's editorial in the fall 1989 Atlantic Salmon Journal:

"ASF's worst fears have been realised...

We now know that tags were alloted to commercial fishermen indiscriminately and in great numbers. Apparently, the local fisheries officers responsible for the distribution of these tags did not bother to make records of how many tags were given out, nor how many each fisherman received...

Obviously the concept of allowances has been meaningless" (Clark 1989).

Towards the end of the summer leaders of the major salmon conservation groups constituting ASF's Newfoundland council - supported by the ASF - called for an immediate closure of the commercial fishery in insular Newfoundland, and some closures of commercial fisheries and rivers to angling were subsequently announced by DFO to take effect August 9th 1989. The Salmon Association of Eastern Newfoundland went even further, and asked DFO for a five-year closure, without compensation, of the commercial fishery from 1990 to 1994 to allow Newfoundland salmon stocks to recover.

One respected and normally very moderate, but now extremely angry, volunteer who has been involved with an effort to rebuild a salmon stock in a small river near the provincial capital St. John's, summed up things in a letter to the press, in which he said "I personally am not willing to pledge any organisation I am involved in to any further salmon enhancement work until a sensible management plan is in place that does not condone destroying years of work in one short season"[6].

It seems certain that if DFO really wants to build "strong partnerships with the volunteer sector" (Meyboom 1989) the department is going to have to act seriously in marrying good intentions with meaningful actions.

PROGNOSIS FOR THE FUTURE

Despite the false start of the 1989-1993 Atlantic Salmon conservation strategy it seems inconceivable that the Newfoundland commercial fishery will not soon be bought under control. Efforts on the international scene to further minimise interception of North American fish will have to be maintained, and probably intensified. User groups will also press DFO hard to quickly bring in a workable river-by-river management system. A pilot project, originated by an ASF affiliate in Nova Scotia - the St. Mary's River Association - has already been proposed (Turner 1988).

As stocks continue to recover there will doubtless be pressure from angling groups to relax restrictions surrounding mandatory release of large salmon in the Atlantic provinces. It seems inconceivable, however, in the light of the change in attitudes, that retention of more than one or two large salmon per season would ever become the rule again before the end of the century.

Innovative solutions - possibly involving "big fish" tag lotteries whereby some anglers would "win" a chance to retain a large salmon - will have to be found to allow such a harvest on a watershed basis. Management of angler demand (already the major issue in Quebec), rather than of fish supply will become a crucial element in balancing demands for access, and pressure on the resource, especially if the availability of quality angling experiences at affordable prices is to be maintained.

Refinements in data collection, stock prediction techniques and basic biological knowledge (especially of the marine phase) will be extremely important in sustaining and managing stocks once they have been rebuilt. Experimental management schemes, such as the proposed development of a nearshore recreational (trolling) fishery for Atlantic salmon off the shores of PEI, will have to be closely evaluated.

Regular protection activities will have to be increased and become better co-ordinated, with greater attention paid to surveillance at the end of the season, when egg-laden salmon become a target for poachers who strip the fish, and sell the eggs to unscrupulous hatchery operators raising smolt for the sea-cage industry.

Atlantic salmon conservationists will continue to battle traditional problems such as habitat degradation and impediments to salmon migration. They will have to address changes resulting from global warming, and will also have to face up to other new challenges such as the worrisome potential for interaction of wild and farmed salmon.

It might be desirable, given the sheer volume of farmed fish and the potential for genetic dilution of wild stocks by escapees, that a gene bank for North American stocks should be created. In this respect, the expertise of scientists working in the 16-year collaborative ASF/DFO Salmon Genetics Research Program may prove invaluable.

Salmon Enhancement

There is, of course, great potential for opening up currently unused habitats, or bringing back unproductive rivers, through enhancement activities. Some ambitious programs have just begun, such as the attempt to bring back Atlantic salmon to rivers flowing into Lake Ontario, but there have also been a fair number of success stories to date, in all five eastern Canadian provinces, including the successful restoration of the historic Jacques Cartier river.

However, as with salmon conservation prior to 1984 there has been a great deal said and promised regarding a ($55 million total), comprehensive Atlantic Salmon Enhancement Program (ASEP), but ultimately nothing concrete has transpired. Despite the lack of a co-ordinated plan enhancement efforts have proceeded nonetheless, on an ad hoc basis. They have often been driven by energetic cadres of volunteers, banded together in local conservation groups, and funded from a patchwork of mainly-government make-work and other funds.

The five-hundred million dollar Canadian west coast (Pacific) Salmonid Enhancement Program (SEP) has long been the envy of those concerned with Atlantic salmon restoration and enhancement on the east coast. Frustrated by the fact that the Minister of Fisheries and Oceans has proven quite unable to open up government purse strings for the modest east coast ASEP, two other, independent enhancement initiatives have developed. The Quebec government is reputedly set to announce its own salmon enhancement program to begin in 1990. Financing, which will be in the tens of millions of dollars, is coming from both federal and provincial regional development funds, as well as the Ministry of Leisure, Hunting and Fishing which is responsible for salmon management in Quebec.

The Atlantic Salmon Federation also announced that it intended to launch a Salmon and Habitat Improvement Program (SHIP) to provide funding to ASF affiliates involved in local projects. The parameters for the SHIP program are currently being set and a capital campaign will be launched to assure long-term funding for the program.

---

[6]Felt, Larry. 1989 Personal communication. Salmon Association of Eastern Newfoundland, St. Johns, Newfoundland.

A "salmon stamp" has often been proposed as a means of funding enhancement programs, and a Pacific salmon stamp has already been developed to help support the Pacific Salmon Foundation, which was recently formed by DFO on the west coast. One can only hope that an Atlantic salmon version becomes a reality in the foreseeable future.

CONCLUSIONS

Fifteen years ago Dr Wilf Carter addressed the first Wild Trout symposium (Carter 1974). His thoughtful paper, written not long after the Greenland fishery peaked, detailed some of the problems facing the salmon, and, in effect, emphasised the truism that one couldn't manage the fish without managing all elements of the fishery.

He concluded by suggesting that "unrestricted use of a depleted resource struggling to regain a foothold assures almost certain failure." This paper has shown that, once galvanised into action, Canadians have, via a comprehensive management plan which addressed all elements of the fishery, not only helped the Atlantic salmon resource regain a foothold, but have also held its hand as it has taken the first few steps back up the ladder to success.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of Larry Marshall, John Anderson, Yvon Côté and Dave Meerburg in the preparation of this manuscript.

LITERATURE CITED

Anderson, J.M. 1986. Review of the Atlantic salmon tagging program. Atlantic Salmon Federation. 28p.

Anderson, J.M. 1988. Effects of aquaculture on salmon management. 83-92. In: R.H.Stroud (ed). Present and future Atlantic salmon management - measuring progress to international co-operation. Marine Fisheries 12. Published by the Atlantic Salmon Federation (Ipswich, Mass) and the National Coalition for Marine Conservation Inc. 1988. 210p.

Anderson, J.M. 1989. Farmed to success. Atl. Salmon J. 38(3):36-37.

Anon. 1987. The status of Atlantic salmon stocks in Atlantic Canada and advice for their management in 1988. CAFSAC Advisory Document 87/24

Anon. 1988(a). Report of the ICES North Atlantic Salmon Working Group. NASCO Council Paper (88) 13. 112p.

Anon. 1988(b). Canadian Atlantic salmon market situation and outlook. Market Analysis Group, Economic and Commercial Analysis Division. Department of Fisheries and Oceans, Ottawa. 22p + 20 tables.

Anon. 1988(c). Evaluation of the Atlantic salmon management plan. CAFSAC Advisory document 88/19. 15p.

Anon. 1988(d). The status of Atlantic salmon stocks in Atlantic Canada and advice for their management in 1989. CAFSAC Advisory document 88/26. 24p.

Anon. 1988(e). Recreational fishing for Atlantic salmon. Situation and outlook. Document presented to Atlantic salmon workshop, Montreal, 1989 by Jane Quiring, Director of Recreational Fisheries, Department of Fisheries and Oceans, Ottawa.

Anon. 1988(f). Securing the Atlantic salmon's Future: A long-term management policy for the Atlantic Salmon. Atlantic Salmon Federation. 9p.

Anon. 1989. Report of the ICES advisory committee on fisheries management. NASCO Council paper CNL(89)10. 18p.

Atlantic Salmon Review Task Force, 1979. Dept. of Fisheries and Oceans, 27p. + Appendix reports A-I.

Belding, D.L., and G. Prefontaine, 1938. Etudes sur le saumon de l'Atlantique. (Salmo salar L) - 1. Organisation et résultats généraux des recherches dans le Golfe Saint-Laurent en 1937. Rapport de la Commission de Québec pour l'étude du Saumon. Contributions de l'Institut de Zoologie de l'Université de Montreal. - No 2. 50p.

Bielak, A.T. 1988. Promoting catch and release - the ultimate low consumption fishing technique. p.57-67. In: National Recreational Fisheries Conference Proceedings 1986. Can. Spec. Publ. Fish. Aquat. Sci. 37:174p.

Bielak, A.T. 1989. Promoting catch and release of Atlantic salmon. p 126-142, in: Proceedings of National Sport Fishing Symposium on Catch and Release fishing, Oct. 1987. Edited by R. A. Barnhart and T. Roelofs, Humboldt State University, Arcata, Calif. 299 p.

Carter, W.M., 1968. Le Saumon de l'Atlantique (Salmo salar L.) au Quebec. Rapport sur le saumon et plan directeur pour l'aménagement de cette resource. Ministère du Tourisme, de la Chasse et de la Pêche. 236p.

Carter, W.M. 1974. Atlantic salmon management. 17-21. Wild Trout I, Sept 1974.

Chadwick, E.M.P. 1985. Fundamental research problems facing the management of Atlantic salmon (Salmo salar L) in Atlantic Canada. J. Fish Biol., 27 (supplement A). 9-25.

Clark, D.R. 1989. Editorial: New five year plan quotas not working. Atl. Salmon J. 38(3):5-6.

Côté, Y. In press. Innovative fisheries initiatives in eastern Canada. Paper presented to canadian Wildlife Federation Annual General Meeting, Halifax, June 1989.

Cullman, J., and L.G. Rolland. 1983. A crisis in conservation and management of Atlantic salmon. Position statement by the Atlantic Salmon Federation. 13p.

Davis, T. 1989. Maria band trades nets for jobs. Salar, Vol 8(3)::4.

Dunfield, R.W. 1985. The Atlantic Salmon in the history of North America. Can. Spec. Publ. Fish. Aquat. Sci. 80:181p.

Gouvernement du Quebec, 1977. Colloque sur le saumon. Un aperçu des études biologiques menées au niveau gouvernemental pour l'exploitation et l'aménagement des populations de saumons du Québec. Ministère du Tourisme, de la Chasse et de la Pêche, Service de la recherche biologique. 109p.

Gouvernement du Québec, 1979. La situation de Saumon Atlantique au Québec et ses perspectives. Document de Consultation. Ministère du Tourisme, de la Chasse et de la Pêche. 20p.

Hazell, S.D. 1988. The Indian Atlantic salmon fishery on the Restigouche river: Illegal fishing or aboriginal right? 535-556. In: D. Mills and D. Piggins (eds.) Atlantic salmon: Planning for the future. Proceedings of the 3rd International Atlantic salmon symposium, Biarritz, France, 1986. Timber Press, Portland, Oregon, 587p.

Marshall, T.L. 1988. Harvest and recent management of Atlantic salmon in Canada. 117-142 In: D. Mills and D. Piggins (eds.) Atlantic salmon: Planning for the future. Proceedings of the 3rd International Atlantic salmon symposium, Biarritz, France, 1986. Timber Press, Portland, Oregon, 587p.

Menzies, W.J.M., 1951. A report on the present position of the Atlantic Salmon Fisheries of Canada with recommendations for their regulation and improvement. Atlantic Salmon Association. Document No. 17. 40 p.

Meyboom, P. 1989. Comment: The Atlantic salmon conservation strategy: forging a strong partnership. Atl. Salmon J. 38(3):18.

Muir, B. 1983. Atlantic Salmon Task Group - a report to the Assistant Deputy Minister Atlantic Fisheries Service. Summary memorandum of Task Group Chairman.

Muir, B. 1986. (Chairman). Strategies for the long-term management of Atlantic salmon. Report of the Special Federal-Provincial working group on Atlantic salmon to Atlantic Deputy Ministers. 35p.

Netboy, A. 1968. The Atlantic Salmon: A vanishing species? Faber, London. 457p.

Nettle, R. 1857. The Salmon Fisheries of the St. Lawrence. Montreal. 144p.

Nobbs, P. 1949. The critical condition of the Atlantic salmon industry in Quebec. Atlantic Salmon Association, Document No. 3. 13p.

Parsons, L. 1989.Holding pools protect spawning salmon. Salar, Vol 8(3):8.

Pearse, P. 1988. Rising to the challenge. A new policy for Canada's freshwater fisheries. 180p. Published by the Canadian Wildlife Federation.

Randall, R.G., and P.R. Pickard. 1983. Biological assessment of Atlantic salmon in the Restigouche River, 1983. CAFSAC Research document 83/88.

Randall, R.G., G. Landry, A. Madden and R. Richard. 1989. Biological assessment of Atlantic salmon in the Restigouche river, 1988. CAFSAC research document 89/33.43p.

Silverstone, M. 1989. ASF action saves salmon on the Restigouche. Salar, Vol 8(3):1-2.

Taylor, B. 1989. Kingsclear agreement signed. Salar, Vol 8(3):4.

Taylor, V.R. 1985. The early Atlantic salmon fishery in Newfoundland and Labrador. Can. Spec. Publ. Fish. Aquat. Sci. 76: 71p.

Tuomi, A.L.W. 1987. Canada's Atlantic salmon recreational fisheries and their future: An economic overview. ASF Special Publication Series No 14. 29p.

Turner, G.E. 1988. St. Mary's river fisheries management plan. Resource Allocation and Licensing Division, Scotia-Fundy Region, Department of Fisheries and Oceans, Halifax. 19p + 3 app.

Vezina, B.P. 1988. Historical overview of Atlantic salmon fisheries. Resource Allocation Branch, Atlantic Fisheries. Department of Fisheries and Oceans, Ottawa. 57p.

Watt, W.D. 1988. Major causes and implications of Atlantic salmon habitat losses. 101-111. In: R.H.Stroud (ed). Present and Future Atlantic salmon management - measuring progress to international co-operation. Marine Fisheries 12. Published by the Atlantic Salmon Federation (Ipswich, Mass) and the National Coalition for Marine Conservation Inc. 1988. 210p.

Watt, W.D., D.Scott, and W.J. White. 1983. Evidence of acidification of some Nova Scotian rivers and its impact on Atlantic salmon (Salmo salar). Can. J. Fish. Aquat. Sci. 40:462-473.

Wulff, L. 1958. The Atlantic salmon. A.S. Barnes & Co. New York.

Native Brook Trout Restoration Program in Great Smoky Mountains National Park[1]

Stephen E. Moore[2] and Gary L. Larson[3]

Abstract.--Eradication of non-native rainbow trout from native brook trout streams was attempted using electrofishing between 1976 and 1981. Brook trout biomass increased when the rainbow trout biomass was reduced. Later work demonstrated that rainbow trout had been eradicated from two streams.

INTRODUCTION

The distribution of native brook trout (Salvelinus fontinalis) in the Southeast has undergone a major shrinkage since 1900 (Seehorn, 1978). One of the best documentations of this decline is in Great Smoky Mountains National Park (GRSM). Prior to the establishment of the park in 1936, the area was extensively logged and brook trout disappeared from downstream segments of many streams in logged watersheds (Powers 1929). Rainbow trout (Oncorhynchus mykiss) were introduced into these stream segments and into other streams inhabited by brook trout beginning about 1910 (King 1937). Park management later supplemented these stockings from rearing facilities in the park to provide recreational angling. The general view was that the brook trout would recover its former range as the forests recovered. But early work by King (1937) suggested that rainbow trout populations were expanding into brook trout waters, thereby further reducing the distribution of brook trout. Although surveys in the 1950's (Lennon 1967) did not show much change in brook trout distribution relative to King's initial observations, later surveys by Jones (1975) and Kelly et al. (1980) clearly demonstrated a substantial decline. The gravity of the problem prompted the National Park Service to initiate a series of studies between 1976 and 1981 to evaluate rainbow trout encroachment into brook trout streams and to determine the feasibility of eradicating rainbow trout from selected isolated streams using the backpack electrofishing technique. The objectives of this paper are to summarize the results of these studies and report on a recent investigation which evaluated the success of the restoration program.

Methods

Backpack electrofishing was the only technique approved for the removal and sampling of fish. Moore et al. (1981, 1983, 1986) provide details of the equipment and field methods. Small second and third order montane streams were chosen for the study sites. Initially, field crews consisted of two people, one electrofishing and the other netting. During subsequent years a four-person field crew was used so that two people could process the catch while the others continued to electrofish. All stream segments were electrofished three times during each field trip.

Encroachment by rainbow trout into brook trout waters was investigated in two ways. First, trout distributions in stream segments surveyed by Willis King, 1935 - 1936 (unpublished map), were compared to mapped survey data collected between 1972 - 1977 by Allan Kelly. Second, selected segments of four streams were sampled to evaluate the abundance and size structure of brook trout and rainbow trout under allopatric and sympatric conditions. Details of methods are described in Larson and Moore (1985).

Eradication of rainbow trout sympatric with brook trout upstream from natural obstructions (i.e., waterfalls and cascades) was attempted in 4 streams

---

[1]Paper presented at Wild Trout IV. (Yellowstone National Park, Mammoth, Wyoming, September 18-19, 1989).

[2]Stephen E. Moore, Fisheries Biologist, Resource Management and Science Division, Great Smoky Mountains National Park, Gatlinburg, TN.

[3]Gary L. Larson, Aquatic Ecologist, Cooperative Park Studies Unit, College of Forestry, Oregon State University, Corvallis, OR.

(upper Sams, Taywa, Silers and Beetree). Each stream, plus control sections, was electrofished for five or six consecutive years between 1976 and 1981. Project direction changed in 1979. Rainbow trout were not removed from Sams Creek and Beetree Creek after that year, but removal continued at Silers Creek and Taywa Creek. Field methods and procedures used to estimate population densities are described by Moore et al. (1983, 1986).

Based on the initial field results later reported by Moore et al. (1981, 1982), the U.S. Fish and Wildlife Service (USFWS) field office in GRSM initiated a restoration project on large third-order park streams. Young Adult Conservation Corps (YACC) workers electrofished about 1400 m of Road Prong in 1978, 3500 m of Sams Creek in 1978 and 1979, and 2500 m of Desolation Creek in 1979. The study section on Sams Creek began at a downstream waterfall and extended upstream through our study area. Multiple electrofish shockers were used and each stream section was fished until no young-of- the-year were captured. The number of adult and young fish were recorded.

In 1986 and 1987, the restoration project was evaluated in the four streams electrofished by Moore et al. (1981, 1983, and 1986) and the three streams sampled by the USFWS. Representative sections of each stream, plus appropriate controls, were electrofished to determine the fish population structure. Each section was electrofished three times and population estimates were made following the methods described by Van Deventer et al. (1985). All fish were returned to the stream sections from which they were caught.

Results

The brook trout distribution surveys by King (1937; unpublished map) and Kelly et al. (1980) had 59 stream segments in common. Natural barriers isolated brook trout populations in nine streams and their distributions in this 23.5 km of streams remained unchanged. The distribution of allopatric brook trout expanded from 4.6 km to 6.3 km in three streams. In the remaining 47 streams, however, the distribution of allopatric brook trout decreased from 130.3 km to 33.8 km, a 74.2 % loss. Overall, the distribution of brook trout declined from 157.8 km to 63.6 km and that for the rainbow trout increased by 94.2 km in approximately 40 years.

Analyses of the survey data collected in the 1970's showed, in general, that brook trout were restricted to relatively short segments of high gradient (10 - 15%) streams above 1000 m in elevation (Fig. 1). These results contrasted with King's finding, which showed brook trout inhabiting stream segments down to an elevation of about 600 m and a gradient of about 5%. Rainbow trout now occupy these lower stream segments. Additional analyses showed that sympatric zones in tributaries did not exceed about 3.2 km in length. Streams less than this length were frequently entirely sympatric or contained very short segments of allopatric brook trout in the headwaters. In longer streams, zones of allopatric rainbow trout were observed downstream from sympatric zones which were often downstream from short allopatric brook trout segments (Larson and Moore 1985).

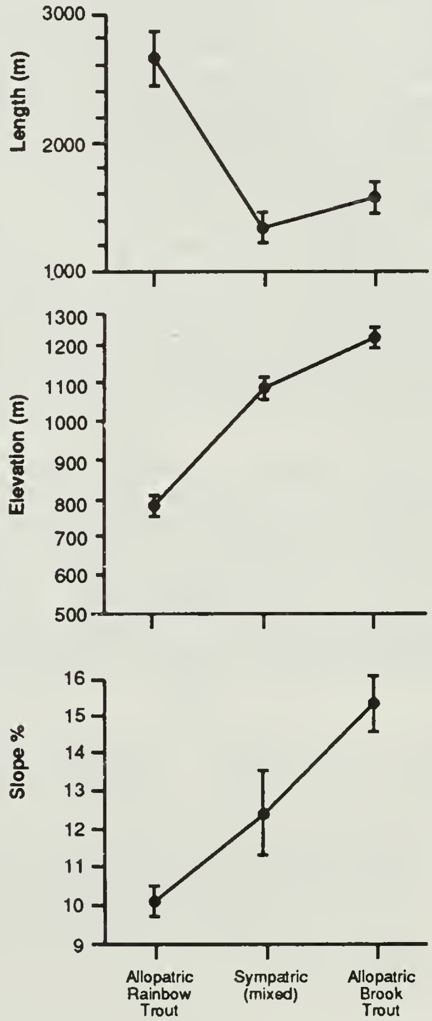


Figure 1. Mean stream length, elevation and slope occupied by brook trout and rainbow trout under allopatric and sympatric conditions in Great Smoky Mountains National Park. Analysis based on the distribution data collected between 1972 and 1977 by Kelly et al. (1980). (After Larson and Moore, 1985.)

The abundance and size structure of brook trout and rainbow trout populations changed during the encroachment process. Downstream areas of sympatric zones were dominated by rainbow trout adults and fry. Progressing upstream, rainbow trout adults and fry decreased in abundance, with the fry decreasing first; while brook trout adults and fry increased in abundance, with the adults increasing first. Upstream areas of sympatric zones, therefore, were dominated by brook trout (Fig. 2). Analysis of these data suggested two important points. First, the presence of three or more adult brook trout or rainbow trout / 100 m^2 substantially reduced the density of age zero fish of the other species. Second, adult rainbow trout replaced adult brook trout in a 1:1 ratio, but the biomass increased by a factor of about 1.8 owing to the larger mean body size of the rainbow trout (Larson and Moore 1985).

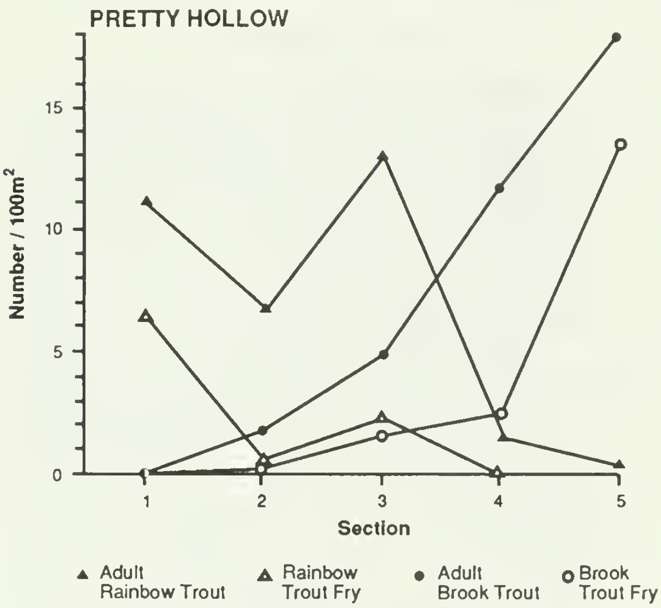


Figure 2. An example of the changes in abundance of adult and fry brook trout and rainbow trout. The stream sections were not contiguous. Section 5 is the upstream section. (After Larson and Moore, 1985.)

Restoration Efforts

Four streams with sympatric populations were electrofished 5 - 6 consecutive years, which resulted in the removal of 1064 rainbow trout. At the end of the project in 1981, the density of rainbow trout had been reduced by an average of 89% and recruitment virtually eliminated (Fig. 3). The density of adult rainbow trout was reduced to less than 1/100 m^2 in the four streams.

Brook trout increased in abundance following the reduction of rainbow trout, but the results varied among streams (Fig.3). The largest increases in adult densities were observed in Sams Creek and Silers Creek. Recruitment was especially high in Silers Creek and Taywa Creek in 1981.

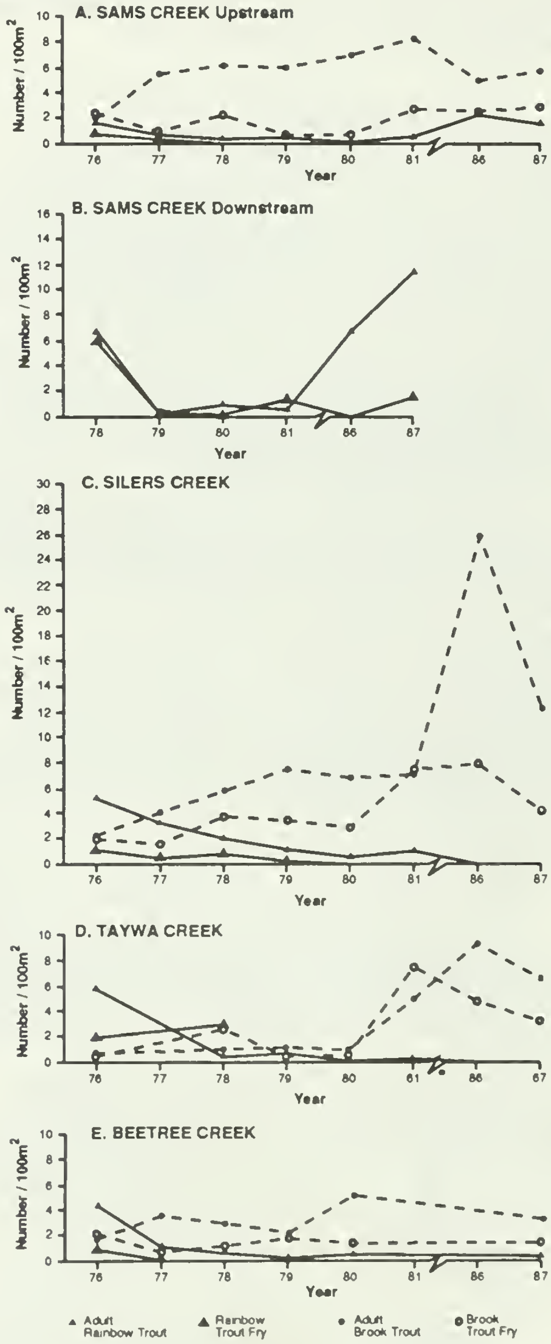


Figure 3. Abundances of brook trout and rainbow trout adults and fry in four park streams electrofished between 1976 and 1987 (A-D) and the downstream section of Sams Creek (B) between 1978 and 1987.

The total standing crop in the four sympatric study areas was 116.3 kg/ ha in 1976 (Moore et al, 1983). This was the highest level observed during the study and was dominated by rainbow trout (78.6%). Brook trout made up 55% of the crop in 1977, and increased to 71.8% in 1978 and 80.7% in 1979.

In Silers Creek and Taywa Creek, brook trout accounted for 90.4% and 93.4% of the biomass in 1980 and 1981, respectively. In Sams Creek and Beetree Creek, brook trout made up 80.3% of the biomass in 1980 and 79.1% in 1981.

Restoration Evaluation

The USFWS restoration project at Sams Creek was evaluated by Whitworth (1979). His data showed that in the most downstream section, which had numerous large deep pools ($\geq$ 1 m), the density of rainbow trout had been reduced by 78.7%. In the middle and upper sections, however, where pool depths rarely exceeded 0.6 m, the reductions were 92.7% and 98.2% , respectively. He also showed that rainbow trout recruitment was limited to the downstream section.

In 1986 and 1987, selected stream sections of the four stream electrofished by Moore et al. (1981,1983) and three streams electrofished by the USFWS were sampled to evaluate the success of the restoration projects. It was concluded that rainbow trout had been eradicated in Taywa Creek and Silers Creek, but not from the others (Fig. 3; data for Road Prong and Desolation Creek not shown). The densities of brook trout adults in our four streams showed an overall increase as compared to the densities observed during the early years of the restoration program. Brook trout recruitment only showed substantial increases in Taywa Creek and Silers Creek, however. Recruitment in control areas mirrored that of the restoration area with large year classes being found in some years and not in others.

The density of adult rainbow trout increased substantially in the downstream reach of Sams Creek by 1986 and 1987. Some recruitment was observed in 1987 (the sample in 1986 was in early May and this was probably too early to capture any emerging fry). In Road Prong, 1987, the densities of rainbow trout and brook trout were similar to those recorded in 1978 (data not shown). By comparison, the density of brook trout in Desolation Creek was greater in 1987 than in 1979, while that for rainbow trout was about the same (data not shown).

Discussion

Our analyses of past survey data, evaluation of changes in the density and population structure of the two species in sympatric zones, and the response by brook trout populations to rainbow trout removal support the hypothesis that encroachment by rainbow trout is an important reason for the continued decline of brook trout in the park. As discussed by Larson and Moore (1985), the encroachment process is difficult to document due to complex and dynamic abiotic and biotic interactions. Although the mechanisms are poorly understood, it seems clear that rainbow trout have a negative effect on native brook trout.

The initial restoration work by Moore et al. (1983,1986) did not appear to eradicate rainbow trout. These results did show that the density of adult rainbow trout were reduced to less than 1/100 m^2 in one field trip (three passes) in some streams, but additional effort was required in others. This variation in success was due to the complexity of the stream channels which affected the efficiency of the electrofishing. Efforts by the USFWS on large third-order park streams using three electrofishing units and a large crew to net the fish had the same results (Allan Kelly, personal communication). Nonetheless, the results indicate that the backpack electrofishing technique can be used to control the density of rainbow trout. In fact, eradication is feasible in small streams, as shown for Silers Creek and Taywa Creek.

Reclamation by electrofishing is labor-intensive and time-consuming (Moore et al., 1983). A two-person crew expends about one-person day fishing a 100-m section of stream three times, including processing time but not travel time to and from the site. The use of large crews and multiple shocking units increases the capture rate, but does not appear to necessarily reduce labor costs (Larson et al., 1986).

Our experience with the backpack electrofishing technique suggests that several precautions should be considered before undertaking a restoration project. First, streams must be of an appropriate size to make the effort worthwhile. If large streams are targeted for restoration then other techniques should be explored. Second, the project should be adequately funded because several years of effort may be required to control non-native fish populations. Third, the targeted restoration area should be upstream from a known barrier to fish immigration if eradication is attempted. Otherwise non-native fish may immigrate upstream into the restored section.

ACKNOWLEDGEMENTS

Special thanks are extended to Alan Kelly for his assistance in locating study areas and helpful advice during the initial stages of this project. Thanks are extended to Dr. Jerry West for his assistance with the collection and analyses of the restoration evaluation data. Sincere appreciation is expressed to the numerous field assistants who spent many arduous days in the streams assisting with electrofishing and data collection. We wish to thank Jim Wood for his review of this manuscript. Thanks are also extended to Mary Lynn Morgan and Rebecca Chladek for typing the manuscript.

LITERATURE CITED

Jones, Ronald D. 1978. Regional distribution trends of the trout resource. Pp 1-10, Proceedings Southeastern Trout Resource: Ecology and Management Symposium. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, N.C. 145 pp.

Kelly, G. Alan Jack S. Griffith, William Ensign and Ronald D. Jones. 1980. Changes in distribution of trout in Great Smoky Mountains National Park, 1900-1977. U.S. Fish and Wildlife Service Technical Paper 102. Washington, D.C. 10pp.

King, Willis. 1937. Notes on the distribution of native speckled and rainbow trout in the streams of Great Smoky Mountains National Park. Journal of the Tennessee Academy of Sciences. 12:351-361.

Larson, Gary L. and Stephen E. Moore. 1985. Encroachment of exotic rainbow trout in the southern Appalachian mountains. Transactions of the American Fisheries Society. 114:195-203.

Larson, Gary L., Stephen E. Moore, and Danny C. Lee. 1986. Angling and electrofishing for removing non-native rainbow trout from a stream in a national park. North Amer. J. Fish Manage. 6(4):580-585.

Lennon, Robert E. 1967. Brook trout of Great Smoky Mountains National Park. U.S. Department of the Interior, Fish and Wildlife Service, Technical Paper 15, Washington, D.C. 18pp.

Moore, Stephen E., Bromfield L. Ridley, and Gary L. Larson. 1981. Changes in standing crop of brook trout concurrent with removal of exotic trout species, Great Smoky Mountains National Park. U.S. Department of the Interior, National Park Service, Southeast Region, NPS-SER Research/Resources Management Report No. 37. Atlanta, GA. 87pp.

Moore, Stephen E., Bromfield L. Ridley, and Gary L. Larson. 1983. Standing crops of brook trout concurrent with removal of rainbow trout from selected streams in Great Smoky Mountains National Park. North American Journal of Fisheries Management. 3:72-80.

Moore, Stephen E., Gary L. Larson, and Bromfield L. Ridley. 1986. Population control of exotic rainbow trout in streams of a natural area park. Environmental Management. 10:215-219.

Powers, Edwin B. 1929. Freshwater studies: I. The relative temperature, oxygen content, alkali reserve, the carbon dioxide tension and pH of the waters of certain mountain streams at different altitudes in the Smoky Mountains National Park. Ecology. 10:97-111.

Seehorn, Monte E. 1978. Status of brook trout in the Southeast. Pages 16-17 in R.D. Estes, T. Harshbarger and G.D. Pardue, Editors. Brook Trout Workshop. Tennessee Cooperative Fisheries Research Unit, Cookeville, TN, USA (Abstract).

Van Deventer, John S. and William S. Platts. 1985. A computer software system for entering, managing and analyzing fish capture data from streams. U.S. Department of Agriculture, Forest Service. Intermountain Forest and Range Experiment Station. Research Note INT-352, Ogden, Utah. 12pp.

Whitworth, Wilbur E. 1979. Evaluation of rainbow trout (Salmo gairdineri) removal project: Sams Creek, Great Smoky Mountains National Park, Gatlinburg, TN (mimeo).

Brown Trout Management in the Natural State[1]

Mark Hudy[2] and Larry L. Rider[3]

Abstract.--Trout managment in Arkansas is on a species level. Brown trout are managed to provide quality (> 13 inches) and trophy (> 20 inches) trout fishing opportunities, including opportunities to catch brown trout of world record proportions. Recent studies on growth and survival of wild and stocked brown trout have documented the potential to improve quality and trophy brown trout fishing opportunities through restrictive harvest regulations. Objectives of a new special regulation (16 inch minimum length limit with a daily creel limit of 2) on the tailwater brown trout fisheries are discussed.

INTRODUCTION

Arkansas is known as the "Natural State", although it has not always been a "natural" for trout. Arkansas has no native trout and prior to construction of numerous dams by the U.S. Army Corps of Engineers in the late 1940's no trout fishing existed in the state. Today, numerous and diverse trout fishing opportunities exist on 13 distinct trout fisheries that encompass over 160 miles of tailwaters and 126,000 acres of reservoirs. An aggressive stocking program (2.2 million trout annually) supported by trout stamp sales and mitigation fish provided by the U.S. Fish & Wildlife Service maintain catch rates and fishing opportunities for over 140,000 trout fisherman annually. A put-and-take trout fishery that features annual stocking rates of 8,000 nine inch rainbow trout and 2,000 twelve inch rainbow trout per mile, is the mainstay of the statewide trout program. This program brings in over $135 million dollars to the states economy each year.[4]

In the past, enough stocked trout escaped and quickly grew to quality and trophy size to supplement the put-and-take stocking program, providing a diversity of trout fishing opportunities (Baker 1959). However, as annual fishing pressure has increased the quality (> 13 inches) and trophy (> 20 inches) size aspect of the Arkansas trout fishing experience has been all but eliminated for rainbow trout and cutthroat trout and greatly threatened for brown trout.

Recent efforts by the Arkansas Game & Fish Commission have focused on evaluating and protecting the quality and trophy brown trout fishing opportunities on its major tailwater fisheries (Hudy in press). This paper will focus on the potential and constraints of the quality and trophy brown trout fisheries on Arkansas's 4 major tailwater trout fisheries, the Bull Shoals Dam, Norfork Dam, Beaver Dam and Greers Ferry Dam tailwaters.

TAILWATER FISHERIES

A total of 79% of all trout fishing in Arkansas occurrs in the tailwaters below Bull Shoals Dam (36%), Norfork Dam (16%), Beaver Dam (8%) and the Greers Ferry Dam (19%).[4] Trout fishing is open year round, 24 hours a day, with a 6 trout per day limit. There currently are no bait or lure restrictions. Since January 1988, a 16 inch minimum length limit on brown trout , with a creel limit of 2 per day, is in effect on the Beaver Dam tailwater. These 4 tailwaters are below U.S. Army Corps of Engineer Dams that were built for flood control and hydropower generation. Year round trout habitat in these tailwaters ranges

[1]Paper presented at the Wild Trout IV Symposium, Yellow Stone National Park, September 18-19,1989.

[2]Mark Hudy is Fisheries Program Manager, U.S. Forest Service, Francis-Marion and Sumter National Forests, Columbia, SC 29202

[3]Larry L. Rider is Fisheries Program Coordinator, Arkansas Game and Fish Commission, Hartman, AR 72840

[4]Unpublished data, 1989 trout fishermen survey, Arkansas Game and Fish Commission, Little Rock, AR 72205.

from 4.5 miles to 90 miles, minimum flow from 55 to 210 cfs and maximum flows from 10,000 to 24,000 cfs (table 1)(Brown et al 1967).

Table 1.--Characteristics of 4 Arkansas tailwater trout fisheries (miles of year round trout habitat, minimum and maximum flows (cfs)).

Tailwater (river)	miles	minimum flow (cfs)	maximum flow (cfs)
Bull Shoals (White)	92	210	24,000
Norfork (North Fork)	5	115	6,000
Beaver (White)	6	55	6,000
Greers Ferry (Little Red)	28	70	6,000

Annual fishing pressure is heavy on all 4 tailwaters and can exceed 5,000 angler days per mile. (Aggus et al 1977; Oliver 1984) These 4 fisheries are vital to the states tourism industry. Each year anglers travel great distances and spend over $135 million[4] dollars to fish these tailwaters (table 2). Average daily trout fishermen expenditures range from $63 to $123. On the Bull Shoals Dam tailwater, 49% of the fishermen travel over 200 miles (one way) to pursue trout fishing opportunities. Tailwater trout managment is on a species level with rainbow trout utilized primarily as a put-and-take fish, with cutthroat trout and brown trout as a put-grow-and-take fish (table 3). Brown trout in the Bull Shoals and Greers Ferry Dam tailwaters are naturally reproducing in significant numbers to support a fishery.

Tailwater Brown Trout

In spite of tremendous fishing pressure, few harvest restrictions, inadequate minimum flows and greatly fluctuating hydropower generation flows, these tailwaters in some areas, are maintaining a high population of quality and trophy size brown trout. However, other sections based on habitat and productivity appear to be far below the potential for producing quality and trophy trout fishing opportunities (table 4). Many tailwater sections have few if any quality or trophy size brown trout. Goals for tailwater brown trout (both naturally reproduced and fingerling stocking programs) are to; 1) supplement the put-and-take rainbow trout fishery, 2) provide trout fishing diversity by providing opportunities for quality and trophy size trout, 3) take full advantage of the growth potential of each tailwater and 4) manage for naturally reproduced populations if conditions permit.

Seven recent line class world records including the world record (38 lbs. 9 oz.) and population estimates of trophy size brown trout of over 200 per mile indicate that these tailwaters are still very productive.

Table 2.--Dollars spent per day trout fishing and percentage breakdown of the one way distances (miles) anglers travel to fish Arkansas tailwater trout fisheries.

Tailwater	$ / day[1]	One way miles			
		0-50	50-199	200-499	>500
Bull Shoals	$123	21%	30%	31%	18%
Norfork	$87	20%	35%	23%	12%
Beaver	$66	51%	24%	19%	6%
Greers Ferry	$63	25%	60%	11%	4%

[1]Average money spent (enroute and on site) on food, lodging, transportation, rental equipment, guide fees; does not include purchase of fishing tackle and equipment (boats, motors, waders, etc.), these purchases averaged $211 per year per angler.

Table 3.--Trout stocking records (1989) of 4 Arkansas tailwater trout fisheries.

Tailwater (river)	Rainbow trout (9-12")	Brown trout (6")	Cutthroat trout (6")
Bull Shoals (White)	952,000	100,000	100,000
Norfork (North Fork)	63,000	10,000	10,000
Beaver (White)	72,600	10,000	0
Greers Ferry (Little Red)	251,250	0	0

Brown trout growth occurs year round and can average 0.35 inches per month in the Bull Shoals tailwater, 0.56 in the Norfork, 0.39 in the Beaver and 0.45 in Greers Ferry. However, growth rates can be exceptional as individual fish have grown over one inch per month for extended periods of time.

Table 4.--Selected brown trout population estimates on 4 Arkansas tailwater trout fisheries.

Tailwater (date)	#/mile (95% CL)	#/mile > 13"	#/mile > 20"
Bull Shoals			
Feb 86	541 (280-1139)	511	266
Feb 87	782 (487-1223)	453	220
Feb 88	750 (548-1055)	494	192
Feb 89	1315 (998-1859)	1062	208
Norfork			
Mar 88	48 (27-112)	4	2
Beaver			
Apr 86	370 (217-595)	0	0
Dec 86	56 (33-105)	13	0
Jan 88	80 (59-110)	27	1
Mar 88	77 (57-106)	25	1
Sep 88	265 (226-457)	38	4
Dec 88	347 (210-936)	16	4
Mar 89	860 (547-1673)	15	12
Greers Ferry			
May 86	436 (279-879)	218	22
Oct 88	4306 (2618-9475)	775	31

Brown Trout Fisheries Concerns

While the brown trout fishery remains satisfactory, there are many causes for concern about the future of quality and trophy brown trout fishing opportunities in Arkansas, 1) the gradual decline in the number of trophy brown trout per mile in the annual February population estimates on the upper sections of the Bull Shoals tailwater (table 4), 2) a dramatic increase in fisherman pursuing and harvesting brown trout,[4] 3) the documented 95% annual mortality rates on fingerling brown trout stockings over the first two years (Hudy in press),and 4) evidence from other states that fisherman can overharvest brown trout.

While these problems are of great concern they were not yet critical, as recent studies on growth and survival of wild and stocked brown trout have documented the potential to improve quality and trophy brown trout fishing opportunities through restrictive harvest regulations (Hudy in press).

The initial attempt to improve quality and trophy brown trout fishing through restrictive harvest regulations took place on the Beaver Dam tailwaters. Goals on this new brown trout fishery (first stocked with brown trout in 1985) were to provide increased opportunities to catch quality and trophy size trout. Stocking brown trout fingerlings with no harvest restrictions did not meet the goals of the fishery. In January 1988, a 16 inch minimum size limit on brown trout with a creel limit of two a day went into effect. The regulation had an immediate impact on recently stocked brown trout by more than doubling the one year survival rate over previous unprotected stockings (table 4). More importantly than showing early biological success and the potential to meet the goals of the fishery, the regulation was accepted well by the public and enforcement personnel.

Because of the apparent biological and political success of the Beaver Dam regulation and the high potential for success on the other tailwater fisheries (Hudy in press), a new regulation identical to the Beaver Dam tailwater (brown trout daily limit of 2 with a 16 inch minimum length limit) will go into effect January 1990 on the other three fisheries.

Although the regulation may not best meet the biological needs of all sections of all tailwaters, it was the best single regulation that would simplify regulations and be both biologically and politically acceptable. Although the regulation would be improved by an artificial lure restriction, this type of regulation is not a politically viable alternative at this time, because 41% of Arkansas trout fisherman consider themselves novices or beginners and only 15% utilize artificial lures most of the time.[4]

The regulation was supported by all major trout fishing special interest groups and by 45% of the 1989 trout permit purchasers (27% oppossed and 28% no opinion).[4] Opposition mainly concerned predation on stocked rainbow trout (9 - 12 inches) by increasing populations of hard to catch brown trout. This was addressed by keeping the minimum size limit at 16 inches instead of higher.

Goals of the regulation are to prevent harvest of wild brown trout for 3 years and stocked brown trout for 2 years to 1) obtain a better population of quality size trout, 2) allow the fish to spawn atleast one time and 3) improve utilization of the productivity of the tailwaters.

It is hard to predict the full potential of these tailwaters for quality and trophy size trout. The concept of carrying capacity is greatly confounded by the drastic water level fluctuations and the stocking and harvesting of thousands of catchable rainbow trout each week. It is also not readily apparent in some tailwater sections if special harvest regulations of any kind can dramatically improve the numbers of quality and trophy size brown trout without concurrent increases in trout habitat through an increase in minimum flows.

Specific objectives of the new regulations are to obtain; an average of 125 quality size and 25 trophy size brown trout per mile on the 92,miles of the Bull Shoals tailwater; an average of 300 quality size and 100 trophy size brown trout per mile on the 5 miles of the Norfork tailwater; an average of 125 quality size and 30 trophy size brown trout per mile on the 6 miles of the Beaver tailwater and an average of 300 quality size and 20 trophy size brown trout per mile on the 28 miles of the Greers Ferry tailwater.

LITERATURE CITED

Aggus, L.R., D.I. Morais, and R.F. Baker. 1977. Evaluation of the trout fishery in the tailwater of Bull Shoals Reservoir, Arkansas,1971-73. Proc. Annu. Conf. Southeast. Assoc.Fish and Wildl. Agencies. 31:565-573.

Baker, R.F. 1959. Historical review of the Bull Shoals Dam and Norfork Dam tailwater trout fishery. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 13: 229-236.

Brown, J.D., C.R. Liston, and R.W. Dennie. 1967. Some physio-chemical and biological aspects of three tailwaters in northern Arkansas. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 21: 369-381.

Hudy, M. (in press). Brown trout population structure in White River tailwaters currently managed under no special regulations. Proc. Brown Trout Workshop, Asheville, NC, April 27-28, 1988.

Oliver, M.L. 1984. The rainbow trout fishery in the Bull Shoals-Norfork tailwaters, Arkansas, 1971-81. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 38: 549-561.

Rainbow Trout Management Plan: Southwest Alaska[1]

R. Eric Minard[2] and Kevin Delaney[3]

Abstract.--The Alaska Department of Fish and Game has developed management plan for southwestern Alaska rainbow trout stocks. The draft plan assures ample biological protection to rainbow trout stocks, provides an array of angling opportunities (catch and release, trophy, and fly fishing only) by establishment of special management areas and recognizes the economic potential of the areas rainbow trout resources to the local area and the State of Alaska. Implementation of the plan will come through the regulation process administered by the Alaska Board of Fisheries.

INTRODUCTION

The southwestern sport fish management area includes all waters and drainages flowing into Bristol Bay north of Cape Menshikof to Kuskokwim Bay, including the Kuskokwim River and its tributaries from the Aniak River downstream to Kuskokwim Bay (Figure 1). Within this 54,700 square mile area are some of the most productive salmon, rainbow trout, Arctic grayling, Arctic char, and Dolly Varden waters in the world.

Wild rainbow trout stocks of the area are world famous and cornerstone to a multimillion dollar sport fishing industry. Over 100 commercial guides and outfitters operate in southwest Alaska offering services that range from outfitted but unguided float trips, to luxurious wilderness lodge accommodations complete with daily fly-out fishing. Current prices for these services range from $1,500 to $4,000 per fishermen per week. In addition to lodges and outfitters, some 50 air taxis regularly provide transportation for fishermen throughout the area. Total economic value of the recreational fishery in Southwest Alaska is estimated to exceed $50 million per year.

NEED FOR A MANAGEMENT PLAN

The Alaska Board of Fisheries sets management policy and promulgates fisheries regulations for all of Alaska on a regional basis. Proposals for fisheries management policies, management plans, and specific regulations are submitted by both the Alaska Department of Fish and Game and the public.

Since statehood in 1959, the Board and the Department of Fish and Game have recognized the unique quality of the wild rainbow trout resources in southwest Alaska and managed these fisheries with increasingly conservative regulations.

However, during recent Board of Fisheries

---

[1]Paper presented at Wild Trout IV Symposium, Yellowstone National Park, Wyoming, September 18-19, 1989.

[2]R.Eric Minard is Area Management Biologist, Alaska Department of Fish and Game, Sport Fish Division, Dillingham, A.K.

[3]Kevin Delaney is Regional Management Coordinator, Alaska Department of Fish and Game, Sport Fish Division, Anchorage, A.K.

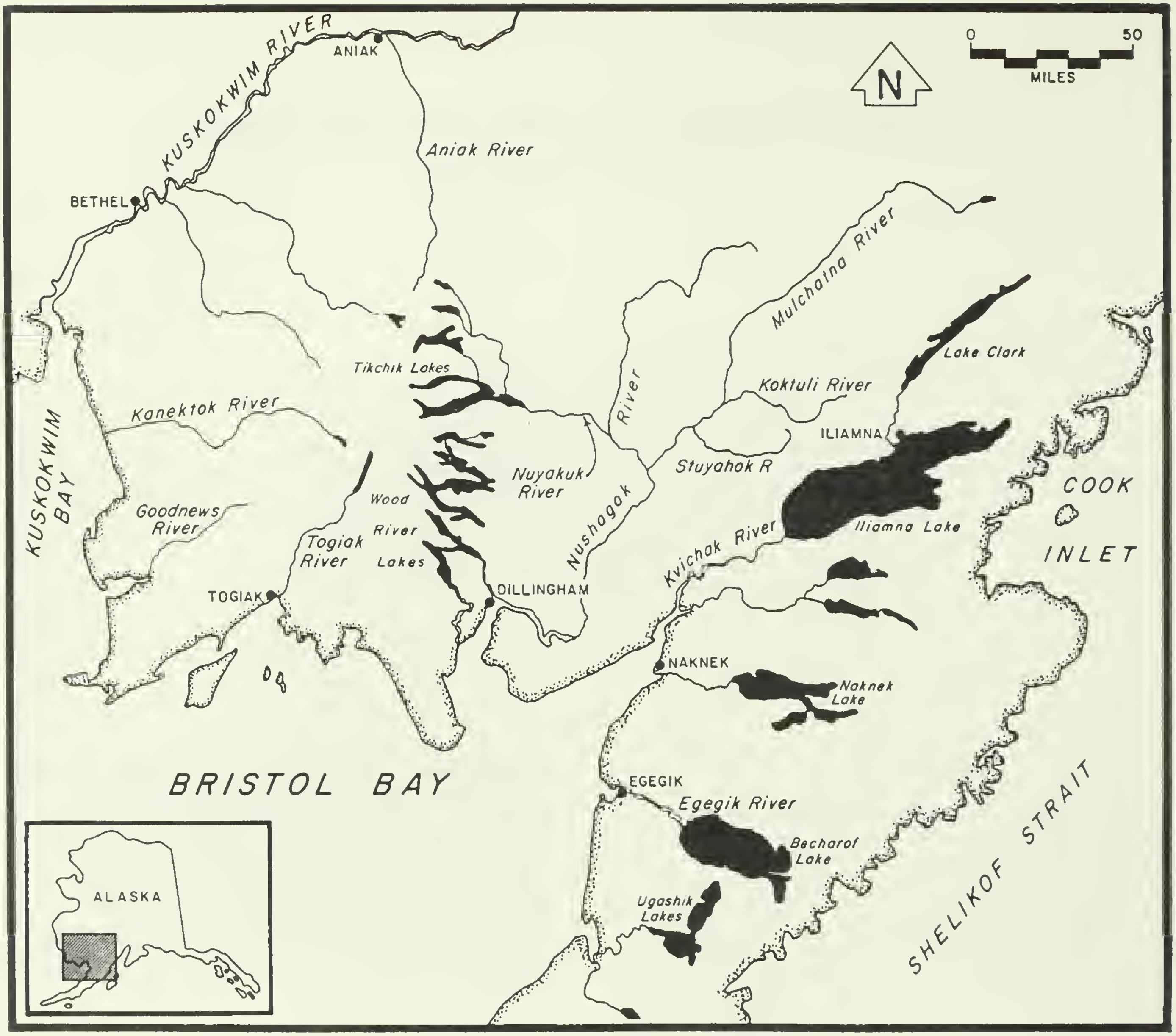


Figure 1.--Southwest Alaska Rainbow Trout Management Area.

meetings, where southwest Alaskan sport-fishing regulations have been discussed, there has been a dramatic increase in the number of proposals rainbow trout. The Board has considered each proposal solely on its own merit with no overall policy to guide them. The result has been a reactive patchwork of regulations with no clear management objective.

As the rainbow trout fishery in southwest Alaska gains in popularity and the value of the sport fishery industry continues to grow, the need to develop and adopt a management policy becomes increasingly important. The plan must: 1) protect the biological integrity of the regions wild rainbow trout stocks, 2) provide recreational benefit to all users, and 3) maximize the economic potential of the area and state.

PHILOSOPHY OF THE PLAN

The overriding philosophy of the rainbow trout management plan is one of conservative wild stock management. The philosophy of conservative wild stock management is not new to fisheries management or to Alaska and, in fact, probably best describes the present approach to management of rainbow trout in southwestern Alaska. Conservative wild stock management does not necessarily preclude limited harvest of rainbow trout for food or trophies. However, maximum yield principles which emphasize harvest are ruled out. Additionally, under a philosophy that emphasizes wild stock management, mitigating losses of wild trout through stocking would be precluded. Conservative wild stock management is predicated on both biological considerations and social concerns. Since growth in the region's rainbow trout sport fisheries is inevitable, managing the areas wild rainbow trout stocks conservatively, minimizes the potential for serious long term conservation problems.

PUBLIC REVIEW PROCESS

One of the most important aspects of development a management plan public involvement. It has been intent of the Department of Fish and Game and the Board of Fisheries that members of the public have several opportunities to comment on the proposed plan. An extensive mailing list was developed which included, but was not limited to, all sport fishermen who purchased licenses in the management area in the past year, all members of the Fish and Game Advisory committees, members of the guiding and outfitting industry, local village leaders both city and tribal, government agencies operating within the area, and various Native corporations who are landholders in the area. Over four thousand individuals and groups will received a draft copy of the plan for comment. Copies were also made available to anyone who desired one but was not included on the mailing list. A questionnaire with a prepaid return envelope, accompanied each draft soliciting opinions concerning specific aspects of the plan.

Initial review of the draft plan took most of the winter of 1988-89. Following public review and prior to the 1989 Board of Fisheries meetings, a second draft will be completed incorporating public comment. The policy will then go through a second review and final review during the Board of Fisheries meeting scheduled for February of 1990. Throughout the process the public will again have an opportunity to comment and participate in the development of the final management plan.

Specific regulation proposals designed to implement the plans policies offered to the Board at the 1989 winter meeting. Although proposals can be made by any member of the public and Advisory Committees, the Department intends to work with interested groups and develop a regulatory package that meets the biological considerations and desires of the angling public.

PROPOSED RAINBOW TROUT MANAGEMENT PLAN

The Southwestern Alaska Rainbow Trout Management Plan contains three policy statements that are intended to protect the biological integrity of the area's wild trout stocks and maximize their recreational benefit and economic potential. These policies provide management biologists within the Department of Fish and Game, Board of Fisheries members, and the public with clear policies to govern management of rainbow trout fisheries in southwestern Alaska and will guide the development of sport fishing regulations designed to implement these policies.

Policy I

Native rainbow trout populations will be managed to maintain historic size and age composition and at stock levels sufficient such that stocking is not needed to enhance or supplement the wild population.

This policy addresses the Department's primary responsibility to ensure that resources are being managed on a sustainable basis and that those management practices do not significantly alter the historic size and age composition of rainbow trout stocks within the management area. Additionally, this policy addresses the desire to maintain wild rainbow trout throughout the area and that mitigating loss of wild stocks through stocking is not a desirable management alternative.

Policy I will be realized by managing rainbow trout stocks in a biologically sound manner under a conservative yield philosophy. Conservative yield is defined as a sustainable level of harvest below the maximum sustainable level. Consistent with this philosophy, the general bag and possession limits for rainbow trout within the area will not exceed two per day of which only one may be greater than 20 inches in length. More restrictive limits may be applied to satisfy the goals associated with waters designated for special management or to address biological concerns.

In the event that a biological problem with a rainbow trout stock becomes evident, Alaska Department of Fish and Game Sport Fish Division will react through its Emergency Order Authority with time and area closures designed to reduce harvest. In addition, the Department can recommend that the Board of Fisheries take action to reduce bag and possession limits, designate size limits of harvestable fish, close areas and/or times to the taking of trout and adopt methods and means restrictions to complement such regulations.

Policy II

A diversity of sport fishing opportunities for wild rainbow trout should be provided through establishment of special management areas by regulation. Selection of areas for special management will be based on criteria adopted by the Board of Fisheries.

Under this policy special management areas would be established to provide the sportfishing public with a variety of angling opportunities. Selection of waters for special management will be based on criteria established by the Board of Fisheries designed to ensure the most suitable waters are selected.

Policy II will be implemented by establishing special management areas that provide the sport fishing public with a range of desired angling opportunities. In southwest Alaska, special management may be designated as either Catch and Release or Trophy. In waters designated for catch and release fishing rainbow trout may not be retained or possessed and all rainbow trout caught must be released immediately. Trophy waters are managed to provide the opportunity to harvest a large rainbow trout. Bag and possession limits will not exceed one fish and a suitable minimum size limit would be established for all designated trophy trout waters. To complement these harvest strategies, in waters designated as Catch and Release or Trophy areas, only unbaited, single hook artificial lures may be used. Catch and Release or Trophy areas may further be designated as fly fishing only. In waters not designated for special trout management, but during times when directed wild trout fisheries occur, the use of artificial lures (no single-hook restriction) will be considered depending on current harvest and effort levels.

Waters designated through regulation for special management will be selected according to a process that addresses stock status, location, historical use patterns, accessibility, aesthetics, geographical distribution of angling opportunities and the economic return in terms of commerce generated and jobs created. Each candidate water (water being considered for special management) will be ranked according to ten criteria to determine its suitability for special management.

1. STOCK STATUS. To be considered for Catch and Release or Trophy designation, a candidate water must meet the biological objectives of conservative yield, which call for the maintenance of the historical size and age composition and stock levels of the rainbow trout population(s). Historical fisheries statistics will be used to make this determination. Any candidate water that meets the conservative yield objectives will be considered by the Board against criteria 210.

2. HISTORY OF SPECIAL MANAGEMENT. This is a subjective category that considers the public's perception of the history of rainbow trout fishing in the candidate water. It is assumed that a water which people associate with having provided "quality" trout fishing can more easily be managed for that purpose than a water with no history of fine trout fishing.

3. PROXIMITY TO LOCAL COMMUNITY. A stream is preferred if it is not located near enough to a permanent community to be commonly used and/or visited by local residents. The intent of this criteria is to avoid conflict with traditional consumptive use patterns of local residents.

4. LEGAL ACCESS. This refers to public ownership of the adjacent lands or the water being classified as navigable. A water with over 50% of its banks publicly owned, or a navigable designation, would be preferred.

5. OVERLAP WITH FRESHWATER NET FISHERIES. Special management areas should be seasonally and/or specially segregated from subsistence and freshwater commercial net fisheries.

6. ABUNDANCE AND SIZE OF RAINBOW TROUT. This refers to the number and average size of the catchable rainbow trout seasonally present in a candidate water. Waters with relatively high numbers of rainbow trout and waters with uniquely large rainbow trout would be favored for special management.

7. WATER CHARACTERISTICS. This refers to the habitat characteristics and appearances of a water. A stream with clear water and riffle-pool configuration with a gravel bottom would be preferred.

8. CLEAR GEOGRAPHICAL BOUNDARIES. This refers to the angling public's ability to clearly distinguish the legal regulatory boundary of a candidate special management area.

9. RELATIVE IMPORTANCE OF RAINBOW FISHERY TO SPORT FISHING INDUSTRY. A candidate water of high economic value to the sport fishing industry would be favored as an area for special management.

10. GEOGRAPHICAL DISTRIBUTION OF SPECIAL MANAGEMENT WATERS. The designation of a candidate water for special trout management should take into consideration its proximity to other special management waters and the availability of alternative locations not designated for special management.

Policy III

Management strategies should be consistent with the prudent economic development of the state's recreational sport fishing industry while at the same time acknowledging the intrinsic value of this fishery resource to the people of the State.

This policy acknowledges that southwest Alaska's wild rainbow trout are of vital importance to the state's growing recreational industry and that wise development of commercial recreation is to the economic benefit of the region and the state. Management practices that maintain or enhance the marketability of high quality recreation would be favored under this policy.

Consideration of the economic impact to the recreational industry, of both the local area and the state in general, should be given in all regulatory actions regarding rainbow trout within the management area. Whenever possible, emergency orders and regulations should be structured to foster the prudent economic development of the industry.

To implement Policy III, department managers will recognize that due to the remoteness, cost and logistical difficulty of travel in southwest Alaska, that fishery closures may severely impact angling opportunity and the related recreational industry.

The Department currently has Emergency Order Authority to implement time and area closures when addressing a biological crisis in season. Only the Board of Fisheries, during noticed meetings, can implement changes in bag limits, size limits or in legal methods and means, that if employed in-season, could avoid disruptive closures. The Board of Fisheries could facilitate the implementation of Policy III by delegating to the Department Emergency Order Authority beyond the normal time and area closures and furnish the Department with criteria for its use.

PLAN IMPLEMENTATION

In conjunction with the development of the drafty management plan, the Department has prepared a series of proposed regulation which, if adopted by the Board of Fisheries will serve to implement the plan. Specifically then proposals include the following:

1. designate all waters in Southwest Alaska as The Wild Trout Zone.

2. that a uniform, conservative bag, possession and size limit package be adopted;

3. that eight streams be designated catch and release waters;

4. that six of the streams designated catch and release waters be further designated fly fishing only waters;

5. and that anglers be restricted to the use of unbaited, single hook artificial lures to reduce angling mortality in eight additional areas that support directed rainbow trout fisheries.

The Alaska Board of Fisheries is currently scheduled to address the Southwest Alaska Rainbow Trout Management Plan in February, 1990.

Genetic Interactions of Hatchery and Wild Steelhead Trout: Findings and Implications of Research at Kalama River, Washington[1]

Patrick L. Hulett and Steven A. Leider[2]

Abstract.--Studies of genetic interactions of hatchery and wild steelhead in the Kalama River have been underway for 15 years, with some surprising results. Hatchery fish parented over 40% of the naturally produced adult summer steelhead, even though wild fish were 8 to 9 times more effective at producing adult offspring. Implications of these findings and management options to protect wild stocks are discussed.

INTRODUCTION

Hatcheries account for a substantial portion of the total production of steelhead trout (Oncorhynchus mykiss) along the Pacific coast of North America. From 1985 to 1987, hatcheries from California to Alaska released about 30 million steelhead smolts annually, producing an estimated 900,000 returning adults (Light 1989). Reliance upon hatcheries for steelhead production is particularly prevalent in Oregon, Washington and Idaho. In 1987, hatcheries in those states produced 90% of the steelhead smolts released along the Pacific coast of North America, with 73% coming from facilities in the Columbia River Basin alone (Light 1989). However, the biological, economic, social and aesthetic values of wild salmonids (Dentler and Buchanan 1986) have also become widely recognized. This situation has led to increasing conflict over the relative management emphasis placed on hatchery and wild production. The possibility of adverse genetic and ecological effects of hatchery production on wild populations has received increasing attention in the scientific literature (Reisenbichler and McIntyre 1977, 1986; Krueger and Menzel 1979; Reisenbichler 1984; Vincent 1984; Chilcote et al. 1986; Nickelson et al. 1986; Lichatowich and McIntyre 1987). In addition, wild steelhead enthusiasts among the sport fishing public have become increasingly critical of management programs considered to favor hatchery production over natural production (e.g. McMillan 1986, 1989; Bakke 1989). It is apparent from these statements that the integration of the management of hatchery and wild steelhead stocks is a desirable goal for fisheries management agencies in the Pacific northwest.

In the mid-1970's, a research project was begun on the Kalama River in southwest Washington to gain information about the interactions of sympatric populations of hatchery and wild steelhead. The primary objectives were to determine whether returning hatchery adults successfully contribute to natural production and, if so, how their natural reproductive success compares to that of wild spawners. The purpose of this paper is to report on the status of ongoing research, to report the major findings of that research, and to discuss the implications of those findings regarding the concurrent management of sympatric hatchery and wild stocks. Although the findings deal specifically with steelhead, the implications are thought to have broad application to other anadromous and resident salmonids. Indeed, the implications may have

---

[1]Paper presented at the Wild Trout IV Symposium (Yellowstone National Park, Mammoth Hot Springs, Wyoming, September 18-19, 1989).

[2]Patrick L. Hulett and Steven A. Leider are Fisheries Research Biologists for the Washington Dept. of Wildlife, Olympia, Washington.

relevance for any species in which locally adapted populations receive some form of hatchery supplementation.

As used in reference to fish throughout this paper, the terms "hatchery" and "wild" deliberately have rather broad definitions. Any fish that has spent a portion of its life cycle in a hatchery is considered a hatchery fish, regardless of its ancestry. Likewise, any fish that was spawned and reared under natural conditions is considered a wild fish, regardless of its ancestry. This definition of wild fish is much less restrictive than other commonly used terms (e.g. native or pristine) that refer only to fish with little or no hatchery ancestry. The broader definitions allow fish to be classified discreetly into hatchery and wild groups without the need for a catch-all third group of fish with mixed (hatchery and wild) ancestry.

DESCRIPTION AND STATUS OF RESEARCH

Summer-run Reproductive Success

In the first main phase of study, we sought to determine the relative natural reproductive success of the hatchery and wild stocks of summer steelhead in the Kalama River. To do this, four broods of hatchery summer steelhead were genetically marked so their contribution to natural production could be estimated at the subyearling, smolt and adult stages of the offspring. Although the rationale and methods for these procedures are detailed elsewhere (Chilcote et al. 1986; Leider et al. 1989, In review), it may be helpful to emphasize a few key points.

The genetically marked hatchery broods were created by selectively breeding adult steelhead that were found to possess a rare form (designated A') of a particular enzyme (G3PDH-1, E.C. no. 1.1.1.8) present in the muscle tissue of fish. Offspring inherit either the rare (A') form or the common (A) form of the enzyme from each parent, and will thus be of one of three enzyme "types": AA, AA' or A'A'. In the Kalama wild population, less than 20% of the fish were naturally of the AA' or A'A' type. After selective breeding, 100% of the hatchery fish in the genetically marked broods were AA' or A'A' types. However, many hatchery fish of AA type were present (averaging 40%) in the Kalama River at the time of return of the genetically marked broods. This occurred in part because the multiple age structure of returning adults (Leider et al. 1986) resulted in the mixing of adults from the genetically marked broods with those from either earlier or later broods that were not genetically marked. However, most of the AA type hatchery adults were believed to have been strays from other rivers (Chilcote et al. 1986). Strays comprised a substantial portion of adult returns to the Kalama in 1980 and 1981. These strays were believed to originate primarily from the nearby Cowlitz and Toutle rivers, which had been severely impacted by the eruption of Mount St. Helens in May of 1980 (Leider 1989). Because all three enzyme types (AA, AA', A'A') were present in both the hatchery and wild adults, we were not able (nor had we intended) to determine whether individual naturally produced steelhead had zero, one or two parents of hatchery origin. Nor could we estimate the degree of interbreeding between hatchery and wild fish. However, the higher frequency of the A' enzyme form among hatchery spawners enabled us to achieve our objectives by comparing the A' frequencies among hatchery and wild spawners to that among their subyearling, smolt and adult offspring (Chilcote et al. 1986; Leider et al. In review).

Another important point of distinction is that the hatchery summer steelhead released into the Kalama River are of the non-local Skamania stock (Howell et al. 1985), which originated from Washougal and Klickitat river populations (Crawford 1979). Therefore, differences in the natural reproductive success of the Skamania hatchery and Kalama wild stocks should not be interpreted to reflect solely the effects of genetic changes incurred through several generations of hatchery propagation. To the extent that locally adapted populations appear to perform better in a given stream (as judged by return rates) than transplanted populations (Reisenbichler 1988), the Skamania stock might be expected to have lower natural reproductive potential in the Kalama River than the local wild stock, even in the absence of any effects of hatchery propagation on the Skamania stock. The relative degree to which the "transplant effect" and "hatchery effect" might influence the relative performances of the Skamania and Kalama stocks in the Kalama River is unknown. Still, this comparison of stocks is a useful one from a practical management perspective, since nearly all summer steelhead stocked in southwest Washington are of the Skamania stock. This stock has also been transplanted to locations in numerous other states (Howell et al. 1985).

This study was completed in 1987 (some 13 years after it began) when the last (age 5) adult progeny of the fourth and final study brood returned to the Kalama River. Results from this phase of study comprise the bulk of the findings discussed in this paper.

Ancillary Studies

Two other studies are currently underway that take advantage of the persistence of the A' genetic mark in Kalama River steelhead populations.

Second Generation Summer-run.--The first ancillary study will examine the natural reproductive success of the second generation adult offspring of our original genetically marked broods. Samples will be analyzed from summer-run adults returning between 1987 and 1993 (see Leider et al. (1989) for details).

Summer-Winter Gene Flow.--Another study will examine the frequency of the A' form of the G3PDH-1 enzyme in the population of wild winter steelhead in the Kalama River before and after possible interbreeding with genetically marked hatchery summer steelhead. An increase in the frequency of the A' form following natural production by the genetically marked fish would be evidence that the hatchery summer-run fish have contributed to the natural production of wild winter steelhead. We know of no other empirical studies that have provided direct evidence of gene flow between "races" or "run forms" of salmonids. This study will involve the analysis of existing data of A' frequencies plus data from winter-run returns for the next few years (see Leider et al. (1989) for details of the study design and methods).

Winter-run Reproductive Success

A second main phase of study was begun in 1987 to determine the natural reproductive success of hatchery winter steelhead relative to that of wild winter steelhead in the Kalama River. This essentially replicates the summer-run study, using winter-run stocks and a different enzyme (SOD-1, E.C. no. 1.15.1.1) for genetic marking. Here again, the comparison is between a transplanted hatchery stock and a local wild stock. The hatchery winter steelhead released into the Kalama River are of Elochoman stock (Howell et al. 1985), which originated from steelhead populations of the Elochoman River, Chambers Creek (south Puget Sound) and the Cowlitz River (Crawford 1979). Thus, we will again be unable to determine the relative degree to which "hatchery effects" and "transplant effects" influence the results of the study.

Three genetically marked hatchery broods have been released and adults returning from the first brood spawned in early 1989. Although not yet available, preliminary estimates of the contribution of hatchery winter steelhead to natural production of subyearlings will be made following analysis of samples collected in late summer of 1989. This study will not be completed until 1997, when the last naturally produced offspring of the third genetically marked brood return as adults to the Kalama River.

It is anticipated that the presence of the winter-run genetic mark may provide a means for carrying out ancillary studies similar to those that followed the summer-run study.

PRINCIPAL FINDINGS

Details regarding the findings of the summer-run reproductive success study are given by Chilcote et al. (1986) and Leider et al. (1989, In review). Some of the important findings reported by those authors are as follows:

(1) Transplanted hatchery summer steelhead were 8 to 9 times less effective at producing returning adult offspring than were wild summer steelhead in the Kalama River.

(2) Even so, over 40% of the returning naturally produced adults were estimated to have had one or more hatchery parents. The high contribution to natural production by the hatchery fish occurred in spite of their poor reproductive success because hatchery spawners outnumbered wild spawners by a wide margin. During the return years of the genetically marked broods, hatchery fish comprised from 75% to 90% of the total summer-run spawning escapement (Leider et al. 1987).

(3) Survival of hatchery offspring was poorer than that of wild offspring during both the freshwater and marine portions of the life cycle. Persistence of the survival difference throughout the life cycle suggests that the factors responsible have a strong genetic basis.

(4) The difference between the reproductive success of hatchery and wild spawners was least evident at the subyearling stage of their offspring. Therefore, factors related to the hatchery fish's ability to successfully spawn appear to be less important overall than factors related to the subsequent survival of their offspring during the subyearling-to-smolt and smolt-to-adult stages.

MANAGEMENT IMPLICATIONS

The management implications of these findings are considerable. If the transplanted hatchery fish interbreed with the wild fish, then the genetic traits responsible for the poor natural reproductive success of the hatchery fish will be incorporated into the wild population. The reproductive success of the wild population will thus be depressed by this maladaptive gene flow. As previously mentioned, we have no direct estimate of the degree of interbreeding between hatchery and wild summer steelhead. However, we believe that such interbreeding does occur in the Kalama River, for the following reasons:

(1) Spatial and temporal spawner overlap is not sufficient to prevent gene flow between hatchery and wild summer steelhead in the Kalama River (Leider et al. 1984).

(2) We know of no empirical evidence to suggest that hatchery and wild fish may tend to segregate behaviorally, that is, "choose" to spawn with their own kind.

(3) Differentially tagged hatchery and wild summer steelhead have been observed together on active redds, providing direct evidence that interbreeding occurs (Leider et al. 1984).

(4) Preliminary analysis of data from the summer-run to winter-run gene flow study indicates that the A' genetic mark has been passed from the hatchery summer-run spawners into the wild winter-run population. Evidence of gene flow between these two spawner groups, which are more reproductively isolated than the hatchery and wild summer-run spawners (Leider et al. 1984), further implicates the probability of interbreeding between hatchery and wild summer steelhead in the Kalama River.

We therefore consider it highly probable that natural production by the transplanted hatchery summer-run stock in the Kalama River is causing degradation of the genetic makeup of the local wild stock. The seriousness of the problem depends to a large degree on the actual level of interbreeding between hatchery and wild fish. We further suspect that this problem is not restricted to the case studied. Similar situations of sympatric transplanted and wild populations with the potential to interbreed may not be uncommon in the Pacific Northwest, considering the high level of hatchery stocking previously discussed. The possibility of deleterious genetic interactions in such cases must be given due consideration.

Despite the potential seriousness of this situation (particularly if ignored), one should not jump to the conclusion that countless wild populations have already been hopelessly and forever destroyed by the infusion of "killer genes". The evidence of superior reproductive success of wild fish in the Kalama River comes after nearly 20 years (4 generations) of previous hatchery stocking and potential interbreeding between hatchery and wild fish. Over that period, the wild stock has retained genetic traits of considerable adaptive value relative to those of the transplanted hatchery stock. It may be that the wild stock has been resilient to genetic degradation, or it may be that the hatchery and wild stocks have incurred similar degrees of genetic degradation over the generations. We cannot resolve that issue because we lack data on the natural reproductive success of the two stocks prior to their first potential interbreeding.

We frankly don't know how much damage may already have been done, the permanency of such damage, or if and when some genetic "point of no return" might be reached. Given these unknowns, prudence dictates that we take action now to preserve the valuable genetic resources we have left.

MANAGEMENT OPTIONS

Potentials

A variety of management options are available that can potentially aid in the genetic protection of wild stocks. I have grouped these into three main categories:

(1) Make hatchery and wild stocks so genetically similar that they are, for all practical purposes, genetically interchangeable. Interbreeding would then be genetically acceptable.

(2) Make hatchery and wild stocks so different that they are reproductively incompatible, thus eliminating interbreeding.

(3) Reduce or eliminate the escapement of hatchery fish, thus reducing or eliminating interbreeding.

Genetic Interchangeability

Within the first category are some options that, though divergent in their methods, have a common goal: to make the hatchery stock more "wild". Such options include the use of local wild broodstocks, the modification of hatcheries to more closely simulate wild rearing conditions, and earlier release of hatchery juveniles to decrease their exposure to hatchery selective pressures while increasing their exposure to natural selective pressures.

While each of these options have theoretical merit, the degree to which each approach helps produce a "wilder" hatchery fish is untested. There are also practical and economic difficulties associated with the collection and maintenance of local wild broodstocks, the construction and/or redesign and operation of hatchery facilities that simulate a more natural environment, and the ability to achieve acceptable returns from pre-smolt releases without adversely affecting existing stream populations of salmonids.

Reproductive Incompatibility

Options within the second category include temporal or spatial segregation of hatchery and wild spawners, as well as the use of sterile hatchery outplants. Because time of spawning is heritable (Siitonen and Gall 1989), selection for early spawn timing of hatchery broodstock could be used to further increase the temporal segregation of hatchery and wild spawners. However, it is unclear to what degree temporal isolation of hatchery and wild populations can be achieved and maintained. Naturally produced offspring one or more generations removed from the hatchery may revert to the "wild type" spawn timing in response to natural selective pressures. If temporal isolation is incomplete, the resulting gene flow, though small in quantity, could cause serious genetic degradation. This is because genetic differences between the hatchery and wild stocks will have been increased by both direct and indirect effects of the selective breeding program used to change the run timing.

Spatial segregation may be an option for situations in which there are facilities below spawning areas that permit the sorting of migrating adults. Wild fish could then be passed upstream to spawn and hatchery fish could be recycled back into the sport fishery (Buchanan and Moring 1986), retained for hatchery broodstock, or harvested. However, the limited availability of such facilities and/or cost to build and operate them may severely reduce the practical applicability of this option.

The outplanting of sterile hatchery fish may eventually permit gene flow to be eliminated without restricting hatchery escapement. However, technical problems resulting in low return rates of sterile fish and questions as to the possible effects of attempted spawning between wild and sterile fish have not yet been resolved.

Elimination of Hatchery Escapement

Options under the third category entail harvest and production management strategies to minimize the hatchery spawning escapement (at least relative to the wild escapement). Harvest strategies include regulations that require the release of wild fish, set liberal bag limits for hatchery fish, and/or set season opening and closing dates to target the harvest of hatchery fish. Although many of these strategies are currently used to protect wild steelhead in the state of Washington (and elsewhere), their overall effectiveness has generally not been evaluated. Hatchery fish may escape to spawn in substantial numbers in spite of such harvest management strategies. For example, returns of hatchery summer steelhead in 1986 and 1987 continued to comprise about 80% of the summer steelhead reaching river mile 10 of the Kalama River, in spite of selective (hatchery only) harvest regulations implemented there in 1986 (Leider et al. 1989).

An obvious production management strategy is simply to reduce the number of hatchery steelhead reared and released, thus reducing the number of returning hatchery adults. Because this option may reduce fishing opportunities, it is likely to be unpopular among much of the angling public.

Information Needs

Clearly none of these options can be viewed as a panacea. We don't yet know that we can fully achieve either genetic interchangeability or reproductive incompatibility of hatchery and wild stocks, and the elimination of hatchery escapement may sometimes require measures beyond the realm of socio-political reality. Furthermore, it is not at all clear how much genetic protection is to be gained for given increments of progress made toward achieving the interchangeability, incompatability or elimination of hatchery escapement. In order to help determine which options will be most beneficial in particular situations, we must find answers to some key questions:

(1) To what extent are various means for producing a "wilder" hatchery fish successful from a genetics standpoint?

(2) To what extent can reproductive isolation be achieved by increasing the separation in hatchery and wild spawn timing, and to what extent will the separation "hold" for the naturally produced offspring of hatchery fish?

(3) Can methods be developed to produce and release sterile fish that yield acceptable return rates and do not interfere with the spawning and viability of wild populations of fish?

(4) To what extent must hatchery escapement be reduced to adequately protect the genetic makeup of wild stocks in particular situations?

Current Efforts

Answers to these and similar questions are urgently needed to facilitate thoughtful management plans that minimize the biological and economic costs of mistakes and wasted efforts. Considerable research effort should be directed in these areas. In the mean time, however, we must proceed the best we can with what we know now. And indeed, on many fronts we are. For example, the Northwest Power Planning Council (NPPC), as well as fish management agencies in British Columbia and Oregon have shown an increased emphasis on the use of local wild broodstocks in current and/or proposed hatchery programs. Although the degree of benefit gained from this strategy is yet unclear, it is theoretically a step in the right direction. The use of local wild broodstocks may at least retard those genetic changes in wild stocks that result from interbreeding with hatchery stocks, while new information is being pursued. On another front, an evaluation of the use of hormonally sterilized hatchery steelhead to eliminate interbreeding between hatchery and wild fish has begun in Oregon. As another example, in Washington a model is currently being developed to predict stocking levels of hatchery steelhead that permit adequate genetic protection of wild stocks. And in general, the awareness of the need to protect wild stocks, and the resolve to do so, seems to be at an all-time high among management agencies. Such resolve is exemplified by the plans of the NPPC for rebuilding the salmon and steelhead runs in the Columbia River Basin. These plans specifically call for the assessment of genetic risks of proposed management actions in the Columbia River Basin and consideration of possible genetic and ecological effects of proposed additional hatchery production in the Yakima River (NPPC 1987).

In summary, the potential for the genetic demise of wild stocks (and perhaps ultimately their species) is very real should we choose to ignore the effects of interbreeding between genetically different hatchery and wild fish. However, the prospects for viable management alternatives are good. If we continue to apply what is known about the genetic interactions of hatchery and wild fish, and strive earnestly to answer the many questions remaining, we can develop integrated hatchery and wild management strategies that provide ample angling opportunity without trading the valuable genetic resources of our wild stocks in return.

LITERATURE CITED

Bakke, B. 1989. Wild steelhead conservation. Salmon Trout Steelheader, Sep. 1989:24-29.

Buchanan, D.V. and J.R. Moring. 1986. Management problems with recycling of adult summer steelhead trout at Foster Reservoir, Oregon. Pages 191-200 in R.H. Stroud, editor. The role of fish culture in fisheries management. Fish Culture Section and Fisheries Management Section, American Fisheries Society, Bethesda, Maryland.

Chilcote, M.W., S.A. Leider and J.J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Trans. Am. Fish. Soc. 115:726-735.

Crawford, B.A. 1979. The origin and history of the trout broodstocks of the Washington Department of Game. Washington Dept. of Game, Olympia. 76 pp.

Dentler, J.L. and D.V. Buchanan. 1986. Are wild salmonids worth conserving? Info. Rep. 86-7. Oregon Dept. of Fish and Wildlife, Portland. 27 pp.

Howell, P., K. Jones, D. Scarnecchia, L. Lavoy, N. Kendra and D. Ortman. 1985. Final Report: Stock assessment of Columbia River anadromous salmonids. Vol. II: Steelhead stock summaries - stock transfer guidelines - information needs. U.S. Dept. of Energy, Bonneville Power Admin. Div. Fish and Wildlife. Portland, Oregon. 558 pp.

Krueger, C.C. and B.W. Menzel. 1979. Effects of stocking on genetics of wild brook trout populations. Trans. Am. Fish. Soc. 108:227-287.

Leider, S.A. 1989. Increased straying by adult steelhead trout, Salmo gairdneri, following the 1980 eruption of Mount St. Helens. Env. Biol. Fishes 24:219-229.

Leider, S.A., M.W. Chilcote and J.J. Loch. 1984. Spawning characteristics of sympatric populations of steelhead trout (Salmo gairdneri): Evidence for partial reproductive isolation. Can. J. Fish. Aquat. Sci. 41:1454-1462.

Leider, S.A., M.W. Chilcote and J.J. Loch. 1986. Comparative life history characteristics of hatchery and wild steelhead trout (Salmo gairdneri) of summer and winter races in the Kalama River, Washington. Can. J. Fish. Aquat. Sci. 43:1398-1409.

Leider, S.A., P.L. Hulett, J.J. Loch and M.W. Chilcote. In review. Electrophoretic comparison of the reproductive success of naturally spawning transplanted and wild steelhead trout through the returning adult stage. (Provisionally accepted for publication in Aquaculture).

Leider, S.A., J.J. Loch and P.L. Hulett. 1987. Studies of hatchery and wild steelhead in the lower Columbia region. Progress report for fiscal year 1987. Fish. Mgmt. Div. Rep. 87-8. Washington Dept. of Wildlife, Olympia. 130 pp.

Leider, S.A., J.J. Loch and P.L. Hulett. 1989. Studies of hatchery and wild steelhead in the lower Columbia region. Progress report for fiscal year 1988. Fish. Mgmt. Div. Rep. 89-5. Washington Dept. of Wildlife, Olympia. 89 pp.

Lichatowich, J.A. and J.D. McIntyre. 1987. Use of hatcheries in the management of Pacific anadromous salmonids. Am. Fish. Soc. Symposium 1:131-136.

Light, J.T. 1989. The magnitude of artificial production of steelhead trout along the Pacific coast of North America. Doc. FRI-UW-8913 submitted to the International North Pacific Fisheries Commission. Fisheries Research Institute, University of Washington, Seattle. 11 pp.

McMillan, B. 1986. What remains when hatchery steelhead fail? Salmon Trout Steelheader, May 1986:22-29.

McMillan, B. 1989. The hatchery steelhead hoax. Salmon Trout Steelheader, May 1989:3,30-33.

Nickelson, T.E., M.F. Solazzi and S.L. Johnson. 1986. Use of hatchery coho salmon (Oncorhynchus kisutch) presmolts to rebuild wild populations in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 43:2443-2449.

NPPC. 1987. Columbia River Basin Fish and Wildlife Program. Northwest Power Planning Council, Portland Oregon. 246 pp.

Reisenbichler, R.R. 1984. Outplanting: potential for harmful genetic change in naturally spawning salmonids. Pages 33-39 in J.M. Walton and D.B. Houston, editors. Proceedings of the Olympic Wild Fish Conference (Peninsula College, Port Angeles, Washington, March 23-25, 1983).

Reisenbichler, R.R. 1988. Relation between distance transferred from natal stream and recovery rate for hatchery coho salmon. N. Am. J. Fish. Mgmt. 8:172-174.

Reisenbichler, R.R. and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, Salmo gairdneri. J. Fish. Res. Bd. Canada 34:123-128.

Reisenbichler, R.R. and J.D. McIntyre. 1986. Requirements for integrating natural and artificial production of anadromous salmonids in the Pacific northwest. Pages 365-374 in R.H. Stroud, editor. The role of fish culture in fisheries management. Fish Culture Section and Fisheries Management Section, American Fisheries Society, Bethesda, Maryland.

Siitonen, L. and G.A.E. Gall. 1989. Response to selection for early spawn date in rainbow trout, Salmo gairdneri. Aquaculture 78:153-161.

Vincent, E.R. 1984. Effect of stocking hatchery rainbow trout on wild stream-dwelling trout. Pages 48-52 in Wild trout III symposium (Yellowstone National Park, Wyoming, Sept. 24-25, 1984).

Preserve, Protect, and Perpetuate: The Status of Wild Cutthroat Trout Stocks in the West[1]

Patrick C. Trotter[2]

Abstract.--When settlers first headed west, the cutthroat trout was our most abundant native trout. By the early 1970s, its range had shrunk and its numbers had declined so precipitously that ten of the interior forms were proposed for listing under the U. S. Endangered Species Act. Today, three of the interior forms are still listed as threatened under the federal statute and six others are listed either as threatened or as species of special concern under state statutes. Populations of genetically pure wild cutthroat trout may never be restored to historical levels, but renewed interest in preserving, protecting and perpetuating these fishes by fishery management and land use agencies casts their future in a positive light.

INTRODUCTION

The cutthroat trout *Oncorhynchus clarki*, formerly *Salmo clarki*, had the broadest historic distribution of any species of trout in North America (figure 1). It is the *only* trout native to Colorado, Wyoming, Utah, and Alberta, Canada, and was the dominant native species in terms of distribution in Nevada, Idaho, Montana, and perhaps also New Mexico.

In addition to its broad native range, the cutthroat trout is a polytypic species. Four "major" and ten "minor" subspecies have been recognized based on karyotypes, electrophoretic and DNA evidence, and meristic characters (Behnke 1988). Much life history and ecological diversity also exists, even within a subspecies. Cutthroat trout ecotypes often display characters as variable as those commonly found between trout subspecies or even between trout species.

[1]Paper presented at the Wild Trout IV Conference, Mammoth Hot Springs, Wyoming, September 18-19, 1989.

[2]Patrick C. Trotter, Ph.D., is an independent scholar of trout biology residing at 4926 26th Ave. S., Seattle, WA 98108.

Excluding mention of salmon in the early Viking sagas, the cutthroat trout was the first trout recorded by European man in the new world, and was the first trout encountered by Lewis and Clark in their westward explorations. It provided food for the fur trappers, was exploited by miners, railroad builders, and early settlers, and has the distinction (a dubious one at a gathering like this) of being perhaps the first trout to be propagated in a public hatchery.

Abundance and distribution of interior forms of cutthroat trout have declined dramatically since the American west was settled. When the U. S. Endangered Species Act of 1973 was passed, ten interior subspecies were proposed for listing (Anonymous 1973). Three are presently listed as threatened under the federal statute; six others are listed either as threatened or as species of special concern because of low numbers under state statutes.

In this paper, I review the present status and future prospects for wild cutthroat trout populations across the historic range. Emphasis is on genetically pure or essentially pure stocks.

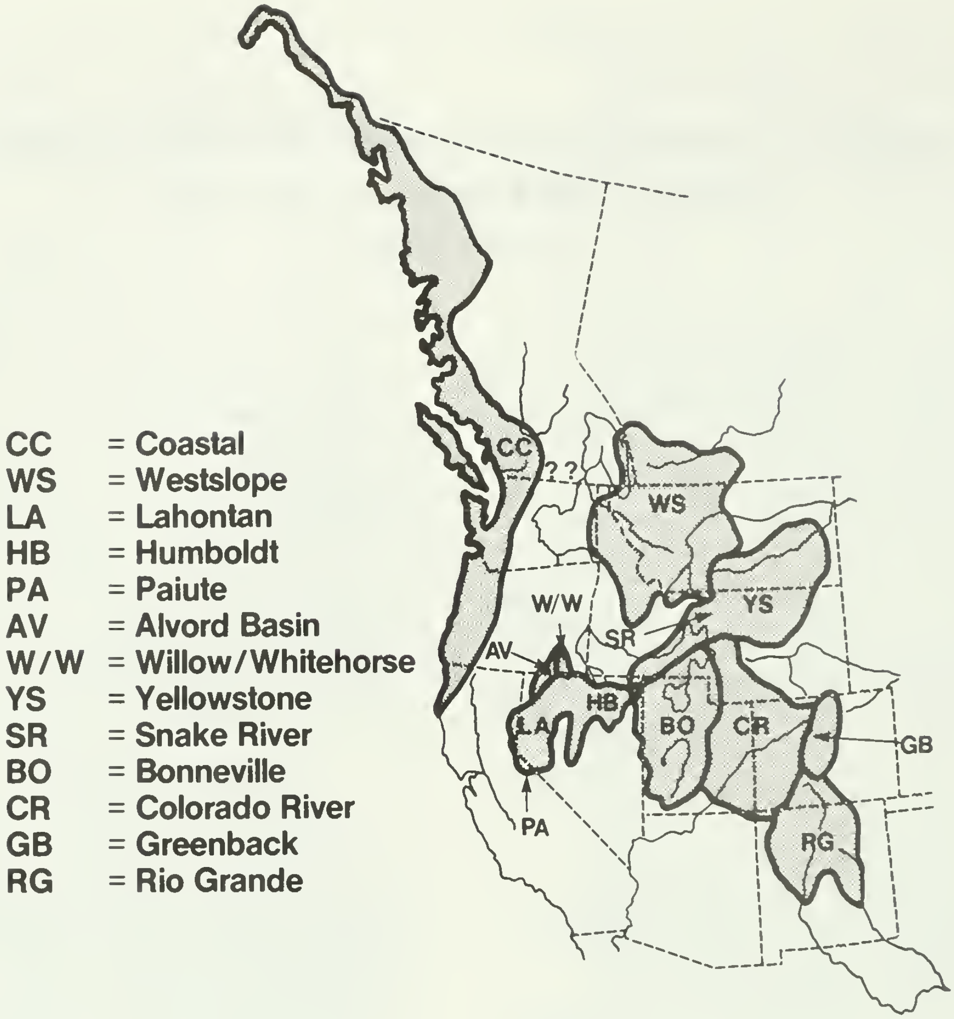


Figure 1.--Historic range of cutthroat trout subspecies in western North America (after Allendorf and Leary 1988).

CUTTHROAT TROUT "FIXES

Coastal Cutthroat Trout

In terms of area, the coastal cutthroat trout O. c. clarki is the most broadly distributed of any of the cutthroat trout subspecies. Its native range extends along the Pacific northwest coast from the Humboldt Bay area of California to Gore Point on the Kenai Penninsula, Alaska (Behnke 1979, 1988), in a band that conforms quite closely with the coastal rainforest belt defined by Waring and Franklin (1979). Several life history forms are found throughout this range, including an anadromous form (Trotter 1989). The coastal cutthroat trout has co-evolved with several other salmonid species (five species of Pacific salmon, steelhead, resident rainbow trout, Dolly Varden charr, and whitefish) and has survived by maintaining niche separation and specialization of habitat use (Hartman and Gill 1968, Behnke 1979).

Behnke (1988) recognizes S. c. clarki as one of the four "major" cutthroat trout subspecies. Its population genetic structure has been studied only a little; Campton and Utter (1987) found that coastal cutthroat trout in north Puget Sound and Hood Canal, Washington are clustered into electrophoretically distinct populations, each occupying a small geographical area that includes only a few adjacent drainages, with little or no gene flow between populations. This would imply that most of the genetic variation in this subspecies is to be found between populations, with little occurring within populations. Thus, to maintain the genetic variation of this subspecies, every population would be important.

It seems to be taken for granted that, in addition to its extensive native range (or perhaps because of it), the coastal cutthroat trout is also the most abundant of the cutthroat trout subspecies. This may well be true, yet there is little solid information to go on. What with the larger and more glamorous steelhead and Pacific salmon present in the same range, the popularity of the coastal cutthroat trout has suffered in comparison, both in the angling press and with the agencies. Thus, it has received low priority and relatively little attention. Consider the following example from the State of Washington. There the searun form does have a small but fiercely loyal following of anglers. Responding to complaints from this group about dwindling numbers, the State of Washington queried its fishery management biologists about the status of populations in their areas (DeShazo 1980). "Unknown" was the response for a big majority of the state's searun cutthroat trout waters; "declining" was the response for a disturbingly high percentage of the rest.

Coastal cutthroat trout abundance does appear to have declined, drastically in many areas. Habitat has been lost to environmental alteration and urbanization. In addition, I think it is probable that efforts of management agencies to boost salmon and steelhead production (to offset severe declines in numbers of those more popular species) by planting millions of fry of those species in habitats formerly occupied only by coastal cutthroat trout or where populations of coastal cutthroat trout were predominate, has disrupted the niche separation so vital to coastal cutthroat trout survival.

Hopefully, the increased appreciation of cutthroat trout, so apparent now in state and federal agency people who deal with the interior forms, will spread to the Pacific states and will lead to more consideration and a higher priority for the coastal subspecies.

Westslope Cutthroat Trout

The westslope cutthroat trout *O. c. lewisi*, the second of the four "major" subspecies recognized by Behnke (1988), was once the dominant trout in a range that encompassed western Montana, central and northern Idaho, a small portion of northwestern Wyoming, southwestern Saskatchewan, southern Alberta, and southeastern British Columbia. The westslope cutthroat trout is the native trout of the upper Columbia and upper Missouri River drainages, and also the upper South Saskatchewan River drainage. The common name implies a range west of the Continental Divide, but a considerable part of the native range is actually on the east side.

Few wild, genetically pure populations of westslope cutthroat trout remain. Likeness (1984, cited in Likeness and Graham 1988) estimated the historic stream range of the westslope cutthroat trout in Montana to be 25,547 km. Of this, 6993 km of streams, or 27.4 % of the state's historic range, still contain cutthroat trout, but nearly three-quarters of these populations have been introgressed. Only 72 genetically pure stream populations of westslope cutthroat trout are now known in Montana, located in 9 river drainages, with the upper Flathead being the largest stronghold. No status information is available from Canada, but Idaho is known to have important stream populations in the middle fork Salmon, north fork Clearwater, Lochsa, Selway, St. Joe, and Coeur d'Alene Rivers.

As for lakes within the historic range, 265 Montana lakes presently contain cutthroat trout populations, but only 22 of these are genetically pure *lewisi*, and 19 of those are located in Glacier National Park.

Glacier National Park is, by and large, the last remaining enclave for lacustrine populations of westslope cutthroat trout in North America, but only sixteen geographically discrete, genetically pure populations are present. These are located in 19 lakes, all within the north fork and middle fork Flathead River drainages (Marnell 1988).

Management biologists in Montana report that they are maintaining their existing westslope cutthroat trout populations and that those populations are holding their own (Likeness and

Graham 1988). In Idaho, steps were taken several years ago, in response to angler surveys, to preserve and protect the wild westslope cutthroat trout populations in that state. Probably every fly fisherman in the country, and most spin fishermen too, knows the Kelly Creek story and how, in the 1970s, establishing a special regulation fishery brought about the marvelous recovery of that wild trout population. Since then, Idaho has expanded its program to include each of its important westslope cutthroat trout rivers. Interestingly, the ever more restrictive regulations under which these fisheries are managed are being urged by the anglers themselves.

In Glacier National Park, that last North American bastion of lacustrine populations of westslope cutthroat trout, the picture does not look so bright. There, population numbers have declined substantially in recent years due, it is thought, to the presence of non-native salmonids in most all of the cutthroat trout lakes (Marnell 1988). Only about 14 % of the lacustrine habitat in the north fork and middle fork Flathead River drainage is free of genetic or ecological disturbance brought about by the introduction or invasion of lake trout, kokanee and lake whitefish, not to mention the widespread introduction over the last 75 years of rainbow trout and Yellowstone cutthroat trout.

From a conservation biology standpoint, each population of westslope cutthroat trout is important. It has been found that almost all of the genetic variation existing within the subspecies occurs between populations and very little exists within populations (Leary et al. 1985).

Lahontan Basin Cutthroat Trout

Behnke (1988) recognizes the Lahontan cutthroat trout O.c. henshawi as one of the four "major" subspecies of cutthroat trout which are separated from one another by large magnitudes of evolutionary divergence. He also proposes that the ancestral Lahontan basin cutthroat trout gave rise to the Paiute cutthroat trout O. c. seleniris, a spotless form isolated in Silver King Creek, California; two additional unnamed subspecies found in the Alvord and Whitehorse basins respectively; and another unnamed subspecies with basically a fluviatile life history that is indigenous to the Humboldt River drainage (Behnke 1988). I will discuss henshawi and the Humboldt River cutthroat trout together here.

When settlers arrived in the Lahontan basin, the native cutthroat trout occurred in at least 6100 km of stream habitat, which included most all of the cooler perrenial streams of the Truckee, Carson, Walker, and Humboldt River drainages, plus streams in the Honey Lake, Smoke Creek Desert, and Black Rock Desert subbasins. Lahontan cutthroat trout also occurred in 135,000 hectares of lakes, including Tahoe, Cascade, Fallen Leaf, Independence, Donner, Pyramid, Winnemucca, Walker, Upper and Lower Twin, and Summit Lakes.

Pyramid, Walker and Tahoe Lakes sustained thriving commercial fisheries during the late 1800s. Pyramid Lake was also known for its very large fish. The world hook-and-line record cutthroat trout (18.6 kg) was caught there in 1920, and an even larger one (estimated at 27.3 kg) was taken in the commercial fishery.

Following European settlement, Lahontan basin cutthroat trout were extirpated to such a degree that the fish was listed as endangered under the U. S. Endangered Species Act of 1973, a status that was changed to threatened in 1975 to facilitate management. Presently, fewer than 100 locations, representing only 7 % of the stream habitat once occupied, are known to contain genetically pure, self-sustaining Lahontan cutthroat trout populations (Gerstung 1988). These are in small, isolated headwater tributaries of the Truckee, Carson, and Walker River drainages on the west side of the basin, and the Humboldt River drainage on the east side of the basin. Genetically pure, self-sustaining lake populations are down to only two: Summit Lake and Independence Lake, and in the latter, there have been less than 100 spawners annually since 1960 (Gerstung 1986).

The States of California and Nevada have drawn up management plans for maintaining and enhancing existing Lahontan cutthroat trout populations, and for establishing new self-sustaining populations within the Lahontan basin (Coffin 1983; Gerstung 1986).[3] These

---

[3] The Summit Lake Paiute Indian Tribe likewise has a management plan for the population in Summit Lake, which lies within its reservation. These plans are supposed to supplement a federal recovery plan, but that plan has evidently not yet been written.

plans assume that distinct races exist in each of these subbasins: Truckee, Carson, Walker, Humboldt, Reese (a Humboldt River tributary), and Quinn Rivers, as well as in Summit Lake. They call for (1) inventorying, monitoring and genetic analysis; (2) reestablishment of self-sustaining populations in former habitats; (3) special angling regulations to protect wild stocks where angling is still allowed; (4) environmental protection and habitat improvement; and (5) artificial propagation and maintanence of populations in the lakes.

Inventorying and genetic analysis have moved along pretty well according to plan. Establishment of new populations has lagged. Twelve fishless streams and some 30 other streams which could be restocked after chemical treatment to remove non-native trout were identified in the Nevada plan (Coffin 1983) and at least 10 streams were targeted in the California plan (Gerstung). But little had been done as of 1987 (Gerstung 1988).

As for environmental protection and habitat improvement, California's wild Lahontan cutthroat trout populations are largely in Wilderness Areas or in areas where widespread habitat alteration is unlikely. This is not the case in Nevada. Water development has impaired or eliminated many Lahontan cutthroat trout waters in that state, and additional losses can be expected. In addition, mining activity is on a "high" right now, and most if not all of this is large-scale surface mining

Figure 2.--Humboldt River form of Lahontan cutthroat trout, Mary's River, Nevada.

accompanied by cyanide leaching. Pollution and siltation of streams as a result of these operations are always potential problems. Nobody, least of all the miners, wants to see dissolved gold leaching back into the ground or into streams. Effective protection measures benefit everybody.

Livestock grazing is another major problem. Both California and Nevada have been active with projects to restore and protect riparian zones. Plans also call for acquisition of key parcels of Lahontan cutthroat trout habitat, but acquisition is always limited by funds available. Both the BLM and the U. S. Forest Service have ownership-consolidation programs which could help by giving priority to exchanges for habitat parcels threatened by adverse development.

Lahontan cutthroat trout are also being introduced into waters well outside their native range. Mann Lake in southeastern Oregon; Omak, Lenore, Grimes, Sprague, Blue and perhaps a few other lakes in eastern Washington; and certain reservoirs in Owyhee County, Idaho are waters too alkaline to sustain other salmonids. These waters have been stocked with Lahontan cutthroat trout to take advantage of this unique aspect of the subspecies' life history. Many of these populations are maintained by stocking, but there are some reports of natural spawning and the development of self-sustaining populations (Washington Department of Wildlife communication, 1989).

Paiute Cutthroat Trout

As already noted, the Paiute cutthroat trout O. c. seleniris probably evolved from an isolated population of Lahontan cutthroat trout in Silver King Creek, a tributary of the east fork Carson River, only a few thousand years ago. The original habitat was probably no more than 9.6 km of stream, from Llewellyn Falls downstream to another barrier falls near the confluence with the east fork Carson River. If it hadn't been for a "coffee can transplant" into fishless water above Llewellyn Falls, made by a sheepherder in 1912, the Paiute cutthroat trout would probably be extinct today (Behnke 1979). The population remaining in the original habitat, where rainbow trout were later introduced, were thoroughly hybridized by the time seleniris was described for science (based on specimens from above Llewellyn Falls) in 1933.

Even in its new sanctuary, the Paiute cutthroat trout has not been secure. In 1949 a mistaken introduction of rainbow trout was made and by 1964 all Paiute cutthroat trout in the Silver King drainage were hybridized except for two small populations located above barriers in tributaries. These have twice been used to reintroduce pure Paiute cutthroat trout into Silver King Creek after chemical eradication of the hybrids, once in 1964 and again in 1976. But in 1986, 15 % of the fish examined again appeared to be hybridized.

The total population of Paiute cutthroat trout stands today at about 500 fish. It is listed as threatened under the U. S. Endangered Species Act of 1973. A recovery plan, written by the U. S. Fish and Wildlife Service (USFWS 1985), calls for (1) reestablishment of a pure population of Paiute cutthroat trout in the waters above Llewellyn Falls---this could likely result in yet another chemical treatment/restocking effort---and (2) securing and maintaining the habitat over a consecutive five year period to insure a stable or increasing overwintering population of at least 500 fish.

Silver King Creek is located in a Wilderness area, but it wasn't always so. The area has been heavily grazed, and livestock use continues. When I visited the area for my book in 1980 (Trotter 1987), the impacts were apparent: caved-in streambanks, riparian vegetation destroyed, areas where the streambed had widened and shallowed, silted-up spawning areas. At that time the Forest Service was not particularly concerned. Now there has been a change of heart. Acknowledging the problem, the grazing program has been revised to greatly lessen the impact (M. D. King, District Ranger, Carson Ranger District toyabe N. F., personal communication 1987). Fenced cattle exclosures have been built and erosion-control measures undertaken in accordance with the recovery plan.

Much of the actual work on these measures has been accomplished by volunteers. Trout Unlimited, the U. S. Forest Service, and Cal Fish and Game have mustered groups of 55-65 people from all across the State of California to trek the 9 or so miles from the trailhead on at least three occasions to do the habitat restoration work and help with population surveys.

With this kind of response and support from the public, the recovery plan goals seem assured.

Yellowstone Cutthroat Trout

The Yellowstone cutthroat trout S. c. bouvieri, Behnke's (1988) fourth "major" cutthroat trout subspecies, is regarded as second only to the coastal cutthroat trout in abundance. Its historic range includes the Yellowstone River drainage in Wyoming and Montana, and the Snake River drainage in Wyoming, Idaho, Nevada, and Utah. All tributaries of the Snake River above Shoshone Falls, Idaho had abundant populations of Yellowstone cutthroat trout (Thurow et al. 1988) except for the main Snake River from the present Palisades Reservoir on the Wyoming-Idaho border to Jackson Lake, Wyoming, where a fine-spotted form of cutthroat trout is indigenous. Behnke (1988) recognizes this form as an unnamed subspecies which most likely arose from a Yellowstone ancestor. Behnke (1988) further proposes that a Yellowstone ancestor also gave rise to the Bonneville basin cutthroat trout, the Colorado River cutthroat trout, the greenback cutthroat trout, and the Rio Grande cutthroat trout, all by the agency of interbasin transfers during the last glacial period.

The Yellowstone cutthroat trout exists in a large assemblage of populations with distinctive life histories, but little electrophoretic distinction. All high-frequency alleles are shared by all populations to about the same degree (Allendorf and Leary 1988).

Within the historic range, the Yellowstone cutthroat trout presently exists in about 38,500 hectares of lakes, including Yellowstone Lake, and about 2400 km of streams. This is about 85 % of the subspecies' original lake habitat, but only 10 % of the original stream habitat (Varley and Gresswell 1988). Introduction of non-native fishes, environmental degradation, and human exploitation have all combined to reduce numbers and distribution, especially of stream-dwelling populations, within the native range. But widespread stocking of this subspecies has established many self-sustaining populations outside the native range.[4]

The Yellowstone cutthroat trout is doing reasonably well within its native range, although there are some trouble spots. Most remaining populations are located in remote headwater areas, many of which are in public ownership (Yellowstone National Park and several National Forests). Early-on, a decision not to intermix different salmonids in Yellowstone National Park helped to preserve the genetic integrety of this subspecies. Plus, the popular and highly successful special regulation fisheries on this subspecies within the park have restored both numbers and age structure of populations to healthy levels.

Outside the park in the Yellowstone drainage, the State of Montana classifies the Yellowstone cutthroat trout as a species of special concern. Here the loss of spawning habitat due to water diversions for agriculture has long been a problem and continues to be (Clancy 1988).

In the Snake River drainage, major indigenous populations still exist in the Blackfoot and Teton Rivers and Willow Creek, as well as in the Snake River itself, but recent surveys (cited in Thurow et al. 1988) document high angling mortality and declining numbers. To offset these declines, Idaho has implemented special regulation fisheries on the Snake and Blackfoot Rivers (IDFG 1986) which are having the desired effect: both total numbers and numbers of larger trout are increasing. Special regulations will no doubt have to be imposed on the Teton River and Willow Creek as well to reverse the declines in those populations.

---

[4]The Yellowstone cutthroat trout, mostly the highly specialized Yellowstone Lake ecotype, was for over 50 years the most commonly introduced cutthroat trout in the world. Eggs went to over half of the United States, most of the Canadian provinces, and to several other foreign countries. Most transplants were failures, but populations did become established in many places. Outside the native range, Yellowstone cutthroat trout hybridized with other cutthroat trout subspecies and is commonly blamed for the decline in genetic integrety of these other forms.

Bonneville Cutthroat Trout

The Bonneville Basin occupies an area of about 14 million hectares, mostly in northern and central Utah, but including bits of eastern Nevada, southeastern Idaho, and southwestern Wyoming. Ancient Lake Bonneville occupied about 5 million hectares of that back in Ice Age time. The Great Salt Lake and Utah Lake are remnants of ancient Lake Bonneville. Major river drainages in the basin today are the Bear, Ogden, Weber, Provo, and Sevier Rivers.

The Bonneville cutthroat trout S. c. utah is the only trout endemic to the Bonneville Basin, and despite the arid nature of the region, was once present in great abundance (Hickman 1978). It was an important source of food for Indians around Utah Lake and the Provo River. European settlers utilized it for food as well, and operated extensive commercial fisheries at both Utah Lake and Bear Lake. The Bonneville cutthroat trout may also have been the first trout reared in a public hatchery, that being the Salt Lake City hatchery in 1872 (Stone 1874).

But as the region developed, the Bonneville cutthroat trout suffered a catastrophic decline. In fact, not so long ago it was believed to be extinct (Sigler and Miller 1963).

What brought about the rapid decline? Physical alteration of habitat by livestock grazing, mining, road building, and irrigation diversions was certainly one factor. But perhaps the most detrimental factor was the indiscriminant introduction of nonnative trouts, particularly rainbow trout, into virtually every stream in the Bonneville basin capable of supporting trout, whether native trout were present or not (Duff 1988). Replacement and hybridization of the native trout populations took place on a large scale.

Today, only 41 populations of pure Bonneville cutthroat trout remain, 39 of these in headwater stream habitat and 2 in lakes (Duff 1988). The two lake populations are in Lake Alice, Wyoming and Bear Lake, Utah/Idaho (for a review of the status and management of the Bear Lake population, see Nielsen and Lentsch 1988). These populations fall into three slightly differentiated groups (Behnke 1979) associated with the Bonneville Basin proper (Jordan, Provo, Weber, and Sevier River drainages), the Snake Valley region on the western edge of the Bonneville Basin, and the Bear

River drainage in the northwestern corner of the basin.

The U. S. Fish and Wildlife Service regards the Bonneville cutthroat trout as a candidate for threatened status under the U. S. Endangered Species Act of 1973, but has decided not to recommend listing it as long as management agencies continue to negate threats to its existence (USFWS 1987). So what advances are being made? A state by state rundown of programs reveals the following.

Idaho. In addition to the Bear Lake population, Idaho has three pure stream populations in headwater tributaries of the Bear River in Caribou National Forest. The main effort here is to revise grazing systems to improve stream and riparian habitat. There are no plans to establish new populations.

Wyoming. Wyoming has 7 pure populations in about 28 km of headwater streams in the Bear River drainage. Four other stream populations may be essentially pure by a subjective rating system developed by Binns (1977) based on Behnke's work with meristic characters. There is also a genetically pure population in 93-hectare Lake Alice. These are cooperatively managed by the Wyoming Game and Fish Department, Bridger-Teton National Forest and the BLM. All agencies are active with stream habitat rehabilitation projects, and grazing management programs are also in place. A broodstock program is also in place to provide fish for eventual reintroduction programs

Nevada. Five genetically pure populations have been identified on the west side of the basin. Three of these are actually outside the basin and were probably established by early transplants. As in Wyoming, grazing on National Forest and BLM lands is being controlled to limit damage, and habitat improvement projects are being carried out to repair past damage. Nevada has a plan to eradicate nonnative trout from a half-dozen other streams in order to reintroduce Bonneville cutthroat trout. In addition, public responses to the new Great Basin National Park General Management Plan favor reintroduction of Bonneville cutthroat trout into all suitable Park waters.

Utah. Utah has 21 pure Bonneville cutthroat trout populations. Twenty of these occupy 151 km of headwater stream habitat on National Forest and BLM land. Plus, there is the Bear Lake population. The Utah Division of Wildlife Resources

Figure 3.--Bonneville cutthroat trout, Salt Creek, Wyoming. Photo by N. Allen Binns, Wyoming Game and Fish Department.

has a management plan (although it has yet to be formalized) that calls for introduction of pure stocks into six additional streams and two reservoirs. The latter will be used for broodstock for additional (unspecified) management programs.

In summary, although wild Bonneville cutthroat trout presently exist in small, isolated, widely distributed populations and some of these populations may still be threatened by one problem or another, the likelihood that any specific action or catastrophe will endanger a major part of the subspecies' current distribution is not great. That, plus the agencies' newfound resolve to preserve existing populations, search for additional populations, establish new ones within the basin, and stop stocking nonnative trout in Bonneville cutthroat trout waters, makes for a bright future for wild stocks of this subspecies.

Colorado River Cutthroat Trout

Maps of the historic range of the Colorado River Cutthroat trout O. c. pleuriticus are usually drawn to extend continuously downstream from the headwaters of the Colorado River basin (which includes the Green River drainage) to encompass the Dirty Devil River drainage, Utah on the west, and the San Juan River drainage on the east. In actuality, the historic distribution was a discontinuous one, because the Green River below the town of Green River, Wyoming and the Colorado River below Glenwood Springs were too warm and turbid for cutthroat trout. Therefore, the trout inhabited only the colder waters of the mountain and foothill zones on either side of the basin (Behnke 1979, Behnke and Benson 1980).

As was the case with the Bonneville cutthroat trout, early settlers found native cutthroat trout in great numbers in all suitable waters of the Colorado River basin (Behnke and Benson 1980). And again, by 100 years later, pure populations of the native subspecies were virtually gone.

Here again, although habitat degradation and loss to other land uses has to be included as a factor, the main causal agent seems to be the indiscriminate introduction of nonnative trouts. In mainstem river habitats. pleuriticus populations were totally replaced. This happened in the upper Colorado, the upper Green, the Gunnison, the Roaring Fork, and the Yampa Rivers. Elsewhere, hybridization occurred. Populations of cutthroat trout resembling pleuriticus could still be found, but in only about 1 % of pleuriticus' original range, and even these were hybridized. In 1976 only two small headwater populations out of many examined could be called wholly pure based on meristic characters and the absence of evidence of their habitats ever having been stocked with nonnative trouts (Behnke and Zarn 1976). Although the Colorado River cutthroat trout was proposed, it was never listed as either endangered or threatened under the U. S. Endangered Species Act of 1973. However it was classified as threatened in Colorado by the Colorado Wildlife Commission.

Since 1977, Colorado and Wyoming fishery managers have used the relative purity ranking system developed by Binns (1977) to evaluate and judge the purity of Colorado River cutthroat trout populations.[5] By 1985, they believed they had either discovered or restored at least 20 stable A-populations (the highest purity rating in the Binns system) within the historic range, and so, that year, Colorado reclassified this trout from threatened to a species of special concern.

However recent work reported by Martinez (1988) indicates that pleuriticus may yet be in jeopardy in Colorado. Her data indicate a continued decline and tenuous existence of Colorado's pure pleuriticus populations. To reverse this, Martinez (1988) recommended isolating them above barriers to preclude introgression or replacement by nonnative trouts; establishing fly-and-lure-only catch-and-release angling regulations; continued monitoring to detect any further changes in distribution, abundance, purity status, and available habitat; and getting agreements with land-use agencies to restore damaged habitat and prevent further degradation. She also called for removing nonnative salmonids from sites of historic distribution and reintroducing pure pleuriticus stocks (Martinez 1988). However, to accomplish those reintroductions, Colorado may need to develop a suitable broodstock. With this in mind, several hundred specimens of pleuriticus from Williamson Lake, California were recently returned to Colorado (they had gotten to California in the first place back in 1931 when fertilized eggs from Trappers Lake, Colorado were planted there). Martinez (1988) believes that progeny from these fish may be the purest existing Colorado River cutthroat trout available for reintroduction.

About half of the native range of the Colorado River cutthroat trout is in Utah. There the clear priority is on the Bonneville cutthroat trout, but even so the (unwritten) management plan does provide for identifying and protecting native pleuriticus stocks and managing such populations as refugia, and, eventually, replicating local stocks into nearby waters to establish new populations (Bruce R. Schmidt, Utah Division of Wildlife Resources, personal communication, 1989).

Greenback Cutthroat Trout

The native range of this subspecies, O. c. stomias, is the mountains and foothills of the South Platte and Arkansas River drainages. The greenback cutthroat trout is the only trout native to these drainages, except for the now-extinct yellowfin cutthroat trout that was found in Twin

---

[5] Hybridization of pleuriticus with rainbow trout can now be recognized by electrophoresis as well as by meristic character examination, but electrophoresis does not detect hybridization with Yellowstone or Snake River cutthroat trout, the two other nonnative trouts widely stocked in the Colorado River basin (Allendorf and Leary 1988).

Lakes, Colorado, in the Arkansas River drainage. The nearby North Platte drainage never had a native trout (Behnke 1979).

Again we have a case where early literature (cited in Behnke and Zarn 1976) portrays a relative abundance of the native trout, and a precipitous decline in numbers after European settlers populated the area. Again, the reasons are the same: habitat alteration and loss to competing land uses, and yet again, the widespread introduction of nonnative trouts (Behnke and Zarn 1976). Here we have another instance where the native subspecies was believed to be extinct (Greene 1937), but subsequently five populations, judged to be pure by the Binns system criteria (Binns 1977), were discovered in isolated headwater reaches. The subspecies was listed as endangered under the U. S. Endangered Species Act of 1973, but that was changed to threatened in 1978 to facilitate management.

The most recent recovery plan for the greenback cutthroat trout (USFWS 1983) calls for an interagency effort between the Colorado Division of Wildlife, the Fish and Wildlife Service, the U. S. Forest Service, the BLM, and the National Park Service, to get the greenback cutthroat trout off the endangered species list by the year 2000. The subspecies will no longer be considered threatened when there are at least 20 pure, stable, naturally reproducing populations distributed throughout its historic range.

The five remnant populations of greenback cutthroat trout referred to above occupy four streams totalling 13 km, and one 5 hectare lake. These are closed to angling and are managed as refugia. To date, reintroductions have been made into 12 streams totalling 64 km and 5 lakes totalling 20 hectares, and 7 of these populations have now stabilized, meaning they are reproducing naturally and have developed multiple age classes (Stuber et al. 1988). When a reintroduction is made and that population stabilizes, it may be opened to angling under catch-and-release regulations. As of 1988, angling is allowed on three such populations, and it is anticipated that seven additional waters will be opened over the next five years.

Rio Grande Cutthroat Trout

The Rio Grande cutthroat trout *O. c. virginalis* is endemic to the upper Rio Grande basin in Colorado and northern New Mexico, and to the upper Pecos River drainage in New Mexico (Behnke 1979). Like other interior cutthroat trout subspecies, *virginalis* has been extirpated from nearly all of its native range during the past 100 years through habitat loss to conflicting land uses and widespread introduction of non-native trouts that either hybridized with the native species or, outcompeted and replaced them.

The Rio Grande cutthroat trout is another of the interior cutthroat trout subspecies that was proposed, but never listed under the U. S. Endangered Species Act of 1973. It was, however, listed as threatened in Colorado until recently, and is now considered a species of special concern in both Colorado and New Mexico (Johnson 1987). State of New Mexico and U. S. Forest Service personnel have identified 39 genetically pure populations of Rio Grande cutthroat trout in New Mexico streams (Stefferud 1988), and the State of Colorado has at least 10 stable, self-reproducing populations in streams on public lands.

Management plans for the Rio Grande cutthroat trout read pretty much the same as plans for other interior forms. The New Mexico plan, for example, calls for (1) protecting existing populations by not stocking nonnative trout where *virginalis* is present and by constructing barriers to isolate populations where nonnative trout are already present (fewer than one-third of the known *virginalis* streams in New Mexico presently have such barriers); (2) restoring pure *virginalis* populations in streams with suitable habitat (this will probably be a low-priority item until substantial progress on item 1 is made); (3) surveying for additional pure populations; (4) habitat protection and enhancement; and (5) artificial propagation and broodstock development to provide progeny for reestablishing self-reproducing populations (New Mexico Department of Game and Fish 1987). The state's management program has been incorporated into resource management plans of the Santa Fe and Carson National Forests where the Rio Grande cutthroat trout is now used as an indicator species (Stefferud 1988).

In addition to these activities, Native Americans are interested in restoring the Rio Grande cutthroat trout. Streams on the Mescalero Reservation are to be stocked with progeny from a broodstock being developed by the Fish and Wildlife Service based on trout native to reservation drainages (Stefferud 1988).

CONCLUSIONS

Behnke (1972) once estimated that at least 99 % of the original populations of interior cutthroat trout have been lost since the American west was settled. Populations of the coastal subspecies, especially the anadromous form, may have declined substantially as well (DeShazo 1980), although here we have no good baseline numbers. That is the bad news.

The good news is, management agencies are showing renewed interest in wild native trouts. At the state level, Wild Fish Management Policies have been adopted by several western states (Washington, Oregon, California, Utah, Nevada, Idaho and Montana are examples) which give special consideration to native forms. The federal land management agencies have mandates to protect and preserve unique forms in areas under their jurisdiction, and the cutthroat trout has been made an indicator species for the health of aquatic habitat in several National Forest management plans, notably the Carson and Santa Fe National Forests in New Mexico and the Humboldt National Forest in Nevada. In addition, the U. S. Forest Service, the BLM, and now the Bureau of Reclamation, have signed agreements with Trout Unlimited providing for habitat improvement activities that should benefit wild native cutthroat trouts.

Figure 4.--Rio Grande cutthroat trout, Placer Creek, Colorado.

It is unlikely that wild cutthroat trout abundance will ever again approach historic levels. Too much habitat has gone to other uses, and too many quality populations of introduced trouts have been established. But if the plans outlined here for preserving, protecting, and perpetuating the wild native cutthroat trouts can be brought to fruition, these fishes should remain a permanent part of our western heritage.

LITERATURE CITED

Allendorf, F. W. and R. F. Leary. 1988. Conservation and distribution of genetic variation in a polytypic species, the cutthroat trout. Conservation Biology 2 (2): 170-184.

Anonymous. 1973. Threatened wildlife of the United States. U. S. Bureau of Sports Fisheries and Wildlife Resource Publication 114.

Behnke, R. J. 1972. The rationale of preserving genetic diversity: example of the utilization of intraspecific races of salmonid fishes in fisheries management. Proceedings of the annual conference, Western Association of Fish and Wildlife Agencies 52: 559-561.

Behnke, R. J. 1979. Monograph of the native trouts of the genus Salmo of western North America. USDA Forest Service, U. S. Fish and Wildlife Service, and Bureau of Land Management. Denver, Colorado.

Behnke, R. J. 1988. Phylogeny and classification of cutthroat trout. American Fisheries Society Symposium 4: 1-7.

Behnke, R. J. and D. E. Benson. 1980. Endangered and threatened fishes of the upper Colorado River basin. Fort Collins,Colorado, Colorado State University, Cooperative Extension Service Bulletin 503A.

Behnke, R. J. and M. Zarn. 1976. Biology and management of threatened and endangered western trouts. USDA Forest Service general Technical Report RM-28. Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station.

Binns, N. A. 1977. Present status of indigenous populations of cutthroat trout, Salmo clarki, in southwest Wyoming. Cheyenne, Wyoming, Wyoming Game and Fish Department Fisheries Technical Bulletin 2.

Campton, D. E., Jr. and F. M. Utter. 1987. Genetic structure of anadromous cutthroat trout (Salmo clarki clarki) populations in the Puget Sound area: evidence for restricted gene flow. Canadian Journal of Fisheries and Aquatic Science 44: 573-582.

Clancy, C. G. 1988. Effects of dewatering on spawning by Yellowstone cutthroat trout in tributaries of the Yellowstone River, Montana. American Fisheries Society Symposium 4: 37-41.

Coffin, P. D. 1983. Lahontan cutthroat trout fishery management plan for the Humboldt River drainage basin. Reno, Nevada Department of Wildlife, Federal Aid in Fish Restoration Project F-20-17.

DeShazo, J. 1980. Searun cutthroat status report 1980. Olympia, Washington Department of Game.

Duff, D. A. 1988. Bonneville cutthroat trout: current status and management. American Fisheries Society Symposium 4: 121-127.

Gerstung, E. R. 1986. Fishery management plan for Lahontan cutthroat in California and Nevada waters. Sacramento, California Department of Fish and Game.

Gerstung, E. R. 1988. Status, life history, and management of the Lahontan cutthroat trout. American Fisheries Society Symposium 4:93-106.

Greene, W. S. 1937. Colorado trout. Denver Museum of Natural History, Popular Series 2.

Hartman, G. F. and C. A. Gill. 1968. Distribution of juvenile steelhead and cutthroat trout (Salmo gairdneri and S. c. clarki)within streams in southwestern British Columbia. Journal of the Fisheries Research Board of Canada 25:33-48.

Hickman, T. J. 1978. Systematic study of the native trout of the Bonneville basin. Master's thesis Colorado State University, Fort Collins.

IDFG. 1986. Idaho fisheries management plan 1986-1990. Boise, Idaho Department of Fish and Game.

Johnson, J. E. 1987. Protected fishes of the United States and Canada. Bethesda, Maryland, American Fisheries Society.

Jones, R. D. 1987. The Yellowstone experience: a decade of catch-and-release. pp 94-99 in Barnhart, R. A. and T. D. Roelofs, editors, Catch-and-release fishing: a decade of experience. Arcata, California, Humboldt State University.

Leary, R. F., F. W. Allendorf, S. R. Phelps and K. L. Knudson 1985. Population genetic structure of westslope cutthroat trout: genetic variation within and among populations. Proceedings of the Montana Academy of Sciences 45: 37-45.

Likeness, G. A. and P. J. Graham. 1988. Westslope cutthroat trout in Montana: life history, status, and management. American Fisheries Society Symposium 4: 53-60.

Marnell. L. F. 1988. Status of the westslope cutthroat trout in Glacier National Park, Montana. American Fisheries Society Symposium 4: 61-70.

Martinez, A. M. 1988. Identification and status of Colorado River cutthroat trout in Colorado. American Fisheries Society Symposium 4: 81-89.

New Mexico Department of Game and Fish. 1987. Operation plan: aquatic management of New Mexico wildlife, 1987-1995. Santa Fe.

Nielson, B. R. and L. Lentsch. 1988. Bonneville cutthroat trout in Bear Lake: status and management. American Fisheries Society Symposium 4: 128-133.

Rankel, G. L. 1976. Fishery management program, Summit Lake Indian Reservation, Humboldt County, Nevada. Reno, Nevada, U. S. Fish and Wildlife Service, Division of Fishery Services.

Sigler, W. F. and R. R. Miller. 1963. Fishes of Utah. Salt Lake City, Utah Department of Fish and Game.

Stefferud, J. A. 1988. Rio Grande cutthroat trout management in New Mexico. American Fisheries Society Symposium 4: 90-92.

Stone, L. 1874. Catalog of natural history specimens collected on the Pacific slope in 1872 by Livingston Stone for the United States Fish Commission. Report of the U. S. Fish Commissioner 1872-73: 200-215.

Stuber, R. J., B. D. Rosenlund and J. R. Bennett. 1988. Greenback cutthroat trout recovery program: management overview. American Fisheries Society Symposium 4: 71-74.

Thurow, R. F., C. E. Corsi and V. K. Moore. 1988. Status, ecology, and management of Yellowston cutthroat trout in the upper Snake River drainage, Idaho. American Fisheries Society Symposium 4: 25-36.

Trotter, P. C. 1987. Cutthroat: native trout of the west. Boulder, Colorado Associated University Press.

Trotter, P. C. 1989. The coastal cutthroat trout: a life history compendium. Transactions of the American Fisheries Society. (In press).

U. S. Fish and Wildlife Service. 1983. Greenback cutthroat trout recovery plan. Denver, Colorado, Greenback Cutthroat Trout Recovery Team.

U. S. Fish and Wildlife Service. 1985. Paiute cutthroat trout recovery plan. Portland, Oregon, U. S. Fish and Wildlife Service.

U. S. Fish and Wildlife Service. 1987. Interagency Bonneville cutthroat conference, summary report. Salt Lake City, U. S. Fish and Wildlife Service.

Varley, J. D. and R. E. Gresswell. 1988. Ecology, status, and management of the Yellowstone cutthroat trout. American Fisheries Society Symposium 4: 13-24.

Wareing, R. H. and J. F. Franklin. 1979. Evergreen coniferous forests of the Pacific Northwest. Science 204: 1380-1386.

Chinook Salmon in Oregon Coastal River Basins: A Review of Contemporary Status and the Need for Fundamental Change in Fishery Management Strategy[1]

Jay W. Nicholas[2] and David G. Hankin[3]

ABSTRACT

Despite an extended period during 1930-60 when the run of chinook salmon to the majority of Oregon coastal river basins declined to a small fraction of the level experienced around 1900, aggregate contemporary return to these basins is at a level unprecedented during the last century and is composed primarily of wild fish. A great deal of diversity exists in heritable life history traits of the stocks of chinook salmon produced in Oregon coastal rivers. The organized, adaptive genetic diversity contained in discrete stocks is simultaneously a valuable commodity for contemporary resource users and a priceless heritage for the future. Rather than being the product of a coherent management plan, the generally positive status of this species has accrued as a result of (1) a decades-long healing of natural production habitats, (2) recent control of exploitation rates in oceanic, mixed stock fisheries, (3) unusually favorable survival in the ocean, and (4) a relatively conservative artificial propagation program. Future strategic approaches to habitat, harvest, and hatchery management should focus on individual stocks, rather than on the species, as the unit of management.

INTRODUCTION

Prior to exploration of the region by Europeans, chinook salmon *Oncorhynchus tshawytscha* were probably present in all but the smallest Oregon coastal river basins. Today, these river basins are by no means in pristine condition; aquatic and riparian habitats in tributary, mainstem, and estuarine reaches of these basins have been changed dramatically from the condition that existed before the region was colonized by white settlers (Sedell and Luchessa 1981). Nevertheless, populations of wild chinook salmon are present today, with rare exception, throughout their native range in Oregon coastal river basins (Figure 1). Many, if not all, of these Oregon coastal river basins support distinct stocks of chinook salmon in subbasins or distinct stream reaches.

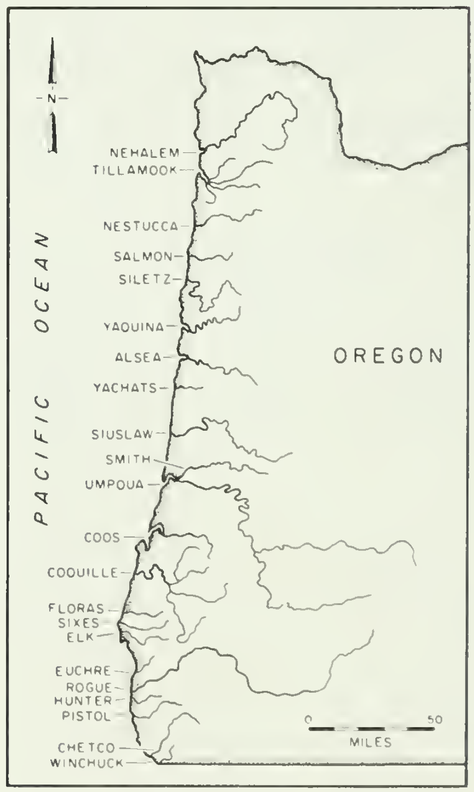


Figure 1. Map of Oregon coast showing coastal river basins that support chinook salmon.

---

[1] Paper presented at Wild Trout IV [Yellowstone National Park, September 18-19, 1989].

[2] Jay W. Nicholas is a fishery research biologist with the Oregon Department of Fish and Wildlife, Corvallis, Oregon.

[3] David G. Hankin is a Professor of Fisheries, Humboldt State University, Arcata, California.

Chinook salmon were harvested by native Americans and settlers for food and were the primary target for commercial fisheries in the late 1800s and early 1900s (see for example McGuire 1894, 1896, 1898; Smith 1979). Concern over the effect of commercial harvest and habitat degradation on production of salmon inspired the development of both private and public hatchery programs in the late 1800s and early 1900s (see for example Hume 1893; Reed 1901). Although chinook salmon were an important economic commodity and were the focus of management activity, only the most cursory efforts to document life histories and abundance of these wild populations were undertaken (see for example McGuire 1896; Rich 1920).

During the 1930s, 1940s, and 1950s, however, many chinook salmon stocks in Oregon coastal rivers were "seriously depleted" when compared with circa 1900 levels (Hodges 1948). Aggregate freshwater commercial landings of chinook salmon from Oregon coastal rivers declined rapidly from an annual level of about 150 thousand in the mid-1920s to about 20 thousand in the late 1940s, a decline that partly reflected the depressed status of many individual stocks (Gharrett and Hodges 1950, Cleaver 1951). Concern over the effect of the terminal net fishery on the runs of salmon entering coastal rivers led to the complete elimination of the fishery by 1961.

For example, the commercial catch of chinook salmon in the Umpqua River ranged from 11 to 19 thousand fish during the 1920s (Cleaver 1951), but the run entering the river declined to about 4 or 5 thousand fish during the 1940s (Fish Commission of Oregon and Oregon State Game Commission 1946). Similarly, commercial catch of chinook salmon in the Alsea River was often 10-14 thousand fish during 1896-1920 (Cobb 1930), but the run entering the river was only about 5 thousand fish in 1951 (Morgan and Cleaver 1954). As a final example, from 15 to 39 thousand chinook salmon were packed in commercial canneries on the Coos River during 1895-87 (Cobb 1930), but by the 1950s the run entering the river had declined so much that surveyors had difficulty locating spawners in the basin (personal interview on 4 September 1989 with Alan McGie, Oregon Department of Fish and Wildlife, Research and Development Section, Corvallis, Oregon). Although data are not available to estimate the number of chinook salmon that returned to the majority of Oregon coastal river basins during the 1930-60 period, we surmise that the return of chinook salmon to individual Oregon coastal river basins was on the order of 10%-50% of the circa 1900 level.

A variety of data are available to characterize the contemporary status of Oregon coastal chinook salmon stocks. Collectively, this information paints a very favorable picture; just last year people were calling 1988 "the year of the chinook." What a headline story this would make. After decades of data analysis, planning, and execution, a fishery management agency has restored the Oregon coastal chinook salmon resource to surpass historic levels of abundance! Is this a tremendous success story for scientific resource management? Actually, the contemporary status of Oregon coastal chinook salmon stocks is more the product of good fortune, circumstance, and decades-long healing of natural production habitat than the result of an explicit management program. The recent surge in production of chinook salmon in Oregon coastal river basins, a surge that can be attributable almost entirely to production of wild fish, was entirely unexpected.

REVIEW OF CONTEMPORARY RESOURCE STATUS

Natural Production Habitat

Contemporary land uses in most coastal river basins are dominated by (1) forestry-related activities in headwater areas; (2) agricultural and residential developments in mainstem floodplain areas; and (3) light to intense commercial-industrial, residential, and recreational development in estuarine areas. In contrast with other regions in the Pacific Northwest, relatively few dams presently exist on Oregon coastal rivers; major exceptions include the Rogue and Umpqua rivers.

Quantitative databases are scant and analyses of historic habitat trends in Oregon coastal river basins are rare. Interviews with coastal management district biologists indicated that the general condition of habitat in most coastal river basins has improved between 1960 and the present, partly because of legislation that encourages generic protection of aquatic habitat. A second factor cited as contributing to the recent recovery of habitat in coastal river basins was that many of the basins were logged or damaged by fire during the late 1800s and early 1900s. Consequently, these areas have not been the focus of recent timber harvest activity. In contrast, land use practices in many relatively small river basins from about Floras Creek south have apparently caused significant changes in aquatic habitats during the last two or three decades; these changes have destabilized fish production habitats (Hankin et al. 1986).

Stock Diversity

Oregon coastal chinook salmon exhibit diversity in many aspects of their juvenile, marine, and adult life histories. Although some phenotypic expression of stock characteristics is influenced by environment, much phenotypic expression reflects genetic distinctions among stocks. For example, season of return to the natal stream, date of spawning, oceanic migration pattern, mean age at maturation, fecundity, egg size, and resistance to certain disease organisms are heritable traits that differ among Oregon coastal chinook salmon stocks (Nicholas and Hankin 1989a). In addition, we believe that differences in the life history strategies of juvenile chinook salmon may also represent heritable stock characteristics (Nicholas and Hankin 1989b).

Oregon coastal chinook salmon stocks can be categorized in relation to three major stock characteristics: oceanic migration pattern, age at maturity, and season of return. Generally, Oregon coastal chinook salmon stocks exhibit either a northern or a southern migration tendency in their oceanic residence, and return to their natal streams in either the spring or the fall. Oregon coastal stocks have been provisionally classified as exhibiting an early, mid, or late maturation (Nicholas and Hankin 1989a). Age three females are relatively common in early maturing stocks, but are rare in late maturing stocks. Mid to late maturing, north-migrating stocks are present in the ocean off the west coast of Vancouver Island and southeast Alaska. Early to mid maturing, south-migrating stocks are present in the ocean off northern California and southern Oregon (Figure 2).

Abundance

Lichatowich (1989) concluded that the contemporary production potential of chinook salmon from Oregon coastal rivers is similar to actual production around the turn of the century. Although Lichatowich (1989) suggested that circa 1900 production of chinook salmon in Oregon coastal river basins may have already been substantially reduced from pristine levels, we were at first surprised by his analysis. To satisfy our curiosity on this matter, we have constructed estimates of circa 1900 abundance, using alternate assumptions deliberately designed to yield a more liberal estimate than the one developed by Lichatowich (1989). The historic record regarding abundance of chinook salmon in individual river basins is sparse. Consequently, the use of alternate assumptions may lead to different estimates of historic levels of salmon production. We set out to apply liberal yet intuitively defensible assumptions and see whether we could generate a higher number than Lichatowich (1989) for circa 1900 production of chinook salmon from Oregon coastal river basins.

Lichatowich (1989) developed his estimate by applying an assumed harvest rate of 40% to the aggregate estimated number of chinook packed in all Oregon coastal commercial canneries, using the estimated values for the 5 peak years between 1893 and 1920. Our liberal estimate of circa 1900 chinook salmon production involved the following steps. First, we examined estimates of the number of chinook salmon packed on individual rivers during 1892-1922 and calculated an average peak value for each river basin using the highest values, regardless of whether the "high pack" years consisted, for example, of 3 or of 10 years during the period of interest. Second, we used values from 1923-30 in order to obtain a higher value than was estimated during 1892-1922 on two river basins, because anecdotal information suggested that the number of chinook salmon packed on these streams in the earlier period did not accurately reflect abundance (e.g., access to rail transportation favored sale of fresh fish). Third, we assumed that a harvest rate of 33% applied to runs of chinook salmon that entered these individual river basins would have yielded the peak average numbers of fish in the estimated cannery pack. Finally, we developed estimates for the runs of chinook salmon entering several small coastal rivers that did not have canneries; the return of chinook salmon to these river basins was not represented by the cannery pack records. These estimates were subjective and were based on our perceptions of historic production potential of individual river basins in relationship to

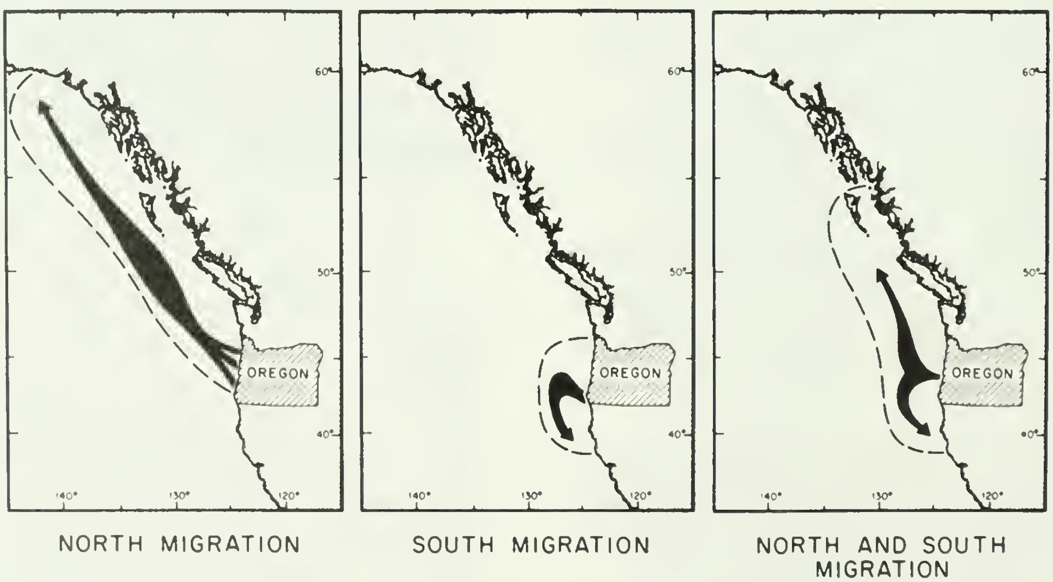


Figure 2. Illustration of general oceanic migration patterns exhibited by stocks of chinook salmon produced in Oregon coastal river basins.

contemporary estimated production in Elk River and Sixes River. Using this approach, we surmise that the aggregate annual run of chinook salmon in Oregon coastal streams may have ranged from the 305 thousand estimated by Lichatowich (1989), up to about 600 thousand fish.

We estimated that aggregate annual return of chinook salmon to Oregon coastal rivers during 1977-85 was about 210 thousand fish (Nicholas and Hankin 1989a). Estimated contemporary (1986-88) return of chinook salmon to coastal river basins is about 420 thousand fish (Table 1). Even at modest harvest rates in oceanic fisheries, this probably represents production (ocean catch plus return to the river) of about 1 million chinook salmon.

Estimates of the contemporary production of chinook salmon from Oregon coastal river basins thus range from a theoretically derived value of 482 thousand fish (Lichatowich 1989) to about 1 million fish. Estimates of circa 1900 production range from 305 thousand fish (Lichatowich 1989) to about 600 thousand fish. We conclude that production of chinook salmon from aggregate Oregon coastal rivers is as strong or stronger than it has been during the past 100 years.

We believe that many factors have helped the majority of Oregon coastal chinook salmon stocks recover to at least the circa 1900 level of production. We have not attempted nor do we know how to estimate the proportion of contemporary production that may be attributable to individual factors. Factors that have contributed to the recovery of individual stocks include:

1. Elimination of commercial gillnet fisheries in coastal river basins, a phase out that was complete in most basins by the late 1950s.
2. Recovery of freshwater rearing capacity in the northern coastal region damaged by a series of extensive forest fires that occurred during the 1930s.
3. Legislation that established rules to control in-stream habitat alterations (e.g., gravel removal and culvert construction).
4. Legislation that provided standards for habitat protection in connection with timber harvest.
5. A hatchery enhancement program that emphasized the use of a modest number of native stock smolts released at times designed to reduce competition with wild fish.
6. Recent restrictions of oceanic harvest rates designed to protect depressed stocks of chinook salmon in regions outside Oregon.
7. An oceanic environment that has been favorable to survival of chinook salmon during the years immediately following the 1982-83 El Nino.

Four cautionary notes are necessary postscripts to an assertion that aggregate production of chinook salmon in Oregon coastal rivers is presently at a historic high level of abundance. First, as Lichatowich (1989) noted, circa 1900 production of chinook salmon may have been depressed compared to pristine levels, because the stocks and their natural production habitats had been actively exploited since the mid 1800s. Second, almost all stocks of south-migrating, fall-run chinook salmon supported by small river basins have experienced severe declines in abundance since the late 1970s (Table 2). Unlike the south-migrating stocks supported by larger river basins such as the Umpqua River,

Table 1. Estimated contemporary abundance of chinook salmon returning to Oregon coastal river basins and hatchery-wild composition of runs (from Nicholas and Hankin 1989a).

		Estimated		
Oceanic migration, run-timing	Number of river basins	Total return to river[a]	Number of hatchery fish	Percent hatchery fish
North-migrating:				
Fall-run	19	194,000	19,000	10
Spring-run	6	10,000	5,000	50
South-migrating:				
Fall-run	7	109,000	10,000	9
Spring-run	3	109,000	53,000	49

[a] *The values shown here represent sums of the most contemporary available estimates in the source document (i.e., either for the period 1986-88 or for the period 1977-85 if more recent values are not available). The values for the following stocks were not explicit in the source document but are included here as 1986-88 averages: North Umpqua (south-migrating) spring-run, 14,000 (60% wild); Rogue (south-migrating) fall-run, 100,000 (95% wild); Rogue (south-migrating) spring-run, 95,000 (50% wild).*

Table 2. Contemporary run-strength classifications for chinook salmon populations in Oregon coastal river basins (from Nicholas and Hankin 1989a).

Oceanic migration, run-timing	Number of river basins	Number of river basins in which chinook salmon stocks are classified as--		
		Depressed	No trend	Increasing
North-migrating:				
Fall-run	19	1	8[a]	10
Spring-run	6	3	3	0
South-migrating:				
Fall-run	7	6[b]	1[a]	0
Spring-run	3	1	2[a]	0

[a] *Individual stocks assigned to this category may be reclassified as demonstrating an increasing trend if the high run sizes experienced in 1986-88 continue.*

[b] *Small tributaries to the Rogue River support distinct stocks of fish, but for accounting purposes were tallied as a single basin in this category.*

Rogue River, and Applegate River, the stocks in small river basins have not made dramatic recoveries since 1985. Third, three of the six north-migrating, spring-run stocks supported by short-reach coastal rivers have declined to what we consider to be remnant levels (Table 2), and aggregate return to these six river basins is less than 10 thousand chinook salmon, about 50% of which are hatchery fish. Even though the return of fall-run chinook salmon to these same coastal rivers has demonstrated a long-term increasing trend (McGie 1981; Nicholas and Hankin 1989a), the runs of spring-run fish to these same rivers have fluctuated around historically depressed levels. Finally, a few otherwise healthy chinook salmon stocks are presently producing relatively few fish compared to circa 1900 numbers.

Fisheries

Oregon coastal chinook salmon are caught in commercial and recreational oceanic fisheries from central California through Alaska (Figure 2) and in freshwater recreational fisheries when they return to their home stream. The freshwater recreational catch of adults (age 3 and older fish only) averaged about 40 thousand fish annually from 1977 to 1985, and was about 64 thousand fish annually during 1986 and 1987. Estimates of the catch of jack (age 2 males) chinook salmon in freshwater recreational fisheries are not available, but these fish make a substantial contribution to fisheries during the early part of the seasonal runs in many coastal rivers. Oregon landings of ocean-caught chinook salmon (not all of which were Oregon produced stocks) were at historic high levels during 1986-88, and averaged about 470 thousand fish annually.

Oregon ocean fishery landings of chinook salmon were apparently dominated by fish from three river basins during 1979-86: the Rogue River in Oregon and the Sacramento and Klamath rivers in California (in order of descending representation). The aggregate numerical contribution of Oregon coastal chinook salmon stocks to oceanic fisheries has not been estimated. Strong contemporary returns of north-migrating fall-run stocks, in concert with data on distribution of catch in the ocean suggest that these stocks, collectively, are important to fisheries off British Columbia and Alaska. Likewise, south-migrating stocks of chinook salmon produced in the Rogue River basin, in particular, are important to fisheries off California. Modest fishery contributions from many numerically small stocks of wild chinook salmon all along the Oregon coast may help stabilize catch.

Oceanic catch of Oregon chinook salmon stocks off northern California and southern Oregon is currently constrained by catch quotas and seasonal closures established through the Pacific Fisheries Management Council that are designed to limit annual ocean exploitation rate of Klamath River fall-run chinook salmon. Oceanic catch of Oregon chinook salmon stocks off Alaska, British Columbia, and Washington is currently constrained by catch quotas designed to permit rebuilding of certain depressed chinook salmon stocks identified for protection under the Pacific Salmon Treaty. At present however, no restrictions of oceanic fisheries have been established specifically to provide increased escapement of Oregon coastal chinook salmon stocks.

Hatchery Production

Historically, few hatchery enhancement programs involving salmon have included marking programs designed to estimate the proportion of hatchery and wild fish in freshwater fisheries, in hatchery returns, or on spawning grounds. At least three major problems are associated with the failure to routinely mark hatchery fish and monitor the hatchery-wild composition of "supplemented" runs. First, it is difficult to recognize situations in which the hatchery fish are surviving poorly or are not surviving at all. Second, it is difficult to detect a decline in the production of wild fish in a system that is periodically dominated by a possibly large but unknown proportion of hatchery fish. Finally, routine hatchery supplementation without routine evaluation conveys an implicit assumption that all hatchery programs are effective, and that the effects of releasing hatchery fish are all positive. The third problem is ultimately the most serious because it prevents timely detection and revision of ineffective or counter-productive hatchery programs, and it places the entire production system (consisting of both hatchery and wild fish) at risk.

During the last decade, fewer than half of Oregon coastal river basins have been supplemented with hatchery fish. To overcome lack of sampling programs to estimate hatchery-wild ratios in most of these river basins, we made provisional estimates of the proportion of hatchery fish in contemporary returns of chinook salmon (Nicholas and Hankin 1989a). We estimated that contemporary returns of fall-run fish have been about 303 thousand fish, including about 10% hatchery fish; contemporary returns of spring-run fish have been about 119 thousand fish, including about 49% hatchery fish (Table 1). Contemporary runs of chinook salmon that return to Oregon coastal river basins are thus composed predominantly of wild fish; the favorable condition of aggregate chinook salmon production in the area is not an artifact of hatchery production.

THE NEED FOR FUNDAMENTAL CHANGE IN FISHERY MANAGEMENT STRATEGY

Future challenges to maintaining diverse, abundant chinook salmon populations will be virtually the same as were historically faced by fishery managers: (1) preventing attrition of natural production habitat, (2) preventing overharvest of individual stocks, and (3) preventing disruption of organized "units" of genetic diversity. Future management programs for chinook salmon should focus on the stock, rather than the species, as the management unit (see also Rich 1939; Ricker 1972). We believe that such a shift in management focus will be necessary because of increasing or cyclic demands that will soon be placed on the fishery resource.

For example, diverse groups will compete for land and water essential to the maintenance of fish production habitat in coastal rivers and estuaries. Many coastal river basins that were logged or burned extensively at various times during the first part of the century have now become reforested and will soon be entering a second harvest cycle. Constraints on ocean harvest rates during recent years are certain to come under assault, and escalation of harvest rates in mixed-stock fisheries may once again place many individual chinook salmon stocks at risk (Ricker 1963). Finally, the continued depressed state of hatchery and wild coho salmon *Oncorhynchus kisutch* stocks in Oregon coastal river basins, together with the recent favorable condition of chinook salmon stocks has recently fostered a renewed interest in artificial propagation involving chinook salmon. The fervor to increase production of hatchery chinook salmon during the last few years is reminiscent of the 1890-1940 period, when ineffective hatchery programs probably contributed to the decline of many wild chinook salmon stocks.

On the whole, traditional fishery management programs for anadromous salmonids suggest that the stock concept (Ricker 1972) is not relevant to the practical conduct of fishery management. As a case in point, a recent letter stating Oregon's position on a proposed forest management plan indicates support for management that will not "result in extinction of any salmon *species* in the (Siskiyou) forest" (Letter to F. Dale Robertson dated 31 August 1989 from Melinda L. Bruce, Oregon Department of Justice, Natural Resources Section, Salem, Oregon). The failure of fishery management programs to appreciate the full extent and ecological importance of between- and within-stock diversity is demonstrated by generally inadequate or haphazard provisions (1) to conserve existing stock diversity, and (2) to foster the persistence and continued evolution of stock diversity. For example:

1. Freshwater harvest regulations in Oregon tend to be relatively uniform over large geographic regions, despite stock characteristics that justify differences.

2. Harvest rates in the ocean on mixed stocks reached levels likely to cause stock collapse for extended periods of years without adequate corrective measures being taken (Fraidenburg and Lincoln 1985). This has resulted in placing relatively less productive stocks at risk of being numerically and genetically impoverished (Nelson and Soule 1987).

3. Transfer of stocks has frequently been permitted in Oregon (ODFW 1982, 1986; Nicholas and Hankin 1989a) in spite of the associated genetic risks (Altukhov and Salmenkova 1987; Nelson and Soule 1987; Nicholas and Hankin 1989b).

4. Traditional hatchery programs have generally not incorporated available genetic principles in broodstock management practices (Allendorf et al. 1987).

5. Hatchery release procedures traditionally have focused primarily on attempts to maximize survival of the hatchery product, regardless of biological risks to wild populations.

6. Few hatchery programs have included provisions to monitor the hatchery-wild ratio of adults in freshwater fisheries and spawning populations.

7. Procedures do not currently exist to identify local stream reaches that are especially important to wild stocks, or to provide an extraordinary level of protection to these critical habitats.

7. Adequate procedures do not currently exist to promptly identify depressed, threatened, or endangered salmonid stocks in Oregon; to determine probable causes for such declines; or to propose ecologically sound remedies.

8. Explicit decisions have not been made as to whether all stocks or merely a subset of contemporary stocks of salmon in Oregon merit preservation.

In order to remedy existing deficiencies in traditional fishery resource management programs, all ongoing habitat, harvest, and artificial propagation management programs should be reviewed to determine if they are consistent (1) with conserving the great diversity of chinook salmon stocks supported by Oregon coastal river basins, and (2) with maintaining the present high level of wild chinook salmon production in the region.

Strategic Approaches to Habitat Management

We expect that more and more conflict will occur over whether to hold firm on existing land-use zoning and habitat protection guidelines. Some will wish to develop more areas whereas others will lobby to protect the same areas from development. Presently available data are not sufficient to determine how much development, or what kinds of habitat alterations are good, bad, or indifferent to production of juvenile chinook salmon. Much greater use of quantitative habitat inventory and life history data will be needed in the future to justify continued protection and restoration of aquatic habitat for fish production. Quantitative databases that will permit assessment of rearing capacities for various fish species, identification of critical limiting factors, and detection of long term changes in the productive capacities of the habitats need to be assembled.

Will the Oregon climate change during the next century? Expert opinions include predictions of significant warming, cooling, drying, and increase in rainfall. During the last four decades, chinook salmon stocks in the Oregon coastal ecosystem have experienced extended periods of strong upwelling, extended periods of weak upwelling, two strong El Ninos (1957-59 and 1982-83), a severe drought year (1976), two severe flood events (1955 and 1964), and a shift in the timing of severe flood events during the typical spawning season (Frissell and Hirai 1989). The best strategic approach to habitat management in light of the very real prospect of dramatic climate change is to emphasize holistic, watershed-focused habitat management that will conserve the greatest possible resiliency of natural production systems.

Strategic Approaches to Harvest Management

The harvesting power of commercial and recreational salmon fishers far exceeds the sustainable productive capacity of existing natural and hatchery production systems. This disparity will require development of decisive measures to limit harvest rates in oceanic fisheries in the future. Government programs to limit mixed-stock fishery exploitation rates by limiting participation in the fisheries have generally been ineffective (McEvoy 1986; Shaw and Muir 1987). However, we believe that the growing cost of managing harvest quotas will eventually precipitate social pressure to reduce commercial fishing fleets such that the cost of managing fisheries will be moderated and harvest rates can be maintained at levels low enough to sustain all but the weakest salmon stocks. Recreational harvest in freshwater terminal fisheries should be tailored to the productivity of individual stocks and, in concert with cumulative oceanic harvest, must be restricted to limit brood-year exploitation rate to an acceptable level for each stock.

Strategic Approaches to Hatchery Programs

A variety of artificial propagation technologies have been available to assist fisheries management programs in the Pacific Northwest for at least a century. However, the record of salmon hatcheries in the Pacific Northwest, from their inception to the present day, includes a disappointing assortment of short-lived successes, spectacularly unpredictable variability, and complete failures. The time is ripe to revise the ecologically naive management philosophies and operational practices that have typified the vast majority of hatchery programs. Two decades of experience managing wild and hatchery populations of chinook salmon in Elk River (Oregon) provide many practical examples of operational procedures that can be used to improve survival and contribution of hatchery fish, commensurate with a peremptory objective of preserving a wild population (Nicholas and Downey 1989).

A sustainable contribution by artificial propagation to stock conservation efforts and to fisheries will require significant changes from typical hatchery operational procedures. We recommend the following changes as a minimum:

1. Native stocks of chinook salmon should be the basis for artificial propagation programs in every coastal river basin.

2. Decentralized rearing facilities (rather than centralized hatcheries that outplant fish to more than one stream) should be the basis for artificial propagation.

3. Artificial propagation programs should be based on the release of a comparatively modest number of fish and tailored to be ecologically compatible with specific natural production systems.

4. Written operational plans should be prepared to guide maintenance of effective population size and guard against loss of genetic diversity in artificially propagated populations.

5. Written operational plans should be prepared to guide breeding practices designed to buffer selective effects of oceanic fisheries that depress average age of maturation.

6. Written operational plans should be prepared to guide breeding programs that select date of return and date of spawning of the hatchery stocks.

7. A sufficient proportion of all hatchery fish should be marked so that their contribution to freshwater fisheries and to spawning populations may be reliably monitored.

8. Hatchery programs should be modified as may be necessary to minimize straying of hatchery fish.

9. Hatchery programs should be modified as may be necessary to minimize competition between hatchery and wild juveniles.

CONCLUDING REMARKS

We do not see any easy answers or quick fixes to the complex process of conserving a fishery resource that is simultaneously a valuable commodity and a priceless heritage. The challenge is to develop new ways to do what is collectively referred to as "fishery management." We believe that these new approaches will, in many respects, amount to starting over with new philosophical and operational approaches to habitat, harvest, and hatchery management.

The Oregon Department of Fish and Wildlife is in the enviable position of being able to place primary management emphasis on attempts to conserve, rather than rehabilitate coastal chinook salmon. The central theme of these efforts should include substantial new efforts to describe and conserve stock units. Attempts to increase production over contemporary levels should focus first on stabilization and restoration of the most severely depressed stocks. Responsible strategic approaches to management of this resource should minimize risk of events that could jeopardize either the contemporary or future sustenance of diverse wild stocks.

Unfortunately, risk avoidance for fishery managers involves conflicting interests because managers are as vulnerable to political "damage" as fish stocks are vulnerable to biological damage. Fishery managers often choose to take action calculated to avoid political risk rather than action to avoid biological risk. This happens because managers are subject to immediate consequences of political risk taking, whereas natural resources, per se, do not punish managers for risk taking or reward managers for risk avoidance. Actions designed to avoid long-term biological risk (e.g., constraining exploitation rates in mixed stock fisheries, protesting against habitat-degrading land-use practices, insisting that hatchery programs be compatible with wild stocks) are likely to result in immediate political consequences for a fishery management agency. Consequently, government administrators may prefer actions designed to avoid immediate political risks (e.g., allowing escalation of mixed stock exploitation rates, taking compromising positions regarding habitat protection, giving in to demands for expanding hatchery programs) despite the long-term biological risks associated with the actions.

Given our personal belief that natural resources belong as much to future generations as to our own, the optimum strategy for management of chinook salmon in Oregon coastal rivers seems clear: (1) the natural production base of numerous, diverse wild stocks must be sustained and nurtured, (2) aquatic habitat must be maintained in suitable condition to support wild stocks, (3) harvest rates must be constrained at moderate levels that will allow maintenance of a great number of wild stocks, and (4) artificial propagation programs must be managed so that they do not erode the genetic distinctions that exist within and between stocks and so that they add to (rather than replace) natural production.

ACKNOWLEDGEMENTS

We thank Wayne Burck, Alan Hemmingsen, James Lichatowich, and Alan Mcgie for their timely critical review of this work; their comments greatly improved the manuscript.

REFERENCES

Allendorf, F.W., N. Ryman, and F.M. Utter. 1987. Genetics and fishery management: past, present, and future. Pages 1-20 *in*: N. Ryman and F.W. Utter, editors. Population genetics and fishery management. University of Washington Press, Seattle.

Altukhov, Y.P., and E.M. Salmenkova. 1987. Stock transfer relative to natural organization, management, and conservation of fish populations. Pages 333-344 *in*: N. Ryman and F.W. Utter, editors. Population genetics and fishery management. University of Washington Press, Seattle.

Cleaver, F.C. 1951. Fisheries statistics of Oregon. Fish Commission of Oregon, Contribution 16, Portland.

Cobb, J.N. 1930. Pacific salmon fisheries. United States Bureau of Fisheries, Report of the U.S. Commercial Fisheries, 1930, Document 1092.

Fish Commission of Oregon and Oregon State Game Commission. 1946. The Umpqua River Study. Portland.

Fraidenburg, M.E., and R.H. Lincoln. 1985. Wild chinook salmon management: an international conservation challenge. North American Journal of Fisheries Management 5:311-329.

Frissell, C., and T. Hirai. 1989. Life history patterns, habitat change and productivity of fall chinook salmon stocks of southwest Oregon. Pages 85-94 *in* B.G. Shepherd, rapporteur. Proceedings of the 1988 Northeast Pacific Chinook and Coho Salmon Workshop. North Pacific International Chapter American Fisheries Society, Penticton, British Columbia.

Gharrett, J.T., and J.I. Hodges. 1950. Salmon fisheries of the coastal rivers of Oregon south of the Columbia. Fish Commission of Oregon, Contribution 13, Portland.

Hankin, D., T. Downey, A. Mirati, R. Riikula, L. Wagoner, and G. Westfall. 1986. Chinook salmon in Oregon's south coast: stock status report. Oregon Department of Fish and Wildlife, Portland. (Unpublished manuscript.)

Hodges, J.I. 1948. Salmon catch by the sport fishery in certain Oregon coastal rivers. Fish Commission of Oregon Research Briefs, 1(2):16-20.

Hume, R.D. 1893. Salmon of the Pacific Coast. Reprinted in 1975 by the Curry County Historical Society, Port Orford, Oregon.

Lichatowich, J.A. 1989. Habitat alteration and changes in abundance of coho (Oncorhynchus kisutch) and chinook (O. tshawytscha) salmon in Oregon's coastal streams. Pages 92-99 *in* C.D. Levings, L.B. Holtby, and M.A. Henderson, editors. Proceedings of the national workshop on effects of habitat alteration on salmonid stocks. Canadian Special Publication Fisheries Aquatic Sciences 105, Ottawa.

McGie, A.M. 1981. Trends in escapement and production of fall chinook and coho salmon in Oregon. Oregon Department of Fish and Wildlife, Information Reports (Fish) 81-7, Portland.

McEvoy, A.F. 1986. The fisherman's problem: Ecology and law in the California Fisheries, 1850-1980. Cambridge University Press, New York.

McGuire, H.D. 1894, 1896, 1898. First, second, third, fourth, fifth, and sixth annual reports of the Fish and Game Protector to the Governor, 1893-1898. Portland, Oregon.

Nelson, K., and M. Soule. 1987. Genetical conservation of exploited fishes. Pages 345-365 *in* N. Ryman and F.W. Utter, editors. Population genetics and fishery management. University of Washington Press, Seattle.

Nicholas, J.W., and T.W. Downey. 1989. Looking back at two decades of work at Elk River Hatchery: Has there been harmony between the natural and artificial production systems, and has Elk River been an example of a conservation hatchery? Oregon Department of Fish and Wildlife, Portland. (Unpublished manuscript.)

Nicholas, J.W., and D.G. Hankin. 1989a. Chinook salmon populations in Oregon coastal river basins: description of life histories and assessment of recent trends in run strengths. Oregon Department of Fish and Wildlife, Information Reports (Fish) 88-1, second edition. (Printed by Oregon State University Extension Service, Catalog Number EM 8402, Corvallis).

Nicholas, J.W. and D.G. Hankin. 1989b. Variations in distribution of juvenile chinook salmon in Oregon coastal river basins: Implications to future stock transfer practices. Pages 189-196 *in* B.G. Shepherd, rapporteur. Proceedings of the 1988 Northeast Pacific Chinook and Coho Salmon Workshop. North Pacific International Chapter American Fisheries Society, Penticton, British Columbia.

ODFW (Oregon Department of Fish and Wildlife). 1982. Comprehensive plan for production and management of Oregon's anadromous salmon and trout. Part II. Coho salmon plan. Oregon Department of Fish and Wildlife, Portland.

ODFW (Oregon Department of Fish and Wildlife). 1986. Comprehensive plan for production and management of Oregon's anadromous salmon and trout. Part III. Steelhead management plan. Oregon Department of Fish and Wildlife, Portland.

Reed, F.C. 1901. Annual reports of the Department of Fisheries of the State of Oregon, 1899-1900. Portland.

Rich, W.H. 1920. Early history and seaward migration of chinook salmon in the Columbia and Sacramento rivers. U.S. Bureau of Fisheries Bulletin 37 (Document 887).

Rich, W.H. 1939. Local populations and migration in relation to the conservation of Pacific salmon in the western states and Alaska. Fish Commission of Oregon, Contribution 1, Portland.

Ricker, W.E. 1963. Big effects from small causes: Two examples from fish population dynamics. Journal of the Fisheries Research Board of Canada 20:257-64.

Ricker, W.E. 1972. Hereditary and environmental factors affecting certain salmonid populations. Pages 19-160 *in* R.C. Simon and P. Larkin, editors. The stock concept in Pacific salmon. H.R. MacMillan Lectures in fisheries, University of British Columbia, Vancouver.

Sedell, J.R. and K.J. Luchessa. 1981. Using the historical record as an aid to salmonid habitat enhancement. Proceedings of a Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. Western Division of American Fisheries Society.

Shaw, S., and J.F. Muir. 1987. Salmon: Economics and marketing. Timber Press, Portland, Oregon.

Smith, C.L. 1979. Salmon fisheries of the Columbia. Oregon State University Press, Corvallis.

Effects of Fire on Aquatic Systems[1]

James K. Brown[2]

Abstract.--Fire affects spawning areas and food habitat in streams by indirectly influencing waterflow, nutrients, erosion, sedimentation, debris, and water temperature. The response of vegetation following fire is the most important factor affecting aquatic areas. Effects of fire on aquatic systems vary over time tending to be detrimental at first but often beneficial later.

INTRODUCTION

The effects of fire on aquatic systems can vary greatly. Aquatic systems can be harmed or benefited by fire. The effects often differ over short and long periods. To understand fire's effects on aquatic life including trout, it is important to appreciate fire's natural role and how ecosystems are shaped by the interaction of fire, vegetation, soil, and climate. Variability in these factors leads to a number of outcomes affecting aquatic life.

THE ROLE OF FIRE

First, consider characteristics of fire: intensity, severity, size, and frequency. Intensity is the amount of heat liberated during flaming from a given area per unit time. A common expression is btu per second for a 1-foot wide swath through the flaming fire front. Intensity describes upward heat transfer and relates to mortality of aboveground vegetation. Severity refers to the overall effect of fire on biological systems and accounts for heat transferred downward into the soil. Severity is rated by amount of organic matter consumed and mortality to vegetation (Ryan and Noste 1985). The size of fires and their frequency of occurrence are also important characteristics of fire.

Fire effects fall into two categories: first and second order effects. First order effects are the immediate results of fire and include mortality of vegetation, consumption of live and dead vegetation including soil organic matter, changes in soil nutrients and physical properties, and production of smoke. Second order effects occur over time and involve changes to resources such as recovery of vegetation, water flow, wildlife, and aquatic life.

Forests, woodlands, and grasslands evolved in the presence of fire. Charcoal deposits found during fossil pollen studies in lakes and bogs indicated that fire has occurred repeatedly since the last glaciation (Mehringer 1985). Lightning probably always has been present in our atmosphere and has been a consistent source of fires. Historical narratives show that Indian-set fires were also a major contributor to recurrent fire on western landscapes (Gruell 1985). Plants have long existed in a fire environment as evidenced by their reproduction after fires and survival of some individuals during fires (Heinselman 1978). Some plants and plant communities are actually dependent on periodic fire for survival.

Plants are adapted to survive fire in many ways. For example, many herbaceous plants and shrubs sprout from buds lying beneath the soil. Some trees such as lodgepole pine (*Pinus contorta*) release seed from cones that require fire to open them. A few plants deposit seeds on the ground that require heating by fire to break the impervious seed coat. Others cast many seeds to the wind that can travel great distances.

The concept of fire regimes is useful for describing the general nature of fires and fire effects. Fire regimes are formed by a classification of the intensity, severity, frequency, and patterns of fires that occurred

---

[1]Paper presented at the Wild Trout IV Symposium. [Yellowstone National Park, Mammoth Wyo., September 18-19, 1989].

[2]James K. Brown is project Leader of the Fire Effects and Prescribed Fire research unit at the Intermountain Research Station, Intermountain Fire Sciences Laboratory, Forest Service, U.S. Department of Agriculture, Missoula, Mont.

naturally without fire suppression in a particular area or ecosystem. Fire regimes include: (1) frequent, low-intensity surface fires, (2) infrequent low-intensity surface fires, (3) infrequent high-intensity surface fires, (4) short interval, stand replacement fires, (5) frequent low-intensity surface fires and long return interval, stand replacement fires, and (6) very long return interval, stand replacement fires (Kilgore 1981). Frequent, low-intensity fires probably have little effect on aquatic systems. However, infrequent stand replacement fires may have major effects because they are usually of high intensity and high severity. Fire regimes vary by vegetation type.

Consider fire's role more specifically, keeping in mind that different vegetation types are associated with different fire regimes. Fire initiates many biological and physical processes. Most visibly perhaps, it renews plant succession by killing varying amounts of aboveground vegetation and stimulating regeneration of young plants. New species may appear for a period of time, then disappear as they are replaced by other species through succession. Fire creates patterns on the landscape by forming a mosaic of different vegetation age classes and plant communities. The diversity of plant communities and age classes provides suitable habitat for a wide variety of wildlife species.

Fire recycles accumulations of dry matter. As time passes, needles, leaves, branches, tree boles, and other plant parts fall to the ground and become part of the forest floor and surface fuel. In many conifer ecosystems, more dry matter is produced than can be decomposed by fungi and bacteria (Bray and Gorham 1964). Cool and dry climates favor dry matter accumulation over decay.

Periodic fire converts the dry matter to ash and smoke. Fire compresses the decay process into a short period, but the products are similar chemically (Wright and Bailey 1982). Significant amounts of nitrogen can be volatilized and lost to the atmosphere. However, over time, nitrogen is replenished in the soil by nitrogen-fixing plants and rainfall. The ash contains a wealth of plant nutrients including forms of nitrogen that are immediately available for plant growth. Available nitrogen is absorbed by regenerating plants, especially grasses and forbs that respond rapidly after fire. Some nutrients may enter the ground water and stream water by passing through the soil or flowing overland depending on the ability of soil to retain nutrients and the nature of rainfall events.

Fire can be a regulator of insects and diseases because they are interrelated. For example, in short interval, low-intensity fire regimes such as in ponderosa pine (Pinus ponderosa) forests, periodic fire maintains an open stand of vigorous trees. If fire is excluded, the understory thickens with regenerating fir trees. As the forest continues to grow, stress on individual trees increases making them susceptible to insect attack by defoliators such as western spruce budworm (Choristoneura occidentalis) and tussock moth (Orgyia pseudotsuga) (Arno 1988). In wilderness areas, unnatural exclusion of fire could allow extensive accumulation of fuel resulting in large, intense wildfires and unnatural effects. Periodic fire disturbance appears necessary to maintain species diversity, productivity, and long-term ecosystem stability (Heinselman 1978).

AQUATIC SYSTEMS

How does all of this relate to aquatic systems and fisheries? Fundamentally, fire indirectly influences the flow of water in streams, substances carried in the water, and water temperature. In turn, these factors affect spawning areas and food-producing habitat that account for the primary influence of fire on fish populations. The extent of these effects depends on fire characteristics; weather; site characteristics such as vegetation, soil, and landform; and distance from the fire.

High-intensity and high-severity fires potentially can have the greatest effect because vegetation is usually changed substantially. Fire's effect on vegetation is probably the most important relationship influencing aquatic systems. The kind and amount of vegetation and how quickly it regenerates after fire directly influences streamflow, sedimentation, stream nutrients, and water temperature. Small streams and streams in youthful landscapes with steep terrain are the most sensitive to fire disturbance (Everest and Harr 1982; Swanson 1981).

The effects of fire on aquatic systems must be viewed over short, intermediate, and long periods (Minshall et al. 1989). Recovery from some fire effects is rapid while other effects are long lasting.

Stream Temperature

High-intensity fires can remove streamside vegetation and shading, thus causing water temperatures to rise. The amount of temperature rise depends on extent of water exposed and streamflow rate. Temperature may increase only a few degrees up to 12 °C or more (Tiedemann 1981). Temperature increase is less in streams with high flow rates (Everest and Harr 1982). Large streams and rivers may experience little temperature rise due to fire.

Higher temperatures decrease water's capacity to hold oxygen and increase the faunal demand for oxygen. Thus, dissolved oxygen supply is reduced. An increased incidence of fish disease may result and fish production may decrease (Lyon et al. 1978). Detrimental effects of increased temperature tend to be short-lived as streamside vegetation recovers. In normally cool environments such as high elevation mountain areas, increased temperatures may not reach the detrimental threshhold, and, in fact, may be beneficial. For example, following fires in Yellowstone Park, slightly warmer stream temperatures were correlated with earlier trout fry emergence, increased macroinvertebrates, and higher fish productivity (Albin 1979).

Streamflow

Increased streamflows can be expected where most or all of the aboveground vegetation is killed because interception and evapotranspiration are reduced and sometimes overland flow is increased (Swanston 1980). Both peak flows following snowmelt and rain storms and late summer flows will be increased. Generally, these increases are temporary and may disappear within 5 years (Everest and Harr 1982). The return to prefire stream flows depends primarily upon the rate of revegetation. Increased streamflow is important because of the sediment, debris, and nutrients that it brings to the stream and subsequent erosion and reshaping of the channel that might occur.

Nutrients

Nutrient concentrations commonly increase in streams following severe fire that liberates nutrients tied up in vegetation and the forest floor. Nutrients leached from the ash may be transported to the stream (Swanston 1980). In low-severity fires, available nutrients may be captured in the soil or by new vegetation, and never reach the stream in significant amounts. Concentrations of nutrients are seldom toxic (Wright and Bailey 1982). However, little is known about the effects of nutrient levels on fish productivity. Increased nutrients may enhance algae production, which in turn appears to sustain a greater biomass and diversified population of insect larvae (Fredriksen et al. 1975). But changes in nutrient levels after fire may be inadequate to increase production of algae and macroinvertebrates (Lotspeich et al. 1970)

Erosion and Sedimentation

The greatest impact of fire on fish habitat results from erosion and sedimentation. In comparison, other effects are usually minor (Everest and Harr 1982). The potential for erosion is greatest in granitic and sedimentary soils because the soil particles are easily detached and moved by the action of water. Steep slopes increase the risk of erosion. Movement of sediment into streams can occur by hill and gully erosion, which transports the most sediment to streams and by sheet erosion from splash of raindrops. Streamside vegetation plays a critical role in filtering sediment from the stream. If streamside vegetation is removed, the filter is temporarily lost and streambank erosion may occur. Sparsely vegetated riparian areas are more vulnerable to erosion.

Sediment in streams may reduce the area of suitable spawning gravels or deposit fine material that smothers eggs, prevents emergence of fry, and reduces preferred food species (Lyon et al. 1978). The process of scouring out channels and depositing sediment creates a new arrangement of gravels and sand. This is not necessarily damaging and in some cases may result in a net improvement to fish habitat (Swanston 1980).

Rate of recovery depends on redevelopment of vegetation and associated reduction in surface runoff. Sediment impacts on habitat may be greatly reduced within 1 year and full recovery achieved within 3 years (Hecht 1982). In steep areas exposed to rapid snowmelt and when infiltration capacity is low--for example, the Absaroka Mountain Range in the Yellowstone ecosystem--significant recovery may take 3 to 10 years (Christensen et al. 1989).

The amount of sedimentation and rate of recovery to prefire conditions depends partly on fire severity and the area burned within a watershed. High-severity fires consume the protective forest floor layer of matted needles, leaves, stems, and other dead fallen debris. Several years are required for this material to be replaced. Severe fires favor revegetation by plants sprouting from seeds and perenniating buds below the soil surface (Morgan and Neuenschwander 1988). If plant species capable of surviving severe fires are sparsely distributed before fire, revegetation will proceed slowly the first few years after fire.

Debris

High-intensity fire in forested areas creates large woody debris that helps stabilize soil movement on slopes. Some tree boles and other debris reach stream channels. Stream currents are changed at the point of accumulation (Brown 1974). Generally, woody debris creates habitat diversity that improves rearing potential of anadromous fish (Everest and Harr 1982) and provides survival cover. Woody debris also provides a source of nutrients for aquatic life. Debris dams trap organic matter that increases abundance of macroinvertebrates (Smock et al. 1989). However, excessive accumulations may bury good spawning sites and damage habitat during major storm flush outs (Brown 1974). But over long periods, the benefits of fire generated debris probably outweigh damaging aspects.

LITERATURE CITED

Albin, Douglas P. 1979. Fire and stream ecology in some Yellowstone Lake tributaries. California Fish and Game. 65:216:238.

Arno, Stephen F. 1988. Fire ecology and its management implications in ponderosa pine forests. p. 133-139. In Baumgartner, David M. and James E. Lotan, eds. Ponderosa pine--the species and its management, symposium proceedings. [Spokane, Wash., September 29-October 1, 1987] Washington State University, Cooperative Extension, Pullman, Wash.

Bray, J. R. and E. Gorham. 1964. Litter production in forests of the world. p. 101-157. In Advances in Ecological Research 2. Academic Press, New York.

Brown, George W. 1974. Fish habitat. Environmental effects of forest residues management in the Pacific Northwest, a state-of-knowledge compendium. USDA Forest General Technical Report PNW-24, 15 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Christensen, Norman L., James K. Agee, Peter F. Brussard, and others. 1989. Ecological consequences of the 1988 fires in the Greater Yellowstone Area. Final report from the Greater Yellowstone Postfire Ecological Assessment Workshop; [Denver, Colo., November 18-20, 1988]. 58 p.

Everest, Fred H. and Dennis R. Harr. 1982. Influence of forest and rangeland management on anadromous fish habitat in western North America silvicultural treatments. USDA Forest Service General Technical Report PNW-134, 19 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Fredriksen, F. L., C. G. Moore, and L. A. Norris. 1975. The impact of timber harvest, fertilization, and herbicide treatment on streamwater quality in western Oregon and Washington. p. 283-313. In North American Forest Soils Conference. Les Presses De L'Universite Laval, Quebec.

Gruell, George E. 1985. Fire on the early western landscape: An annotated record of wildland fires 1776-1900. Northwest Science 59(2):97-107.

Hecht, Barry. 1982. Sequential changes in bed habitat conditions in the upper Carmel River following the Marble-Cone fire of August, 1977. p. 134-141. In Proceedings of California Riparian Systems Conference. [Davis, Calif., September 17-19, 1981] Davis, Calif.

Heinselman, Miron L. 1978. Fire in wilderness ecosystems. p. 249-278. In Hendee, J. C., G. H. Stankey, and R. C. Lucas, eds. Wilderness management. USDA Forest Service, Misc. Pub. 1365. Washington D.C.

Kilgore, Bruce M. 1981. Fire in ecosystem distribution and structure: Western forests and scrublands. p. 58-89. In Mooney, H. A., T. M. Bonnicksen, N. L. Christensen, J. E. Lotan, and W. A. Reiners, eds. Fire regimes and ecosystem properties, proceedings. [Honolulu, Hi., December 11-15 1978] USDA Forest Service General Technical Report WO-26. Washington, D.C.

Lotspeich, F. B., E. W. Mueller, and P. J. Frey. 1970. Effects of large scale forest fires on water quality in interior Alaska. 115 p. USDI Federal Water Pollution Control Administration, Alaska Water Laboratory, College, Alaska.

Lyon, L. Jack, Hewlette S. Crawford, Eugene Czuhai, and others. 1978. Effects of fire on fauna. USDA Forest Service General Technical Report WO-6, 41 p. Washington, D.C.

Mehringer, Peter J., Jr. 1985. Late-Quaternary pollen records from the interior Pacific Northwest and northern Great Basin of the United States. p. 167-189. In Bryant, V. M., Jr., and R. G. Holloway, eds. Pollen records of late-Quaternary North American sediments. American Association of Stratigraphic Palynologists, Dallas, TX.

Minshall, G. Wayne, J. T. Brock, and John D. Varley. 1989. Effects of the 1988 wildfires on Yellowstone's stream ecosystems: a temporal perspective. (Submitted to Bioscience for fall 1989 special issue).

Morgan, Penelope, and Leon F. Neuenschwander. 1988. Shrub response to high and low severity burns following clearcutting in northern Idaho. Western Journal of Applied Forestry. 3(1):5-9.

Ryan, Kevin C., and Nonan V. Noste. 1985. Evaluating prescribed fires. p. 230-238. In Lotan, James E., Bruce M. Kilgore, William C. Fischer, and Robert W. Mutch, tech . coords. Proceedings--symposium and workshop on wilderness fire. [Missoula, Mont., November 15-18, 1983] USDA Forest Service General Technical Report INT-182. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Smock, Leonard A., Glenn M. Metzler, and James E. Gladden. 1989. Role of debris dams in the structure and functioning of low-gradient headwater streams. Ecology. 70(3):764-775.

Swanson, Frederick J. 1981. Fire and geomorphic processes. p. 401-420. In Mooney, H. A., T. M. Bonnicksen, N. L. Christensen, J. E. Lotan, and W. A. Reiners, eds. Fire regimes and ecosystem properties, proceedings. [Honolulu, Hi., December 11-15, 1978] USDA Forest Service General Technical Report WO-26. Washington D.C.

Swanston, Douglas N. 1980. Influence of forest and rangeland management on anadromous fish habitat in western North America impacts on natural events. USDA Forest Service General Technical Report PNW-104, 27 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Tiedemann, Arthur R. 1981. Regional impacts of fire. p. 532-556. In Mooney, H. A., T. M. Bonnicksen, N. L. Christensen, J. E. Lotan, and W. A. Reiners, eds. Fire regimes and ecosystem properties, proceedings. [Honolulu, Hi., December 11-15, 1978] USDA Forest Service General Technical Report WO-26. Washington, D.C.

Wright, Henry A., and Arthur B. Bailey. 1982. Fire ecology United States and southern Canada. 495 p. John Wiley and Sons, New York.

Changes in Wild Trout Habitat Following Forest Fire[1]

G. Wayne Minshall,[2] Douglas A. Andrews, James T. Brock,
Christopher T. Robinson, and Deron E. Lawrence[3]

Abstract.--The responses of streams to the 1979 Mortar Creek Fire in Central Idaho provide valuable insights into the extended impact of wildfire on trout habitat. The fire dramatically increased runoff and fine sediment levels and reduced shading and cover from undercut banks and woody vegetation. Although habitat conditions for all life stages of cutthroat trout were adversely affected by the fire, these conditions gradually improved over the succeeding 8 years. Habitat for adults is expected to recover most rapidly and to reach optimal conditions about 15 years post-fire. Recovery of spawning and rearing habitat will be much slower with suboptimal conditions likely to persist well beyond the first 25 years.

INTRODUCTION

Although resource managers periodically recognize the need for information on the effects of fires on stream fish habitat, the amount of research on the topic is amazingly sparse. The reasons include the sporadic nature of fires, the tendency to treat fires as short-term crises rather than regularly recurring phenomena, and short-comings in the organization (including the frequent transfer of personnel) and funding of government agencies responsible for watershed management. In addition, most of the considerations to date suffer from the lack of a long-term temporal perspective.

In 1979, following the 26,000 ha Mortar Creek Fire in central Idaho, we began a study to document the changes induced by wildfire on streams of various sizes. The purpose of this report is to present results for the first ten years after the fire concerning mainly physical habitat conditions for native cutthroat trout (Oncorhynchus clarki) in tributary mountain streams of the Idaho batholith. Tributary streams, particularly those 2nd to 4th order in size, provide the main habitat for cutthroat trout in this area (Platts 1979) and were the most severely impacted by the Mortar Creek fire (Minshall et al. 1981). Streams larger than 5th order did not show any discernible effect from the fire (Minshall et al. 1981). The steep, erosive landscape of the Idaho Batholith is believed to be among the most sensitive to fire disturbance (Swanson 1979).

STUDY AREA

The Mortar Creek Fire occurred in the 41,440 km^2 Idaho Batholith, an area of granitic bedrock characterized by highly erodible soils, including large amounts of sand (Bjornn et al. 1977). The fire affected watersheds draining into the Middle Fork of the Salmon River. The Middle Fork is a major (7th order) tributary of the Salmon River. It drains a 7330 km^2 watershed, representative of much of the forested mountainous terrain found in central Idaho. Watershed elevations range from 2800 m at the headwaters to about 1550 m where they enter the Middle Fork. Most hillslope gradients range between 40 and 70%. The fire perimeter delineated an area representing about 4% of the Middle Fork basin, however, approximately 50 to 100% of the affected tributary watersheds burned.

The focus of this report is Little Loon Creek a 109-km^2 basin area mountain stream. Two sites were selected for analysis: one, a 5th order

---

[1]Paper presented at Wild Trout IV Symposium. [Yellowstone National Park, Wyoming, September 18-19, 1989].

[2]Professor of Ecology and Zoology. Stream Ecology Center, Department of Biological Sciences, Idaho State University, Pocatello, Idaho.

[3]Research Associates. Stream Ecology Center, Department of Biological Sciences, Idaho State University, Pocatello, Idaho.

East Fork of Little Loon Creek

1980

1982

1983

1985

1987

1989

Figure 1. East Fork of Little Loon Creek. Photographic record of stream and riparian conditions.

Main Stem of Little Loon Creek

1980

1982

1983

1985

1987

1989

Figure 2. Mainstem of Little Loon Creek. Photographic record of stream and riparian conditions.

segment, just upstream of its confluence with the Middle Fork (= mainstem site) and the other (= East Fork site), a 4th order segment, just upstream of the entrance of the West Fork of Little Loon Creek. Over most of its length, Little Loon Creek flows through a narrow canyon with steep (> 60%), rocky side slopes and sparse to moderately dense prefire forest vegetation. About 60% of the watershed burned; most of it as a hot crown fire.

RESULTS

Photographs taken annually from approximately the same location on the East Fork of Little Loon Creek illustrate several important changes in stream channel and riparian conditions during the period of the study (Fig. 1; for brevity only six of the ten years are included here). The stream channel increased in both depth and width in the years following the fire, probably as a result of increased runoff from snow melt and summer rain storms due to reduced infiltration and evapotranspiration following the fire. Stream widening was accompanied by loss of undercut banks. Increased flow volumes and associated erosion of the stream channel resulted in an increase in the mean particle size after the first year due to differential removal of sand and gravel. The result was a coarser streambed "texture," which we interpret as providing more resting habitat for trout. Although increased gradient might be expected to be correlated with increased turbulence, values measured with an inclinometer remained about the same over the 10-year period (East Fork 3% vs 2%, mainstem 5% vs 6% in 1979 and 1989, respectively). Additional materials were contributed by the mass movement from steep (> 45%) side slopes when undercutting by the stream and loss of binding by vegetation destabilized talus accumulations.

Large woody debris initially was removed by high discharge in the first spring and summer following the fire and exported downstream or deposited along the floodplain. But woody materials gradually began to accumulate in the stream channel from the undercutting and blowdown of fire-killed trees within an approximately 30-m corridor on either side of the stream (Figs. 1, 2). This debris served as points for accumulation of sticks and finer particulate organic matter. Downed trees first became evident in the East Fork of Little Loon Creek in year 4 and increased progressively thereafter. However, formation of "debris jams", incorporating accumulations of branches and sticks, was not evident until year 10 (Fig. 1).

Regrowth of the woody riparian vegetation (e.g. Alnus, Salix) responded rapidly following the fire but by year 10 still was not providing substantial amounts of overhanging cover or shading for trout. Further downstream, near the mouth of the mainstem, moderately burned (ground fire only) locations evidenced a similar fate except that the riparian vegetation recovered much more rapidly and woody debris inputs were limited to trees destabilized by bank undercutting (Fig. 2). In this area, riparian vegetation began providing substantial cover and shading by year 2.

Changes in the cross-sectional profile of the stream were documented by measurements from transects across the stream (Fig. 3). These are referenced to semi-permanent steel pins located on opposites banks of the stream above the bankfull discharge level. Data for Indian Creek, an unburned 4th order reference stream are included for comparison. Similar patterns of change in the burned-stream cross-sections are apparent from Figure 3a-b, which show that most of the channel cutting took place between 1982-1984. The variability in the Indian Creek profile (Fig. 3c) is due in part to channel rearrangement but inter-investigator measurement differences also are responsible for some of the apparent change (verified through examination of photographs). Since the fire, channel width has increased about 2.5 m in the East Fork of Little Loon Creek and about 5.5 m in the mainstem while remaining relatively constant in Indian Creek (Fig. 4a). Changes in width and depth for Figures 4a-c were calculated using 1980, for the burned sites, and 1981, for Indian Creek, as reference points and then determining the change from that year to each following year. Accurate data were not available for the missing points in each graph. Channel depth (Fig. 4b) in the mainstem of Little Look Creek increased until 1984 and then stabilized while in the East Fork a continuous increase in depth was apparent. The changes in depth for Indian Creek are most likely caused by year-to-year variations among investigators. Increases in sediment transport and in the mean annual flood may be expected to increase the channel width-depth ratio (Schumm 1977). In the present study (Fig. 4c), the mainstem of Little Look Creek fits this pattern. As seen from Figure 3b, the great increase in width was caused by a complete lateral shift of the main channel, while increase in the width of the East Fork (Fig. 3a) is less pronounced. Relatively greater increases in depth in the East Fork than in the mainstem resulted in opposite trends in the width-depth ratio between the two streams (Fig. 4c).

DISCUSSION

Based on our observations of stream conditions in the decade following the Mortar Creek Fire, we identify several important effects of wildfire on trout habitat (Fig. 5). All of these appear to show important changes over time. Because stream ecosystem dynamics are closely tied to the conditions of the watershed, it is possible to extend our observations an additional 15 years with reasonable confidence, based on knowledge of forest regeneration under comparable conditions in the Rocky Mountain region (Schimpf et al. 1980, Romme 1982, Lyon 1984, Arno et al. 1985, Stickney 1986). Obviously the magnitude of the

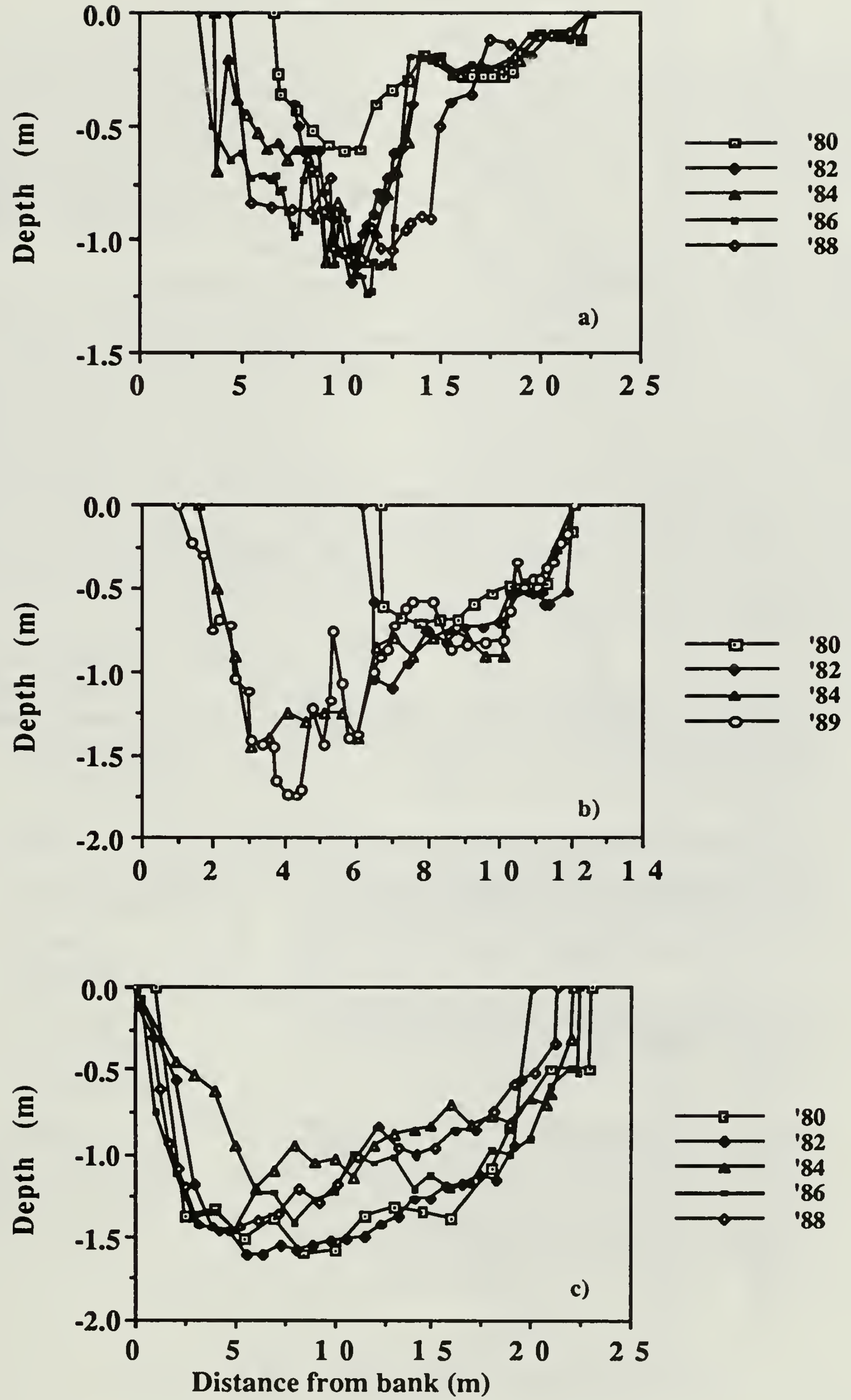


Figure 3. Channel cross-sections for (a) East Fork Little Loon Creek, (b) Mainstem Little Loon Creek, and (c) Indian Creek.

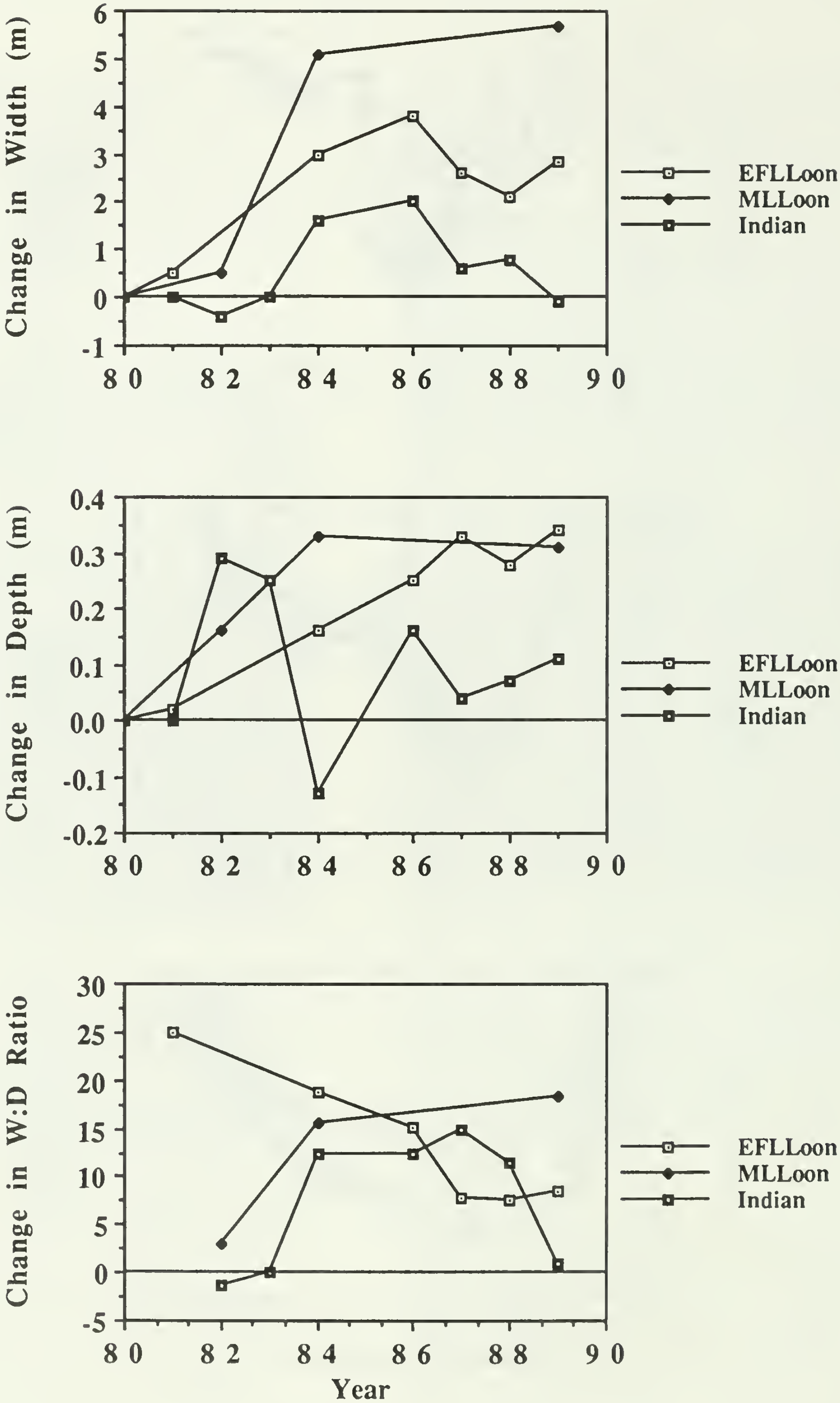


Figure 4. Changes in width, depth, and width:depth ratios in the first decade following wildfire in the Mainstem and East Fork of Little Loon Creek and in the unburned Indian Creek.

effect of fire and the trajectory of the recovery sequence are the result of a number of variables, including fire severity (intensity and extent), vegetation recovery pattern, geology, topography, and climate. Thus, this general model will need to be modified accordingly in order to be applicable to streams in other areas. Some suggestions as to the form these modifications might take are given elsewhere (Minshall and Brock 1989, Minshall et al. 1989).

As seen from Figure 1a, considerable movement and channel deposition of fine sediment occurred with the first spring/summer postfire runoff (Fig. 5). Most of this was removed during the following year, especially with spring 1981 runoff. Over the next few years, erosion and transport of sediments depleted near- and in-stream sediment storage sites and may have severely limited spawning and rearing substrata for several years. Optimum spawning substratum for cutthroat trout consists of gravel with small amounts of fines and rubble (Beschta and Platts 1986). Attenuation of peak discharges and resumption of normal geologic processes should result in the gradual reestablishment of suitable spawning substratum conditions after 12-15 years, under conditions found in Little Loon Creek. Megahan et al. (1980) found a more rapid recovery from watershed-induced sedimentation in the much larger South Fork of the Salmon River and we observed a similar response in the Middle Fork. In the South Fork, the spawning areas recovered more rapidly than the rearing areas.

Given the present rate of recovery, we do not expect the riparian vegetation or bank undercutting to develop sufficiently to provide measurable cover for trout until year 25 or later (Fig. 5). However, some shading by the riparian vegetation began around year 10 (Fig. 1) and can be expected to increase progressively as shrubs such as willow (Salix) and alder (Alnus) increase in stature and density. Maximum levels of shading are dependent on the development of a forest-stream overstory and may require 50 years or more. Heavy shading is expected to be detrimental to trout production due to decreased primary and secondary production. (Hawkins et al. 1983, Wilzbach et al. 1986, Thedinga et al. 1989). Hillman et al.'s (1987) findings suggest that undercut banks may be especially important for survival of overwintering juvenile salmonids.

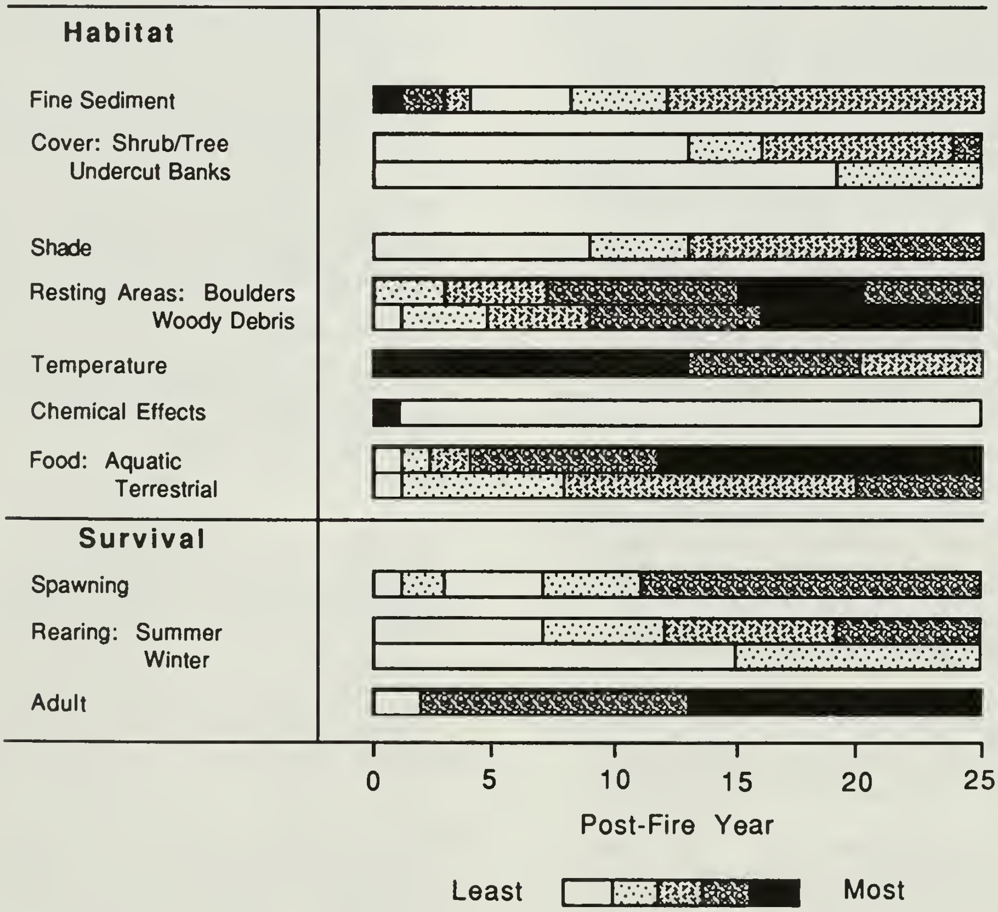


Figure 5. Effects of crown fire on trout habitat and survival in mid-size Rocky Mountain streams based on results for Little Loon Creek following the 1979 Mortar Creek Fire.

The development of resting areas in eddies and pools around boulders (Fig. 5) is largely dependent on stream channel erosional processes. Although these may be maximal during the first decade, increased water yield in excess of prefire levels is expected to persist in Rocky Mountain streams for about 25 years or more (Troendle 1983). Since development of boulder-associated pool habitat is thought to be a cumulative process, maximum levels should be attained in 15 -20 years. Channel erosion also is responsible for the input of considerable amounts of woody debris beginning about year 2 (Fig. 1). Dead falls also contribute substantially to the woody accumulations. Approximately ≥50% of the near-stream standing-dead trees had snapped off or fallen completely by year 10 and all are expected to be down by about 20 to 25 years (Lyon 1984). However, the development of long-lived debris jams, formed around the downed timber, and associated pool habitat did not begin until year 10 and is not expected to peak for several more years.

Temperature levels outside of those experienced before a fire are controlled mainly by shading. Stressful or lethal summer temperatures, if they do occur, probably are restricted to the first 0-15 years, until the riparian vegetation develops to reduce solar heating sufficiently (Fig. 5). Slight warming of the water above prefire conditioning but below sublethal levels may enhance trout production. Maximum temperatures in Little Loon Creek after the fire (18°C), from recording thermometers read annually, probably had no negative effect on cutthroat trout. No adverse effects of water chemistry on trout have been observed in Little Loon Creek but some mortality In Yellowstone National Park streams immediately following the 1988 fires was attributed to altered chemical conditions from wood ash and fire retardants (Minshall et al. 1989).

Reduced turbidity and increased turbulence after year 1 generally provided improved living conditions for riffle-dwelling aquatic insects.[1] Abundances of these trout food organisms (Fig. 5) are expected to reach their maximum around year 12 and persist for a number of years (Minshall et al. 1989). The availability of terrestrial insects to stream trout is believed to be a function of the amount of streamside and overhanging vegetation and consequently is seen as increasing gradually over the first 25 years. However, the effect of fire on the availability of terrestrial insects to fish apparently has never been documented and needs further study.

The rigorous conditions found during the first couple of postfire years are believed to be detrimental to survival of all trout life stages (Fig. 5). Mortality of eggs and fry is thought to be especially critical during the early stages of recovery. These seem to be controlled initially by high fine sediment transport and deposition and later by the lack of suitable spawning and rearing conditions. Bjornn et al. (1979) found that amounts of fine sediments exceeding 20-30% reduced summer rearing capacity of salmonids when deposited in the larger interstitial spaces of the substratum. Both factors were considered to be more important for survival than was the effect of fine sediments on spawning success. After the first couple of postfire years, habitat conditions should not be detrimental to the survival of adult trout and artificial supplementation of fire-depleted stocks might speed the recovery process. However, prior to the first dozen or so years, adult trout populations may be food limited. Conditions for young trout are expected to lag behind those for adult trout due to the slow rates of recovery of stream morphology and riparian vegetation. Chapman and McLeod (1987) have suggested that stream morphology may outweigh embeddedness and levels of fine sediments in determining fish rearing densities. Development of woody riparian vegetation will provide advanced shading, overhanging tree cover, and allochthonous food resources well beyond year 25. Optimal conditions for cutthroat trout should occur following the first decade after a wildfire but well before mature ("climax") forest conditions are reestablished in the watershed. We speculate that these enhanced conditions will occur in the Mortar Creek Fire area around 30 to 60 years following the 1979 fire. In the Rocky Mountain region mature- forest stands are attained within 50 to 300 years depending on climatic conditions (Schimpf et al. 1980, Romme 1982, Lyon 1984, Arno et al. 1985, Stickney 1986). Attainment of forest maturity is expected to be accompanied by a decline in stream habitat quality due to heavy shading, reduced quality and quantity of allochthonous detritus, and decreased habitat heterogeneity (Minshall et al. 1989, Thedinga et al. 1989).

ACKNOWLEDGMENTS

Financial support for this study has come from a variety of sources but most consistently and reliably from Idaho State University grants in aid for research. Results for the first year following the fire were obtained under a contract from the U.S. Forest Service (USFS) Intermountain Region office and those in 1988 and 1989 through USFS "Challenge" Grants from the Payette and Challis National Forests, respectively. A grant from Eisenhower Consortium funds to Thomas LaPoint through the University of Wyoming provided the 1982 data. A large number of graduate students and other colleagues have contributed immeasurably to the successful completion of this study, often with little or no financial remuneration. We are especially thankful for their help and good fellowship during extended expeditions into the Frank Church River of No Return Wilderness where this research

[1]G.W. Minshall unpublished data.

was conducted. Without the help and interest of numerous USFS field personnel, our work would have been much less productive and enjoyable. V.K. Moore and R.L. Vannote read an early draft of this article and contributed substantially to its improvement.

LITERATURE CITED

Arno, S.R., D.G. Simmerman, and R.E. Keane. 1985. Forest succession on four habitat types in Western Montana. U.S. Forest Service, General Technical Report. INT-177, 74 p., Intermountain Forest and Range Experiment Station, Ogden, Utah. 74 p.

Beschta, T. L. and W. S. Platts. 1986. Morphological features of small streams: significance and function. Water Resources Bulletin 22:369-379.

Bjornn, T. C., M. A. Brusven, M. P. Molnau, and J. H. Milligan. 1977. Transport of granitic sediment in streams and its effects on insects and fish. USDI Office of Water Research and Technology. Research Technical Completion Report Project B-036-IDA.

Chapman, D. W. and K. P. McLeod. 1987. Development of criteria for fine sediment in the Northern Rockies ecoregion. U.S. Environmental Protection Agency. EPA 910/9-87-162.

Griffith, J. S. 1982 Comparative behavior and habitat utilization of brook trout (Salvelinus fontinalis) and cutthroat trout (Salmo clarki) in small streams in northern Idaho. Journal Fisheries Research Board of Canada 29:265-273.

Hawkins, C. P., M. L. Murphy, N. H. Anderson, and M. A. Wilzbach. 1983. Density of fish and salamanders in relation to riparian canopy and physical habitat in streams of the northwestern United States. Canadian Journal Fisheries and Aquatic Sciences 40:1173-1185.

Hillman, T. W., J. S. Griffith, and W. S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. Transactions American Fisheries Society 116:185-195.

Lyon, J. L. 1984. The Sleeping Child Burn - 21 years of postfire change. U.S. Forest Service, Research Paper INT-330, Intermountain Forest and Range Experiment Station Ogden, Utah.

Megahan, W. F., W. S. Platts, and B. Kulesza. 1980. Riverbed improves over time: South Fork Salmon. Symposium on Watershed Management Volume 1, p. 300-395. American Society Civil Engineers, New York.

Minshall, G. W. and J. T. Brock. 1989. Anticipated effects of forest fire on Yellowstone stream ecosystems. In B. Keiter and M. Boyce, eds. Greater Yellowstone's Future: Man and Nature in Conflict? Yale University Press, New Haven, Conn.

Minshall, G. W., J. T. Brock, and D. A. Andrews. 1981. Biological, water quality, and aquatic habitat responses to wildfire in the Middle Fork of the Salmon River and its tributaries. U.S. Forest Service, Final Report, Intermountain Forest and Range Experiment Station, Ogden, Utah 122 p.

Minshall, G. W., J. T. Brock, and J. D. Varley. 1989. Wildfires and Yellowstone's stream ecosystems. BioScience in press.

Platts, W. S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho river drainage. Fisheries 4(2):5-9.

Romme, W. H. 1982. Fire and landscape diversity in subalpine forests of Yellowstone National Park. Ecological Monographs 52:199-221.

Schimpf, D. J., J. A. Henderson, and J. A. MacMahon. 1980. Some aspects of succession in the spruce-fir forest zone of Northern Utah. Great Basin Naturalist 40:1-26.

Schumm, S. A. 1977. The fluvial system. J. Wiley & Sons, New York.

Stickney, P. F. 1986. First decade plant succession following the Sundance Forest Fire, Northern Idaho. U. S. Forest Service General Technical Report INT-197, Intermountain Forest and Range Experimental Station, Ogden, Utah.

Swanson, F. J. 1979. Fire and geomorphic processes. In: Proceedings, Fire regimes and ecosystems conference. U.S. Forest Service General Technical Report WO-26.

Thedinga, J. F., M. L. Murphy, J. Heifetz, K. V. Koski, and S. W. Johnson, 1989. Effects of logging on size and age composition of juvenile coho salmon (Oncorhyncus kisutch) and density of presmolts in southeast Alaska streams. Canadian Journal Fisheries and Aquatic Sciences 46:1383-1391.

Troendle, C. A. 1983. The potential for water yield augmentation from forest management in the Rocky Mountain region. Water Resources Bulletin 19:359-373.

Wilzbach, M. A., K. W. Cummins, and J. D. Hall. 1986. Influence of habitat manipulations on interactions between cutthroat trout and invertebrate drift. Ecology 67:898-911.

Impact of a Fire and Flood on the Trout Population of Beaver Creek, Upper Missouri Basin, Montana[1]

Mark A. Novak[2] and Robert G. White[3]

A forest fire followed by an intense convectional rainstorm caused a 100-year flood in the Beaver Creek drainage. This study documented changes in resident trout populations and use of the stream by adfluvial spawning fish. Two months after the event trout populations in the impacted portion of the stream were nearly eliminated. Within 2 years, numbers and biomass of rainbow trout had increased to 55% and 51% greater, respectively, than before the event. Rapid recovery of the rainbow trout population resulted from large spawning runs from the Missouri River.

INTRODUCTION

The North Hill Fire in Helena National Forest began on 27 August, 1984 approximately 30 km north of Helena, Montana (Fig. 1). Sixty-four-kilometer-per-hour winds drove the fire rapidly to the northeast and across the Missouri River near the mouth of Beaver Creek. By 30 August, the fire had advanced 20 km into the Gates of the Mountains Wilderness Area and affected 11,000 ha, including 26% (4811 ha) of the lower Beaver Creek drainage.

On 31 August an intense convectional rainstorm moved over the burn area depositing 32.5 mm of precipitation in 20 minutes (Putnam 1985). Runoff from the burn area caused a flood exceeding that of a 100-year event.

Hydrophobic soil conditions generated by the intense heat of the fire caused immediate overland water flow. Sheet erosion developed within meters of ridgetops. Flows progressed downslope causing rill and gulley erosion in first-order drainages, and severe scouring in second and third-order drainages. Excessive erosion occurred on 1500 ha, with erosion rates of 871 Mg/ha at some sites (Shultz et al.[4] unpub. data.).

Several debris torrents reached Beaver Creek resulting in >50% suspended sediments immediately following the flood (Bill Putnam[5], forest hydrologist, pers. comm.). Severe scouring of the stream bottom and banks, along with heavy deposition of sediment and charred debris resulted in physical and biological debasement of the stream.

In spring 1984, a 2-year study on Beaver Creek was completed as part of a larger project on the Missouri River (White et al. 1984; Carty 1985; Spoon 1985). That study provided pre-event information on fall trout abundance and population structure, and magnitude of spawning of adfluvial brown trout and rainbow trout from the Missouri River. This paper evaluates the effects of the fire-flood event on resident trout populations of Beaver Creek.

---

[1]Paper presented at the Wild Trout IV symposium [Yellowstone National Park, Mammoth, Wyoming, September 18-19, 1989].

[2]Mark A. Novak, temporary fishery biologist, Jackson District, Bridger-Teton National Forest, Jackson, Wyoming.

[3]Robert G. White, Leader, Montana Cooperative Fishery Research Unit, Montana State University, Bozeman, Montana.

[4]Shultz S., R. Lincoln, J. Cauhorn and C. Montagne. 1986. Quantification of erosion from a fire and rainfall event in the Big Belt Range of the Northern Rocky Mountains. Department of Soil Science, Montana State University, Bozeman, Montana.

[5]Putnam, W. C. 1985. Personal communication. USDA Forest Service, Helena National Forest, Helena, Montana.

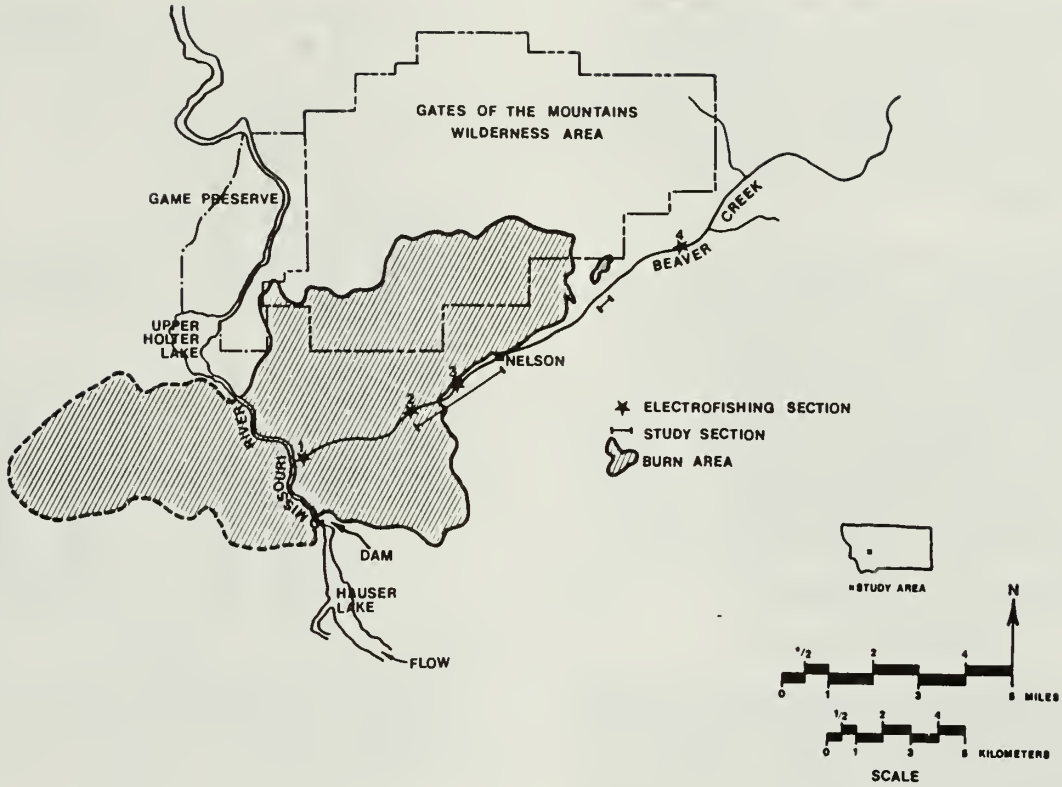


Figure 1.--Beaver Creek study area showing locations of electrofishing sections and extent of burn area.

DESCRIPTION OF STUDY AREA

Beaver Creek, the only perennial tributary to the Missouri River between Hauser Dam and Upper Holter Reservoir, has a drainage area of 18,715 ha. The stream is approximately 27 km long, has an average gradient of 1.72% and flows into the Missouri River 2.7 km downstream from Hauser Dam (Fig. 1). From its headwaters in the Big Belt Mountains to the town of Nelson, the stream flows through a narrow limestone canyon, below which it meanders through a broader floodplain. The confluence of Beaver Creek and the Missouri River is a popular recreation area, with the Beaver Creek fishery valued at $24,000 annually (Putnam 1985).

Beaver Creek flows through ponderosa pine-grassland vegetation, with riparian areas dominated by red osier dogwood (Cornus stolinifera) and willow (Salix spp.). Extensive beaver activity throughout the stream perpetuates the presence of ponds in various stages of senescence.

The drainage continued to exhibit the effects of soil instability during the course of the study, as debris torrents were associated with heavy rain and spring runoff. Ice and snow cover were extensive on Beaver Creek during winter. Information on discharge and temperature during the study, and a list of fish species and aquatic macroinvertebrates occurring in Beaver Creek are given in Novak (1988).

METHODS

Population Estimates

Trout abundance was sampled in fall 1984, 1985 and 1986 using the two-pass method (Seber and LeCren 1967; Seber 1973; Leathe 1983) or the Zippin method (Moran 1951; Zippin 1958; Platts, Megahan and Minshall 1983). Two or more passes through a section were conducted to obtain an acceptable probability of capture for calculating population estimates.

Three 305-m electrofishing sections corresponding to Spoon's (1985) sections 2, 3 and 4 were evaluated. Sections 2 and 3 were located in the impacted portion of the stream; section 4 served as a nonimpacted reference (Fig. 1).

Population estimates and estimated biomass were calculated by age-class for brown and rainbow trout; 80% confidence intervals were calculated for population estimates (Neter, Wasserman, and Kutner 1985). Due to hybridization in nonimpacted section 4, rainbow and cutthroat trout are collectively referred to as rainbow-cutthroat trout.

Trout were sampled with a bank electrofishing unit consisting of a 1500 watt, 115 volt AC generator and Coffelt rectifying unit (Model VVP-2C). Surveys were conducted working upstream with a hand-held positive electrode attached to a 152-m cord; the negative electrode was stationary. Measurements of total length (mm) and weight (to the nearest 5 gm) were recorded for all trout collected. Scale samples were obtained from 10 fish per centimeter group in each electrofishing section.

Spawning Surveys

Brown trout and rainbow trout spawning activity was measured by conducting redd counts while wading upstream or walking stream banks in 1985 and 1986. Brown trout redd counts were conducted once each fall from the mouth of Beaver Creek to Nelson (Fig. 1). Rainbow trout redds were counted twice each spring; once at peak spawning in mid-May and again near the end of spawning in mid-June. Redds were counted in the entire 19.2 km of stream accessible to rainbow trout each year.

RESULTS

Trout Populations

Abundance

Trout abundance decreased dramatically (>99%) in the impacted portion of Beaver Creek from fall 1983 to fall 1984, when only eight brook trout and four rainbow trout were collected in impacted sections 2 and 3, respectively (Fig. 2 and 3). Trout biomass declined more than 98% in the impacted sections as compared to 1983. In the nonimpacted section, brook trout and rainbow-cutthroat trout estimates were 40% and 84% lower, respectively, than fall 1983, but relative differences were not as pronounced as in the impacted area (Fig. 4). This was reflected by a 31% decrease in trout biomass compared to 1983.

By fall 1985, a dramatic increase in trout numbers had occurred in impacted sections of Beaver Creek. Rainbow trout numbers and biomass were 73% and 38%

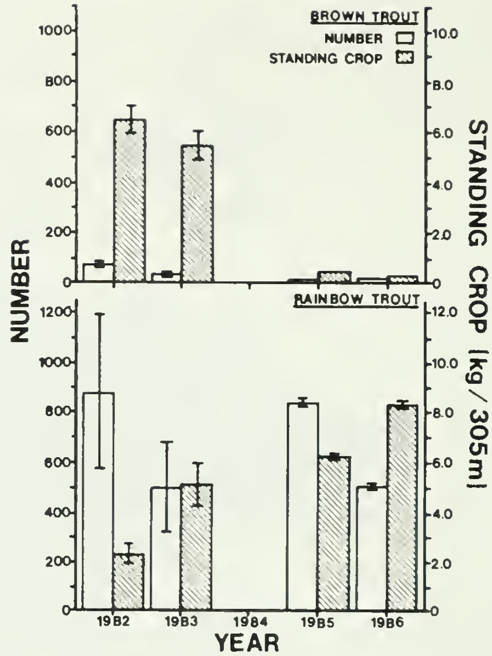


Figure 2.--Number and standing crop of brown and rainbow trout, impacted section 2, fall 1982 (pre-fire) through fall 1986.

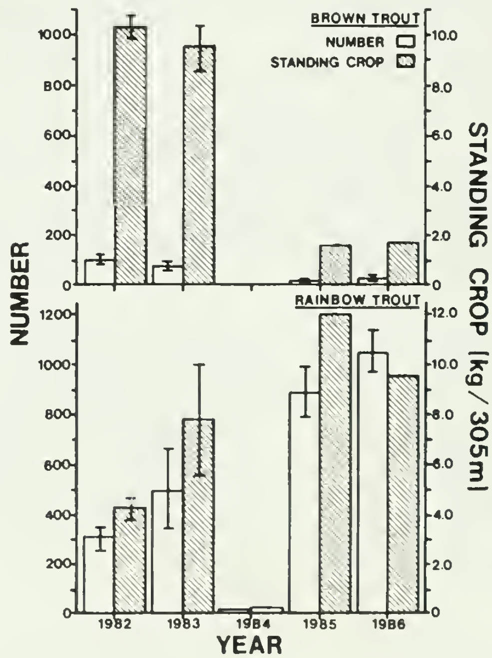


Figure 3.--Number and standing crop of brown and rainbow trout, impacted section 3, fall 1982 (pre-fire) through fall 1986.

greater, respectively, compared to fall 1983 (Fig. 2 and 3). However, numbers and biomass of brown trout in impacted sections remained 88% and 87% lower, respectively, than fall 1983. In the nonimpacted section, rainbow-cutthroat trout numbers and biomass remained 30% and 51%, respectively, below that of 1983. In comparison, numbers and biomass of brook trout had increased 49% and 135% (Fig. 4).

By fall 1986, rainbow trout numbers in section 2 (Fig. 2) were similar to those of 1983, however, biomass was 61% greater. In impacted section 3, rainbow trout numbers had increased to 110% above those of 1983, and biomass was 22% higher (Fig. 3). The brown trout stock did not show similar signs of recovery in impacted sections. Brook trout numbers and biomass in the nonimpacted section (Fig. 4) were 453% and 226% greater, respectively, as compared to fall 1983. In comparison, numbers and biomass of rainbow-cutthroat trout remained considerably lower than fall 1983.

Age-structure

Between fall 1983 and fall 1984 most age-classes of trout were eliminated in the impacted portion of Beaver Creek (Fig. 5 and 6). Successful spawning of adfluvial rainbow trout in spring 1985 resulted in large numbers of YOY rainbow trout during fall in impacted sections. Age-0 fish comprised 92% of the rainbow trout population, while the remaining 8% were largely age-I fish. By fall 1986, age structure of rainbow trout populations in

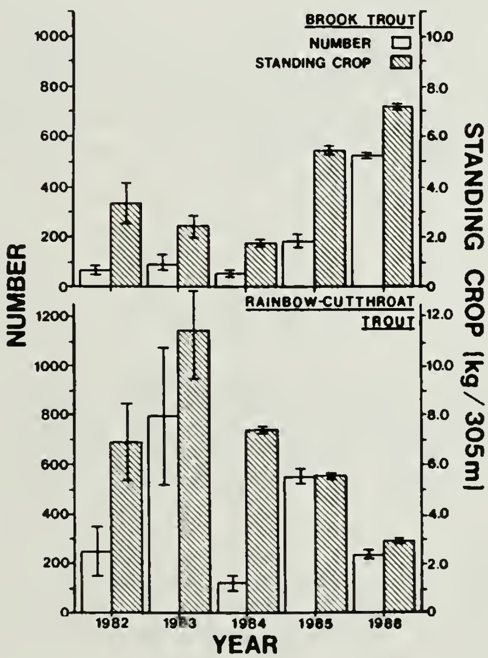


Figure 4.--Number and standing crop of brook and rainbow-cutthroat trout, nonimpacted section 4, fall 1982 (pre-fire) through fall 1986.

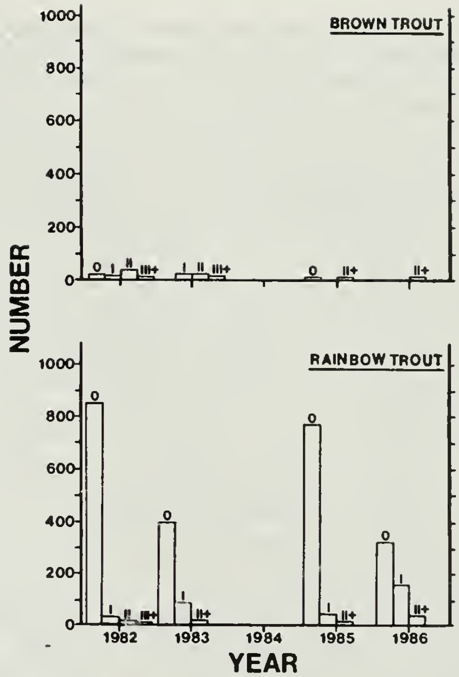


Figure 5.--Brown and rainbow trout age-class distributions, impacted section 2, fall 1982 (pre-fire) through fall 1986.

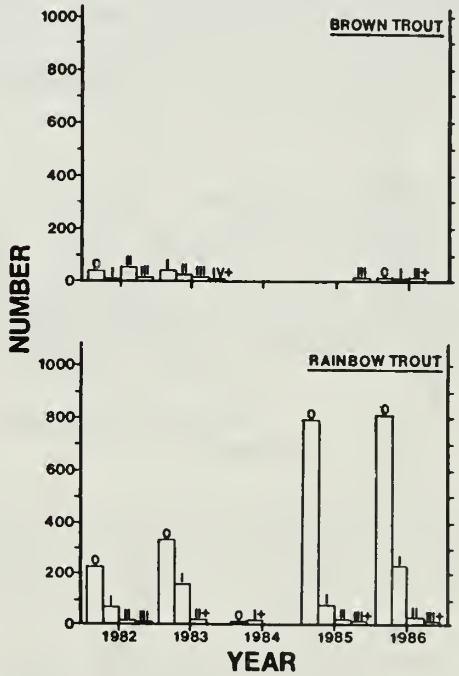


Figure 6.--Brown and rainbow trout age-class distributions, impacted section 3, fall 1982 (pre-fire) through fall 1986.

impacted sections was returning to pre-event proportions with approximately 70% age-0, 26% age-I and 4% age-II and older fish (Fig. 5 and 6).

Age structure of the brown trout population in impacted sections of Beaver Creek indicated little recruitment by fall 1986. Only two brown trout age-II and older were present in section 2. In section 3, an estimated five age-0, four age-I and five age-II and older fish were present (Fig. 5 and 6). Age structures of brook trout and rainbow-cutthroat trout in the nonimpacted section of Beaver Creek were similar to those observed prior to the fire and flood (Fig. 7).

Spawning Surveys

Brown Trout

In fall 1985, 15 adfluvial brown trout redds were observed in the impacted portion of Beaver Creek downstream of Nelson. Adfluvial brown trout were unable to access Beaver Creek in fall 1986 due to an impassable beaver dam near the mouth of the creek; six redds were observed between the dam and the Missouri River (approximately 100 m). Spawning areas in the impacted portion of Beaver Creek known to be used previously by resident brown trout (Ron Spoon[6], fishery biologist, pers. comm.),

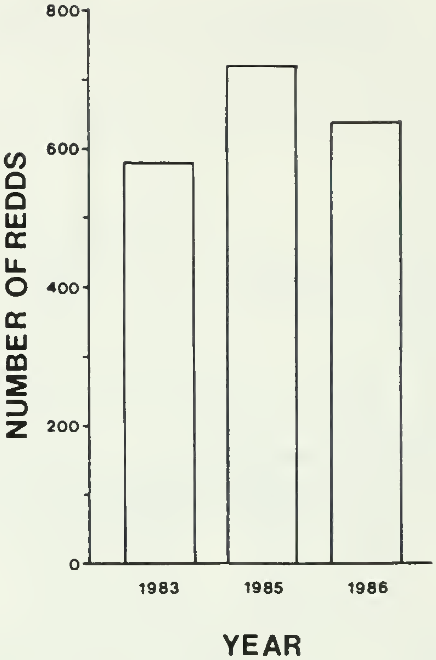


Figure 8.--Rainbow trout redd counts for spring 1983 (pre-fire; from Spoon 1985), 1985 and 1986.

showed no evidence of spawning use in fall 1985 and 1986.

Rainbow Trout

Adfluvial rainbow trout used Beaver Creek extensively for spawning each spring (Fig. 8). Seven-hundred-twenty-two and 640 redds were observed in 1985 and 1986, respectively. A beaver dam near the mouth of Cottontail Gulch, 19.2 km upstream of the confluence with the Missouri River, functioned as the migration barrier in 1985 and 1986.

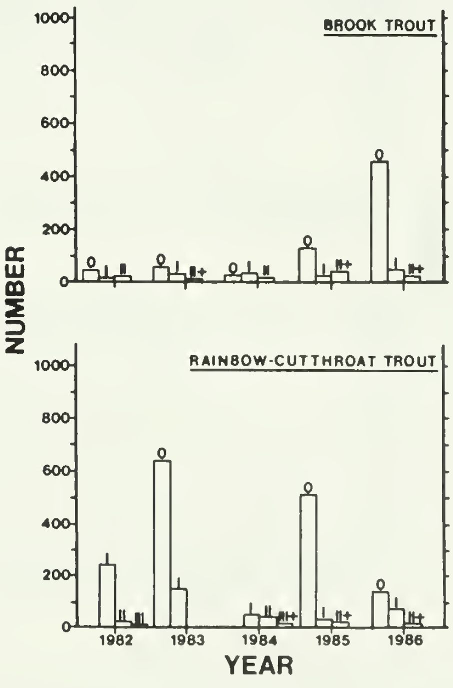


Figure 7.--Brook and rainbow-cutthroat trout age-class distributions, nonimpacted section 4, fall 1982 (pre-fire) through fall 1986.

DISCUSSION

Fire and flood are natural phenomena. Despite drastic changes in the terrestrial community of two Yellowstone Lake tributaries, Albin (1979) found no changes in fish or aquatic invertebrates directly attributable to fire. Hall and Knight (1981) reviewed several studies which illustrated the impacts of floods on salmonid populations. Generally, floods affect incubating eggs and young most severely. The magnitude of impact, however, varies with severity of the event,

---

[6]Spoon, R. L. 1985. Personal communication. Montana Dept. of Fish Wildlife and Parks, Missoula, Montana.

species involved, time of year, and physical characteristics of the stream.

Combined impacts of natural fire and intense rainfall events on stream habitat and fish populations can be devastating. Debris torrents of soil, rock, and organic debris-laden water pose the greatest threat to stream habitat and biota, but have received little study (Frederikson 1963, 1965; Morrison 1975; Swanson et al. 1976; Swanston 1980).

Trout numbers and biomass in the impacted portion of Beaver Creek were severely reduced following the North Hill fire and flood. Decreased trout abundance probably resulted from mortality during the flood, fish moving downstream to the Missouri River, and/or fish becoming stranded in backwater areas in an attempt to avoid the debris torrent in Beaver Creek. Furthermore, fish movement out of the impacted area of the stream may have occurred prior to electrofishing surveys in October 1984 due to habitat degradation following the flood.

Lower trout abundance in nonimpacted section 4 during fall 1984 was probably not related to the fire-flood event. Extensive beaver activity necessitated shifting Spoon's (1985) electrofishing section 4 downstream approximately 150 m. A large beaver pond (approximate surface area 300 m^2 and maximum depth of 2.0 m) flooded an adjacent willow thicket creating extensive overhead cover. Security afforded by such a large pond and the lack of a spillway over the dam may have influenced fish distribution downstream. The beaver dam forming this pond functioned as the upper boundary of the nonimpacted electrofishing section.

Hall and Knight (1981) reported salmonid biomass in streams varying naturally from near 0 to 60 g/m^2. Fall biomass in nonimpacted section 4 of Beaver Creek ranged from 8.4 g/m^2 to 10.3 g/m^2, a variation of 2.0 g/m^2 during the study. This is compared to a range in biomass in the impacted sections of Beaver Creek of 2.4 g/m^2 to 161.5 g/m^2, a variation of 159.0 g/m^2; this is well in excess of the natural range as reported by Hall and Knight (1981).

As fish populations began to recover, marked changes in numbers and biomass of brown trout and rainbow trout were observed in impacted sections of Beaver Creek. Before the flood, rainbow trout comprised 89% of the trout population by number, while biomass of rainbow and brown trout was similar. By fall 1986, rainbow trout comprised 98% of the trout population by number, and 82% of the biomass.

Seegrist and Gard (1972) found similar changes in species composition after flooding in Sagehen Creek, California. They attributed much of the variation in year-class strength of brook trout and rainbow trout to destruction of redds during flood events. Immigration of rainbow trout into Valley Creek, Minnesota after flooding and loss of two year-classes of brook trout, resulted in strong recruitment of rainbow trout fry (Hanson and Waters 1974). Rainbow trout constituted a significant proportion of the total salmonid population and production in post-flood years.

Rapid recovery of the rainbow trout population in Beaver Creek was due to large spawning runs of adfluvial rainbow trout from the Missouri River and Holter Reservoir. Although some spawning by adfluvial brown trout occurs in Beaver Creek, access during the fall spawning period is restricted by the combination of beaver dams and low fall flows (Spoon 1985).

Most of the 666 brown trout redds observed by Spoon (1985) in Beaver Creek from 1981 to 1983 were thought to be those of resident trout. In 1981, Spoon (1985) identified nine adfluvial brown trout redds near the mouth of Beaver Creek. It is not clear if the 15 redds observed in fall 1985 represent a significant increase over previous years. Average discharge during the spawning period in 1985 (0.25 m^3/s) was similar to that during Spoon's study, indicating that flow-related access into Beaver Creek did not improve.

Rainbow trout redd counts in 1985 and 1986 were higher than observed by Spoon (1985). However, moderate spring runoff improved redd identification during this study. Also, a large beaver dam restricted spawning rainbow trout to 10.5 km of Beaver Creek during Spoon's study, which resulted in considerable redd superimposition below the migration barrier.

SUMMARY

A dramatic decline in trout numbers and biomass occurred in the impacted portion of Beaver Creek following the North Hill fire and flood. Most age-classes of trout were eliminated.

Rapid recovery of the rainbow trout population in Beaver Creek was due to extensive and successful spawning of adfluvial rainbow trout from the Missouri River and Holter Reservoir. By fall 1986, abundance and biomass of rainbow trout in the impacted portion of Beaver Creek exceeded those observed prior to the event. Age-class structure was similar to 1983.

Brown trout spawning was negligible in Beaver Creek due to limited access each fall. Brown trout abundance and biomass in the impacted area were much lower than in fall 1983, and age-class structure had not recovered.

REFERENCES CITED

Albin, D. P. 1979. Fire and stream ecology in some Yellowstone Lake tributaries. California Fish and Game 65(4):216-238.

Carty, D. G. 1985. Potential impacts of altering discharge pattern from Hauser Dam, Missouri River, on young-of-the-year brown trout and rainbow trout. M.S. Thesis, Montana State University. Bozeman, Montana. 84 pp.

Frederikson, R. L. 1963. A case history of a mud and rock slide on an experimental watershed. USDA Forest Service Research Note PNW-1. Pacific Northwest Forest and Range Experiment Station. Portland, Oregon.

Frederikson, R. L. 1965. Christmas storm damage on the H.J. Andrews Experimental Forest. USDA Forest Service. General Research Note PNW-29. Pacific Northwest Forest and Range Experiment Station. Portland, Oregon.

Hall, J. D. and N. J. Knight. 1981. Natural variation in abundance of salmonid populations in streams and its implications for design of impact studies. USDI Environmental Protection Agency. Environmental Research Laboratory, Corvalis, Oregon. EPA 600/3-81-021. 85 pp.

Hanson, D. L. and T. F. Waters. 1974. Recovery of standing crop and production rate of a brook trout population in a flood-damaged stream. Transactions of the American Fisheries Society 103:431-439.

Leathe, S. A. 1983. A cost-effective electrofishing technique to determine fish population size in small headwater streams in Montana. Montana Department of Fish, Wildlife and Parks. Kalispell, Montana. 4 pp.

Moran, P. A. P. 1951. A mathematical theory of animal trapping. Biometrika 6:250-258.

Morrison, P. H. 1975. Ecological and geomorphological consequences of mass-movements in the Alder Creek watershed and implications for forest land management. B.A. Thesis, University of Oregon. Eugene, Oregon.

Neter, J., W. Wasserman and M. H. Kutner. 1985. Applied linear statistical models. Second Edition. Richard D. Irwin, Inc. Homewood, Illinois. 1127 pp.

Novak, M. A. 1988. Impacts of a fire-flood event on physical and biological characteristics of a small mountain stream. M.S. Thesis, Montana State University. Bozeman, Montana. 98 pp.

Platts, W. S., W. F. Megahan and G. W. Minshall. 1983. Methods for evaluating stream, riparian and biotic conditions. USDA Forest Service. General Technical Report INT-138. Intermountain Forest and Range Experiment Station. Ogden, Utah.

Putnam, W. C. 1985. North Hills Fire: Burned-area rehabilitation project completion Report. USDA Forest Service. Helena National Forest. Helena, Montana. 7 pp.

Seber, G. A. F. 1973. The estimation of animal abundance and related parameters. Charles Griffin Co., Ltd., London.

Seber, G. A. F. and E. D. LeCren. 1967. Estimating population parameters from large catches relative to the population. Journal of Animal Ecology 36:631-643.

Seegrist, D. W. and R. Gard. 1972. Effects of floods on trout in Sagehen Creek, California. Transactions of the American Fisheries Society 101:478-482.

Spoon, R. L. 1985. Reproductive biology of brown and rainbow trout below Hauser Dam, Missouri River, with reference to hydroelectric peaking. M.S. Thesis, Montana State University. Bozeman, Montana. 144 pp.

Swanson, F. J., G. W. Lienkaemper, and J. R. Sedell. 1976. History, physical effects and management implications of large organic debris in western Oregon streams. USDA Forest Service. General Technical Report PNW-56. Pacific Northwest Forest and Range Experiment Station. Portland, Oregon.

Swanston, D. N. 1980. Impacts of natural events. In: W.R. Meehan, technical editor. Influence of forest and rangeland management on anadromous fish habitat in western North America. USDA Forest Service. General Technical Report PNW-104. Pacific Northwest Forest and Range Experiment Station. Portland, Oregon. 27 pp.

White, R. G., G. A. Liknes, R. L. Spoon, and D. G. Carty. 1984. Potential impacts of altering discharge from Hauser Dam, Missouri River, on fish populations. 1984 Completion Report. Montana Cooperative Fisheries Research Unit, Montana State University. Bozeman, Montana.

Zippin, C. 1958. The removal method of population estimation. Journal of Wildlife Management 22(1):82-90.

Wild Fire and Wild Trout in 1988: Do You Want To Hear the Bad News or the Good News First?[1]

John D. Varley[2]

Abstract.--The 1988 forest fires in Yellowstone National Park affected 19 separate major basins or subbasins. Preliminary estimates suggest that burns affected 28 percent of the Yellowstone Lake watershed, 8 percent of the Shoshone Lake watershed, 33 percent of the Lewis Lake watershed, and 50 percent of the Heart Lake watershed. Similarly, 32 percent or 860 miles of park streams were directly influenced by the fires. Short-term disturbances, such as fish mortality caused by water-heating, slurry bomber retardant, or ash, were found to be minimal and relatively insignificant. Long-term effects are not well studied and should be clearer as ongoing postfire research, now underway, proceeds.

As a result of the media's treatment of the great Yellowstone fires of 1988 there is a widespread public perception throughout the United States and the world that Yellowstone National Park was destroyed and lies devastated in ruins. In almost all cases, news watchers perceived the fires the way journalists portrayed them, as mile after mile of stark, blackened moonscape devoid of life or future. "The ecology of Yellowstone is dead," proclaimed one local saloon owner on a prime-time evening television newscast. Trout anglers and nature lovers from far and wide must have mourned that night, for there were many days during July, August, and September of 1988 when, according to the media, the future of Yellowstone's fish, fur, and fowl looked pretty bleak.

But as the 1989 summertime visitors have now seen for themselves, media-produced perceptions are sometimes false, and that was certainly true in the case of the Yellowstone fires. As Dr. Conrad Smith of The Ohio State University School of Journalism has pointed out in his studies of media accuracy in the Yellowstone fires, journalists outdid themselves with the sheer volume in print about the fires, but they missed many of the several dimensions available that could be called "the real story" (Smith 1989a, Smith 1989b, Smith 1989c).

With any luck the future will bring us full circle to a newfound reality summed up by the old adage, "Fortunately, news is not history." In the year or so following the fires, many intelligent and considered reports have appeared in journals, magazines, and television documentaries by journalists who really did their homework correcting the false information and misimpressions created by the journalists who came only to cover the firestorms. In the years ahead, because of that accurate literature and, perhaps more importantly, because of word-of-mouth stories told by people who have seen the park firsthand, these common misconceptions are slowly disappearing. The words most often used to describe the fires - destroyed, devastated, nuked, and so forth - will inevitably be transformed into accurate, positive statements about renewal, transformation, dynamic processes, and "ecological beginnings."

The park, it will likely be judged, has remained as authentic and as inspiring as ever and even more interesting and educational than it was before the fires. As ecologists and other scientists analyze the aftermath, there will be increasing recognition that fire is as important as soil, water, and sunshine in determining the wondrous patchwork of landscapes in our nation's wildlands.

---

[1] Paper presented at Wild Trout IV, Yellowstone National Park, September 18, 1989.

[2] John D. Varley is Chief of Research with the National Park Service, Yellowstone National Park, WY.

When we stand back and view the fires from the distance objectivity demands, as big as the Yellowstone fires were they were really not all that big. Less than 10 percent of the greater Yellowstone ecosystem was affected in any way by the fires, and the area has experienced these effects countless times before since the last ice age. To be sure, the fires caught managers and fire experts by surprise, but they were no surprise to nature. So when spring of 1989 finally arrived, the new natural flowering of Yellowstone began, as it has for so many thousands of years.

Somewhere between 700,000 and 750,000 acres within Yellowstone Park were affected in some way by the fires. There were intense crown fires that burned all the trees, and there were surface fires that burned the undergrowth but spared the canopy. In some places, all vegetation was burned but in many other places the tentacle-like fires left an alternating mosaic, a burned and unburned patchwork, a jigsaw puzzle of endless diversity. There is a macro-mosaic visible from satellite photographs, a micro-mosaic that can only be seen with a magnifying lens, and an infinite array of categories in between. Each will experience regrowth at its own unique pace, further assuring the promise of increased biological diversity in the near future.

The forests that were most affected by fire - that is, crown fires that killed all coniferous species - germinated a new forest from the "seed rain" released by specialized pine cones that only release their seeds if they are burned. In these stark looking areas, it will take about three years for the landscape under the burned canopy to be wholly covered with grasses, forbs, shrubs, and the new, young forest. In other areas the speed at which nature works was more stunning. By late June of 1989, the average person would not have suspected that there had even been a fire in many meadows and forests that had experienced creeping ground fire. Deciduous species, such as aspen, willow, birch, and alder, not constrained by the delay of seedling establishment, resprouted from roots and root crowns and, in many areas, had new four- to five-foot leaders by summer's end. But the journalists did not tell you that. More than likely they told you it would be three to four hundred years before we would see the "old Yellowstone" again.

The media's images of the park's wildlife were perhaps even more dramatic. The "money shots" for the visiting videocamera people were those of animals fleeing from the flames, as if to reinforce in the public's mind that vivid Bambi image. Because most large animals were exceedingly unconcerned about the fire activity around them, it turned out that these "money shots" were pretty rare. I was with a camera crew when they filmed a running cow and calf moose. They were fleeing alright, but they were fleeing from a double-rotor Veritol helicopter and the activity around our vehicle. That night, I saw the footage on one of the network newscasts and, to my surprise, learned the moose were really fleeing from "walls of flame."

A few hundred large animals, mostly elk, did indeed succumb to the fires, but the tens of thousands that survived the fires and survived the severe winter of 1988-89 have largely been replaced by a new generation born this year. It is clear to ecologists that the wild residents of Yellowstone have had a lot less difficulty with the fires than we human ones have.

But the subject of Wild Trout IV is trout. What really happened to the aquatic ecosystems as a result of the greater Yellowstone fires?

Slightly over 5 percent (111,000 acres) of the park's 2.3 million acres are covered with water. To be more specific, over 150 lakes comprise approximately 106,000 acres and literally hundreds of rivers and streams make up over 2,700 miles or 5,000 acres of running water.

Nineteen different major basins, or subbasins, were affected by the fires to varying degrees. The four large oligotrophic lakes (Yellowstone, Shoshone, Heart, and Lewis Lakes - combined they make up 94 percent of the park's water area) had significant portions of their drainages burned. We now have provisional data which suggests that about 28 percent of the Yellowstone Lake watershed burned. Shoshone Lake had the least burned, approximately 8 percent. About 33 percent of the Lewis Lake drainage burned, and Heart Lake, with 50% of its drainage affected, had the largest proportion burned of the four big lakes. Interestingly, the Heart Lake drainage burned heavily in 1981, so between that fire and the fires of 1988, the majority of this lake's basin has burned in recent years. Research following the 1981 fires, demonstrated that the fires had no deleterious effects on the fisheries and may very well have had a stimulatory effect on the productivity of Heart Lake.

Preliminary estimates suggest that approximately 32 percent or about 860 miles of the park's stream systems were influenced directly by the fires (fig. 1).

There were very few instances where heat from the fires caused direct fish mortality. A small stream on the Shoshone National Forest apparently had water temperatures elevated enough to cause direct mortality of trout. There was only partial mortality, and there were many survivors. Stream ecologist Dr. Wayne Minshall of Idaho State University observed heat fracturing of the surfaces of rocks in some first order streams and the scorching of exposed and shallowly submerged aquatic plants along the stream course (Minshall et al. 1989).

There were several instances in the park where significant but localized fish mortality occurred as a result of inadvertent drops of fire retardant from slurry bombers. The most common

Figure 1.--Extent of the greater Yellowstone fires by drainage basin.

retardant used was ammonium phosphate, a concentrated agricultural fertilizer.

Some fish mortality was reported in several of the park's second and third order streams following the first postfire rains. This was reportedly due to an increase in the concentration of certain ions which occurred when dissolved ash was washed into the streams. However, laboratory tests done last fall with ash under controlled conditions failed to kill hatchery rainbow trout (Dan Woodward unpubl. report[3]). Thus, the cause of trout mortality in these particular streams remains a mystery.

And so the short-term effects on aquatic ecosystems and trout appeared to be fairly minimal considering the enormous scale of things. How about the intermediate effects?

Hydrologists had warned us to expect some very dynamic fluid processes for one to three years following the fires (Mills 1989, Christensen 1989). The first and greatest event they told us would be the first postfire snowmelt. We had a normal snowpack during the 1988-89 winter, so a rapid melt could have potentially moved a lot of soil. It did not happen that way. In fact, nature gave us an extended, cool spring which in turn gave us a gradual and uneventful runoff. Measured sediment loads during the spring of 1989 were actually lower than had been measured in prior years.

Hydrologists predicted that summer storm events - thunderstorms - also had the possibility of moving some of the landscape around. This prediction proved to be accurate. Roughly a dozen or so "debris flows" occurred in the park in 1989, some a hundred yards wide and a quarter mile long. Though some certainly disrupted fishing because of muddy water or the very peculiar "blackwater" phenomena caused by charcoal in suspension, we have observed no particular disruption to fishlife.

So what of the long-term prospects? Here we must get into the business of extrapolating beyond our data set - always a tenuous proposition. The

---

[3] Woodward, Report. 1989. Preliminary report, U.S. Fish and Wildlife Service, Jackson, WY.

land management agencies in the greater Yellowstone area went about it in several different ways:

1. An interagency team of about a dozen biologists assessed the fire-related effects on fish and aquatic ecosystems throughout the greater Yellowstone area and published their findings in a March 1989 report (Mills 1989).

   Recognizing that the agencies suffered a substantial credibility hit in the American public's eye as a result of the 1988 fires, agency executives saw certain wisdom in going an extra step by:

2. Convening an nongovernment panel of 13 fire-ecology experts to evaluate the ecological implications of the fires. Their report was completed in June of 1989, and it has a full section on hydrology and aquatic ecosystems (Christensen 1989).

The findings of the two groups were largely consistent. They concluded that impacts to aquatic systems and fisheries from the fires will be minimal and generally short-termed. The conclusions were drawn considering basin hydrology, geologic types, and the character of soils in Yellowstone.

They noted, however, that there is surprisingly little known about the role of fire effects on the aquatic world. As a result, 15 research projects are already underway to learn more about the fires' effects on aquatic ecosystems and fisheries. The unique aspects of the 1988 fires - their scale and the fact that they burned terrestrial habitats previously thought to be fire-resistant - makes postfire research an essential element of our understanding of dynamic processes in wild aquatic settings.

LITERATURE CITED

Christensen, N. L., J. K. Agee, P. F. Brussard, J. Hughes, D. K. Knight, G. W. Minshall, J. M. Peek, S. J. Pyne, F. J. Swanson, S. Wells, J. W. Thomas, S. E. Williams, and H. A. Wright. 1989. Ecological consequences of the 1988 fires in the greater Yellowstone area. Final report, the greater Yellowstone postfire ecological assessment workshop. Yellowstone National Park, WY.

Mills, S., ed. 1989. The greater Yellowstone postfire assessment. Greater Yellowstone Coordinating Committee, Yellowstone National Park, WY.

Minshall, G. W., J. T. Brock, and J. D. Varley. 1989. Wildfire and Yellowstone's stream ecosystems. Bioscience 39:701-715.

Smith, C. 1989a. Reporters, news sources, accuracy, and the Yellowstone forest fires. Paper presented at the annual meeting of the International Communications Association, San Francisco, May 1989.

_____. 1989b. Flames, firefighters and moonscapes: network television pictures of the Yellowstone forest fires. Paper presented at the third annual Visual Communications Conference, Park City, UT, 26 June 1989.

_____. 1989c. Brave firefighters, endangered national icons and bumbling land managers: network TV myths about the 1988 Yellowstone wildfires. Paper presented to The Association for Education in Journalism and Mass Communication, Washington, D.C., 13 August 1989.

Montana Trout Fisheries and the 1988 Drought[1]

Liter E. Spence[2]

The Montana drought of 1988 caused notable fishery problems on large reservoirs in the northwest part of the state and on streams and reservoirs in the Southwest. Many other waters suffered from lack of precipitation and increased irrigation demands. Some drought impacts on these waters and their fisheries are discussed.

INTRODUCTION

Overview

The large forest fires which occurred in Montana and other western states during the summer of 1988 received national media attention, particularly the fires in Yellowstone National Park. Drought conditions which began in 1985 culminated in 1988 in one of the driest years on record. Poor winter snowpack and lack of spring and summer precipitation produced dry forest conditions which were ripe for fueling natural and man-caused fires.

Receiving less publicity were the significant impacts the same lack of moisture had on water supplies in streams and lakes. In Montana, water supplies were very limited and the combination of low natural streamflows, diversions for irrigation and reservoir releases for hydro-power production significantly affected many streams and lakes during the drought of 1988.

Drought History

Drought episodes in various regions of Montana have occurred to one degree or another in three out of the last four years. In 1985, spring weather caused runoff from a moderately low snowpack to occur 2-4 weeks earlier than normal. Extremely low precipitation and high temperatures during June created critical low flow conditions in many rivers and streams. However, persistent rainfall in August and September provided relief at a time when streamflows were at their seasonal lows. (DNRC, unpublished data)[3]

In 1987, snowpack was lower than it was in 1985. However, soil moisture at the beginning of the summer of 1987 was high, thanks mostly to good precipitation during the fall of 1986. In addition, storage in both large and small reservoirs throughout the state was in good shape heading into the spring and early summer. While summer precipitation was below normal over most of the state, the overall drought conditions could be characterized as relatively mild. (DNRC, unpublished data)[3]

In comparison, 1988 began with poor soil moisture conditions. Snowpack was significantly below average although better than in either 1985 or 1987. Peak snowpack in most river basins was only 70-75 percent of average. However, a warm spring again caused runoff 2-3 weeks earlier than normal. By mid-June, snowpacks were nearly exhausted, with only a few higher elevation sites continuing to hold snow. Continued hot temperatures and low summer precipitation together with existing low soil moisture reserves increased demands for already low streamflows. This time, however, there was no substantial late summer precipitation to provide relief, and streamflows continued to decline. (DNRC, unpublished data)[3]

---

[1] Paper presented at the Wild Trout IV Symposium, Yellowstone National Park, Mammoth, Wyoming, September 18-19, 1989.

[2] Water Resources Supervisor, Montana Department of Fish, Wildlife and Parks, Helena.

1988 Water Availability

Past precipitation deficits were reflected in winter 1987/88 streamflows that ranged between 40 and 70 percent of average because of reduced baseflow. Reservoir carryover in most large federal water projects was above average in anticipation of continued dry conditions across the state. Storage in smaller state irrigation project reservoirs was generally below average because of poor fall runoff conditions and heavy demand during the previous summer. Soils were extremely dry across most of the state. Much higher than normal temperatures and low precipitation throughout the state boosted irrigation demands on reservoirs and streams. Long-term moisture indicators showed severe to extreme drought conditions in all areas of the state except the south central region. (DNRC, unpublished data)[3]

Above normal temperatures and continued growing season precipitation shortages continued largely unabated in July and August. There were occasional, but temporary, improvements in soil moisture from summer storms in some areas. Streamflows in most drainages continued at exceptionally low levels because of the almost complete lack of runoff, low baseflow conditions and high irrigation demand. Low inflow and rapidly declining storage required reductions in normal reservoir releases for numerous irrigation projects. (DNRC, unpublished data)[3] By mid-August, record low streamflows were occurring in the upper Missouri drainage, Marias, Musselshell, Yellowstone, Powder, Blackfoot, upper Clark Fork, and Flathead river basins (USGS, unpublished data)[4]. The first substantial drought relief was brought by several storms that crossed the state in mid-September, dropping up to one inch of precipitation in many locations. (DNRC, unpublished data)[3]

GENERAL DROUGHT IMPACTS

The Department of Fish, Wildlife and Parks' (DFWP) Fisheries Division compiled regional summaries of the effects the 1988 drought had on lakes and streams. Unless otherwise referenced, the following information is from those summaries.

---

[3] Department of Natural Resources and Conservation. 1988 Drought Summary prepared for legislative Water Policy Committee. Helena, Montana. 3 pp.

[4] U.S. Geological Survey Tech. Announcement. August 10, 1989. Helena, Montana.

Flathead/Kootenai River Drainages

Streams in these basins were not impacted as severely as in other parts of the state because of fewer irrigation requirements. Although streamflows were lower than normal and in some cases reached record lows, most of the drought impacts occurred in the basins' numerous lakes and reservoirs. Major impacts occurred at two of the largest federal reservoirs, Libby and Hungry Horse. Drawdowns reached 141 feet at Libby and 178 feet at Hungry Horse in April, 1988, reducing reservoir volumes by 76 and 77 percent, respectively. The worst drawdowns occurred in early spring before the drought really showed up in the rest of the state. These drawdowns occurred primarily to meet winter power demands in the lower Columbia basin. Due to the extreme drawdowns, Hungry Horse filled to only 70 feet of full pool in spring, 1988. Libby refilled to within 20 feet of full pool. Releases at Libby Dam were lowered from the recommended 4,000 cfs minimum to 3,000 cfs.

Anglers were very successful on the reservoirs due to crowding of fish. However, the number of anglers able to use the reservoirs was reduced because of their inability to launch boats. The Corps of Engineers (COE), U.S. Forest Service (USFS), and Bureau of Reclamation (BOR) eventually extended some boat ramps at each reservoir. There were numerous public outcries over the recreational problems associated with Libby and Hungry Horse reservoir drawdowns, which were dramatic and highly visible.

Clark Fork Drainage

Streamflows in the upper Clark Fork (above Milltown Dam) reached record low levels. Portions of the Clark Fork above Deer Lodge were practically dry due to a combination of low runoff and heavy irrigation use. In the upper Clark Fork, in-channel sedimentation and nutrient loading intensified as a result of low flows. These factors, coupled with drought-related habitat reductions and warmer water temperatures, further stressed the already depressed trout populations in the river. In addition, summer drought conditions likely aggravated the poor recruitment that chronically plagues the river's trout fishery.

Flows in the Blackfoot River also reached record low levels. Bull trout redd counts were down 60-70 percent in key spawning areas of the Blackfoot drainage, very likely due to low flow conditions. Lack of adequate spring flushing flows in the last five years has resulted in above normal sediment accumulation within the stream channel that could affect the survival of incubating trout eggs, the supply of aquatic food items, and the quality of habitat. Long-term drought impacts are anticipated, although these impacts may be masked by other environmental problems, most notably toxic metals pollution originating in the headwaters.

No fish kills were reported in either the Clark Fork or Blackfoot rivers, except a fish kill in the Clark Fork headwaters which was not entirely drought related, but instead due primarily to toxic metals pollution.

Upper Missouri River Drainage (Above Canyon Ferry Dam)

Of all the river basins in the state, the upper Missouri received the most attention and notoriety. Streamflows reached severely low levels in the Jefferson, Big Hole, Red Rock, and Missouri rivers, and in the lower Gallatin River to a lesser extent. The entire length of the Big Hole River was affected by well below normal flow which, for the first half of August, constituted the lowest flows of record (65 years) at the USGS gauge at Melrose. Reaches most severely affected were in the upper river near Wisdom where flow actually ceased for about 1/2 mile, and in the lower river from the Pennington Bridges to the mouth where flows of less than 10 cfs occurred between pools. Afternoon temperatures in August approached 80 F. August streamflow at the Melrose gauge ranged between 55 and 75 cfs (average August flow is 479 cfs). By mid to late September, flows increased to 150 to 190 cfs and by mid-October reached 250 cfs in response to reduction in irrigation diversions.

The entire 84-mile length of the Jefferson River was impacted by low flows. Approximately 12 miles of stream virtually stopped flowing. The lowest instantaneous flow recorded in August at the USGS gauge near the mouth at Three Forks was only 43 cfs. The highest average daily flow was 81 cfs, well below what the river requires at that point. Water temperatures reached 82 F. at some locations in the river. Several small fish kills were documented.

The upper 10 miles of the Beaverhead River (Clark Canyon Dam to Barretts) is used to transport irrigation water to the Bureau of Reclamation's East Bench Unit. Therefore, this part of the river suffered no flow reductions until late August - early September. The lower Beaverhead (below Barretts) suffered severe flow reductions during early summer (June-July) but began to benefit from irrigation return flows in August. Flow releases at Clark Canyon Dam were cut to 50 cfs during the fall and winter of 1988/89. Recommended releases are 200 cfs.

Despite adequate fishery flows in the lower Madison River below Ennis Reservoir, fish kills related to elevated water temperatures - a problem resulting from the solar heating of Ennis Reservoir - periodically occurred throughout the summer. Water temperatures reached over 82 F. during these periods. However, excellent survival of trout occurred in the upper river above Ennis Reservoir where water releases by Montana Power Company (MPC) at Hebgen Dam maintained a respectable river flow throughout the summer.

Lima Reservoir on the Red Rock River above Clark Canyon Reservoir lost practically all stored irrigation water by about June 23 and remained nearly empty throughout the irrigation season. The absence of stored water releases from the reservoir resulted in severe dewatering of the Red Rock River by irrigation diversions. About 8 miles of the Red Rock River between Lima and Dell were dry throughout the summer and other portions of the stream were dry into late October. The loss of storage in Lima was due to a combination of insufficient runoff from the upper watershed and the unfortunately timed draining of the reservoir in the fall of 1987 for a dam safety inspection. It requires 80,000 acre feet of water to refill. The reservoir continued virtually empty all fall and winter.

Clark Canyon Reservoir entered the 1988 summer irrigation season with about 180,000 acre feet of storage, slightly above the normal operating pool of about 178,000 acre feet. Spring and summer inflows were much below average. Despite reductions in irrigation water allotments from 5.0 acre-feet to 4.25 acre-feet per acre, high excess water use charges, and an early (August 20) end to irrigation, the storage pool was reduced to about 75,000 acre-feet. The surface area of the pool was reduced from 5,100 to 3,100 acres. This condition remained through the winter of 1988-89, leaving large acreages of normally productive littoral zone exposed and dry. Because Lima Reservoir was nearly dry and had a prior water right to the first 80,000 acre-feet of run-off, the prognosis for 1989 was that, with average snowpack and spring precipitation, Clark Canyon Reservoir would probably only fill to 125,000 to 130,000 acre- feet and would enter next year's irrigation season 25,000 to 30,000 acre- feet below average storage. In fact, the reservoir filled to only 122,000 acre-feet in 1989 and was reduced to about 40,000 acre feet by the end of the 1989 irrigation season.

Canyon Ferry Reservoir was drawn down substantially, but adverse effects on the fishery due to this condition have not been detected. However, due to very low inflows, the fall run of brown trout out of Canyon Ferry Reservoir into the Missouri River was rather poor during the fall of 1988.

Mid-Missouri Drainage
(Canyon Ferry Dam to Fort Peck Dam)

Throughout the summer, water released from Canyon Ferry Reservoir maintained about 3,000 cfs in the Missouri River; however, storage was insufficient to supply the 4,100 cfs needed to adequately wet the river's many side channels which are key rearing areas for young fish and spawning areas for brown trout. Young rainbow trout recruits to this reach of the Missouri River will likely be far below normal due to dewatering of the river's few spawning tributaries, notably Sheep and Little Prickly Pear creeks and the Dearborn River. While serious impacts on the Missouri's adult trout population are not anticipated, the potential shortage of young recruits may limit future adult numbers.

On the Smith River, the 66-mile popular floating section beginning at Camp Baker could not be utilized by floaters after July 4, 2-3 weeks earlier than normal. Flows at the USGS gauge at Camp Baker reached a low of 18 cfs in early September. A flow of at least 100 cfs is recommended for adequate floating.

Fish losses occurred in the trout streams of the Bear Paw Mountains. Loss of forage fish and adult and sub-adult game fish occurred in some tributaries to the Milk and Missouri rivers. The larger irrigation reservoirs, including Fresno and Nelson, were drawn down to the maximum, flushing large numbers of game fish into irrigation canals and ditches. High turbidity, decreased food production, and increased predation in the shrunken reservoir pools further reduced remaining game fish numbers.

Trout in Martinsdale, North Fork Smith River (Sutherlin) and Bair reservoirs were severely reduced by critically low water levels. A serious sediment problem occurred in the North Fork Smith River below North Fork Smith River Reservoir due to the extreme drawdown and wave action on mud flats.

Trout ponds, particularly those northwest of Great Falls, suffered from low water conditions. Many of these ponds were not planted this past spring in anticipation of the drought. Few of the smaller reservoirs and farm ponds experienced summer fish kills but 40-50 percent of these waters were subject to winter kill due to extremely low water levels at freeze-up.

Brown trout populations in the upper Musselshell River, which have been at reduced levels due to chronic low summer flows, and which were reduced by 50 percent in 1987 following extreme dewatering, remained at a similar level following the low flows 1988.

Other small streams were, in general, severely dewatered during the summer's drought, potentially impacting their trout fisheries.

Yellowstone River Drainage

The upper Yellowstone River mainstem at Livingston dropped to 639 cfs in January 1988, approaching the all-time record low of 590 cfs reached in January 1940. Average annual discharge at this site is 3,728 cfs for a 63-year period of record. Side channels of the upper Yellowstone River - key spawning areas for the river's brown trout - were generally avoided by spawners due to the low flow levels. The 1988 crop of young brown trout may have been significantly reduced. Lower than normal flows in spawning tributaries to the upper Yellowstone River reduced the reproductive success of the river's cutthroat trout population, potentially reducing the number of adult cutthroat in future years. Portions of most of these streams dry up every year, but in 1988 they dried up earlier than normal.

The Boulder and Shields rivers were, in general, also severely dewatered. Trout populations will likely suffer from these conditions, but no data is currently available.

Flows in the mid and lower Yellowstone River reached the lowest levels of record as recorded by the USGS over a period of 50 years or more. A number of tributary streams, including the Clarks Fork and Rock Creek, all suffered severe dewatering. Portions of the Stillwater River were similarly affected. Specific impacts on the fisheries in these streams is currently unknown.

The Bighorn River maintained good trout survival due to releases from Yellowtail Dam. However, colder than normal water releases occurred--an anomaly associated with below normal reservoir inflows--which stunted trout growth, reducing the overall size of the trout in the Bighorn River fishery.

SPECIFIC FISHERIES IMPACTS

Other than documented fish kills, specific data on the effects of the 1988 drought are not yet available on many streams and lakes. Additional sampling of fish populations will be required to determine these effects. However, some preliminary information is available on a few waters.

Beaverhead River

Initial observations during spring, 1989 electrofishing on the Beaverhead River between Clark Canyon Dam and Dillon indicate the rainbow and brown trout populations were severely reduced by the low releases (50 cfs) from Clark Canyon Dam during fall and winter of 1988. Rainbow comprise 15-20 percent of the population while brown trout comprise 80-85 percent.

DFWP has two electrofishing sections in the 10 miles of river between Clark Canyon Dam and the Barretts Diversion Dam located 7 miles south of Dillon, Montana. The 1.2 mile Hildreth section begins two miles below the dam and the 2.5 mile Pipe Organ section about five miles below the dam.

Resident rainbow trout population estimates are usually unreliable if made in the spring because of errors inherent with in-migration of adult spawners into study sections. However, during the spring 1989 brown trout population sampling, some effects of low flow on rainbow trout were also observed in the two sections. More conclusive impacts on rainbow will be available after the fall, 1989 estimates are made.

In the Hildreth section, rainbow appear to be at their lowest level in the last 10 years. The number of large adult rainbow actually captured while electrofishing this section has averaged about 100 fish since 1983. In 1989, only four (4) large adult rainbow were captured. Their condition factor, which relates the weight of a fish to its length, was down 15 percent of average. There is a significant rainbow spawning area in the middle of this section. (Oswald, Pers. Comm.)[5]

In the Pipe Organ section, total numbers of rainbow declined 28 percent, total weight was down 43 percent, and the average condition factor dropped 10 percent. These estimates are only approximate, but this section is not as significant for rainbow spawning as is the Hildreth section and some validity can be placed on these numbers for trend information. (Oswald, Pers. Comm.)[5]

More accurate estimates for brown trout were obtained in the same two sections. In the Hildreth section, brown trout numbers were greater in 1988 than in 1989 but the total estimate was influenced by numerous age 2 fish from the 1986 year class. Total weight was down 7 percent. Major impacts occurred on the larger "trophy" trout. Brown trout 18 inches or over (18"+) declined 37 percent and trout 20 inches and over (20"+) declined 50 percent (Figs. 1 and 2). Total weight was down 47 and 58 percent,

[5] Oswald, R. Personal Communication. Montana Department of Fish, Wildlife and Parks, Dillon, Montana.

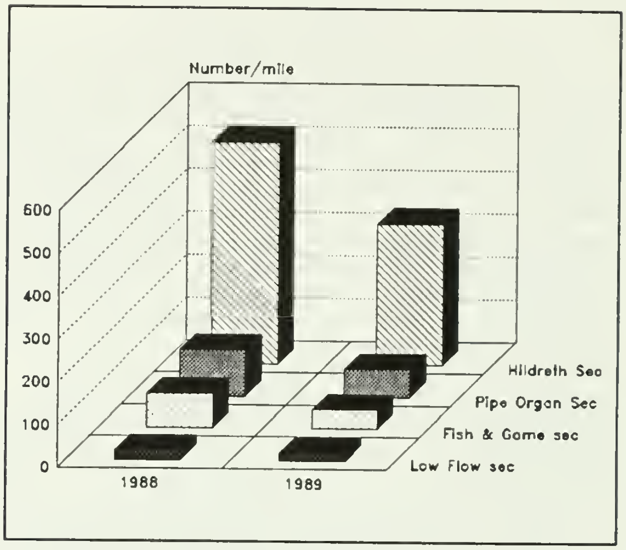


Figure 1. Estimated spring numbers of brown trout 18 inches and over in four sections of the Beaverhead River, 1988 and 1989. (Oswald, Pers. Comm.)[5]

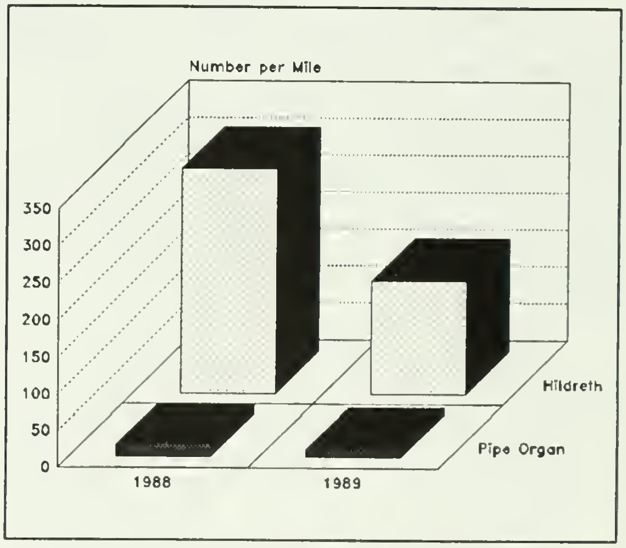


Figure 2. Estimated spring numbers of brown trout 20 inches and over in two sections of the Beaverhead River, 1988 and 1989. (Oswald, Pers. Comm.)[5]

respectively, in 18"+ and 20"+ trout (Figs. 3 and 4). Condition factors were down 14 and 16 percent of average respectively. (Oswald, Pers. Comm.)[5]

In the Pipe Organ section, total brown trout numbers were down 12 percent and weight declined 23 percent from 1988. Average condition factor was down 9 percent. Again, losses were greater in the larger trout. Trout 18"+ were down 37 percent in number and 48 percent in weight (Figs. 1 and 3). Trout 20"+ were reduced 50 percent in number and 55 percent in weight (Figs. 2 and 4) Average condition factor was down 11 and 13 percent, respectively in 18"+ and 20"+ trout. (Oswald, Pers. Comm)[5]

Two additional electrofishing sections are located in the 7 miles of the Beaverhead River between Barretts and the town of Dillon. The 1.7 mile Fish and Game section is located immediately south of Dillon. This section typifies the brown and rainbow trout populations of the upper river below Barretts Diversion. Under normal flow conditions, this section receives ample summer flows because water is delivered past Barretts Diversion to the West Bench Canal. Downstream from the West Bench Canal the river sustains the lowest summer flows within the system. (Oswald, Pers. Comm.)[5]

The 2.5 mile Low Flow section is located downstream from the Fish and Game section within the town of Dillon and it lies within the lowest flow portion of the river below the West Bench Canal (Oswald, Pers. Comm.)[5]

In the Fish and Game section, total numbers of brown trout age 2 and older declined 11 percent, while their total weight dropped 16 percent. This is very similar to what happened in the Pipe Organ section. Trout 18"+ declined 44 percent in number and 48 percent in weight (Figs. 1 and 3). Average condition factor declined 7 percent.

In contrast to the other three sections, brown trout in the Low Flow section increased in both numbers and total weight. Total numbers increased 14 percent and total weight by 20 percent. A 5 percent increase in average condition factor also occurred. Because of the

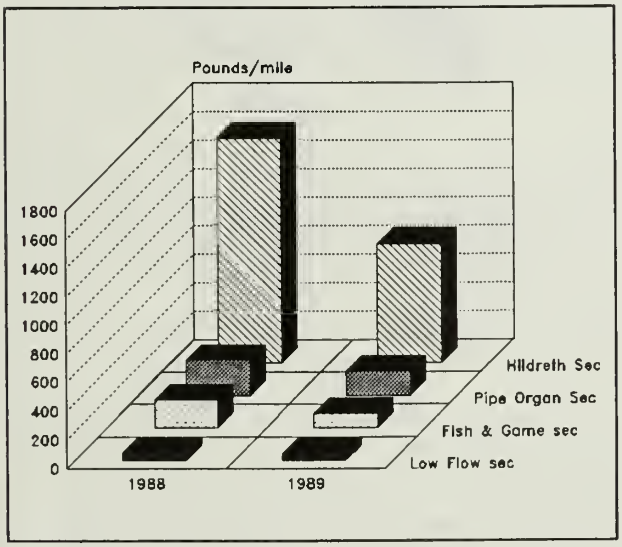


Figure 3. Estimated spring weight of brown trout 18 inches and over in four sections of the Beaverhead River, 1988 and 1989, (Oswald, Pers. Comm)[5]

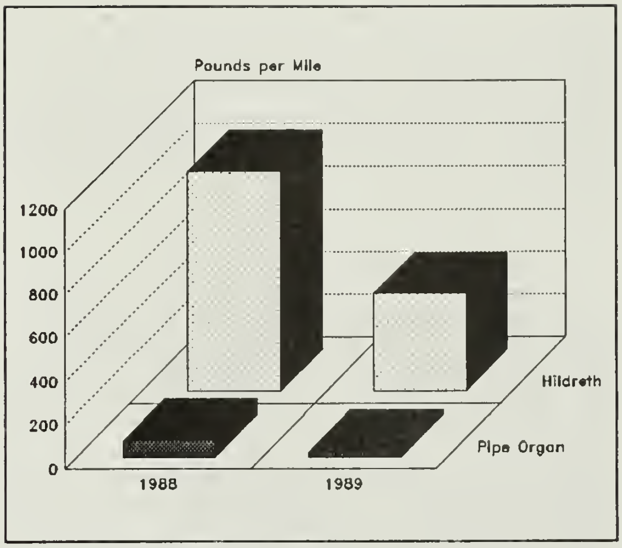


Figure 4. Estimated spring weight of brown trout 20 inches and over in two sections of the Beaverhead River, 1988 and 1989. (Oswald, Pers. Comm)[5]

drought situation, flows higher than those which usually occur in this reach were transported through the reach to satisfy downstream irrigation demands. Thus the section experienced higher than normal flows during the summer, resulting in a larger trout population. The numbers of 18"+ brown trout declined slightly (Fig. 1); however, there are few of these larger fish in this section. (Oswald, Pers. Comm.)[5]

Clark Canyon Reservoir

The fishery in Clark Canyon Reservoir suffered from low lake levels following the 1988 irrigation season. Only 75,000 acre- feet of water remained in the reservoir as it entered the 1988/89 winter period. This was only 42 percent of the normal operating pool level of 178,000 acre-feet. The severe pool reduction had a significant impact on both brown and rainbow trout survival over the winter period.

Spring 1989 gill netting data show rainbow trout were reduced 42 percent and brown trout 50 percent from 1988 numbers. Between 1985-88 there was a steadily expanding rainbow population, with 6.3 rainbow per net set in 1985 and 17.7 rainbow per net set in 1988. In 1989 there were 10.2 rainbow per net set. (Oswald, Pers. Comm.)[5]

There is concern that the winter of 1989/90 may place additional stress on reservoir trout populations because the fall 1989 reservoir capacity, at about 40,000 acre feet, is 47 percent lower than it was in the fall of

1988 (75,000 acre-feet) due to lack of carryover storage from 1988 and the 1989 irrigation demands on the reservoir. Also, because of the low carry-over volume, winter reservoir releases may be even less than the 50 cfs released during the winter of 1988, placing additional stress on trout in the Beaverhead River below the dam.

Big Hole River

Flows in the Big Hole River set record lows at the Melrose gauge (at river mile 31.1). The average daily flow for August was 88 cfs. The long term (65 years) mean August flow is 479 cfs. (Fig. 5).

Two fish population study sections have been established in the Big Hole River below the town of Wise River--an upper section near Jerry Creek, and a lower section (called Hog Back) near Glen. Figure 6 shows 1987 and 1988 fall rainbow trout populations in the Jerry Creek section. Figure 7 compares 1988 and 1989 fall brown trout data for the Hog Back section. Total rainbow numbers were reduced 31 percent in the Jerry Creek section. Brown trout numbers dropped 44 percent in the Hog Back section. In both sections, the most dramatic decreases were in the smaller age groups (age 1 and 2). Age 1 rainbow decreased 56 percent in the Jerry Creek section. Age 2 brown trout decreased 78 percent in the Hog Back section. (Oswald, Pers. Comm.)[5]

The lower Big Hole is a relatively wide, not highly meandered stream with numerous shallow water habitats that can be singularly occupied by smaller fish. As flows drop, smaller fish are forced into deeper water areas occupied by larger trout. Reduced living space, increased predation and other environmental and social stresses most likely accounted for the significant losses.

Larger age classes of brown trout were not affected by low flows. However, such was not the case with rainbow trout. The larger (age 4) rainbow decreased along with the younger (age 1) fish, most likely due to the characteristics of larger rainbow habitats which tend to become dewatered more severely with flow reductions than do the habitats of larger brown trout.

DROUGHT RESPONSES

During a prolonged drought like 1988, DFWP has few tools to combat the effects of low water on fisheries. However, purchasing water from reservoirs when available, protecting instream flow water rights and reservations, implementing restrictive fishing regulations, coordinating reservoir operations with private and federal agencies, and promoting changes in operation of private irrigation diversions were some drought responses implemented by DFWP in 1988.

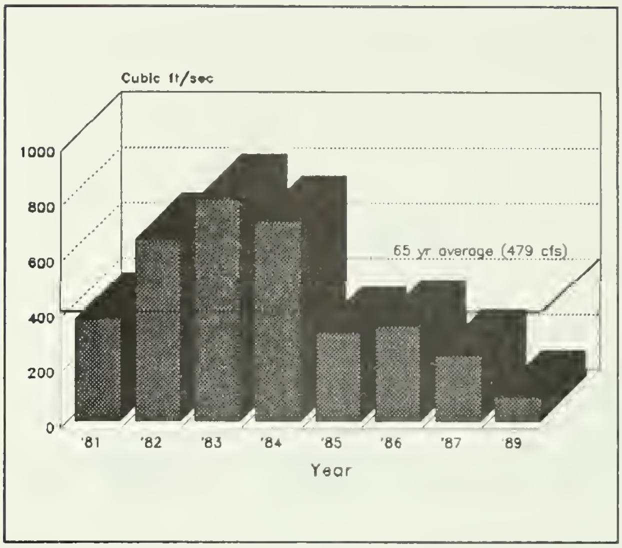


Figure 5. Average August streamflow in the Big Hole River at the USGS gauge near Melrose, Montana, 1981-1988. (Oswald, Pers. Comm)[5]

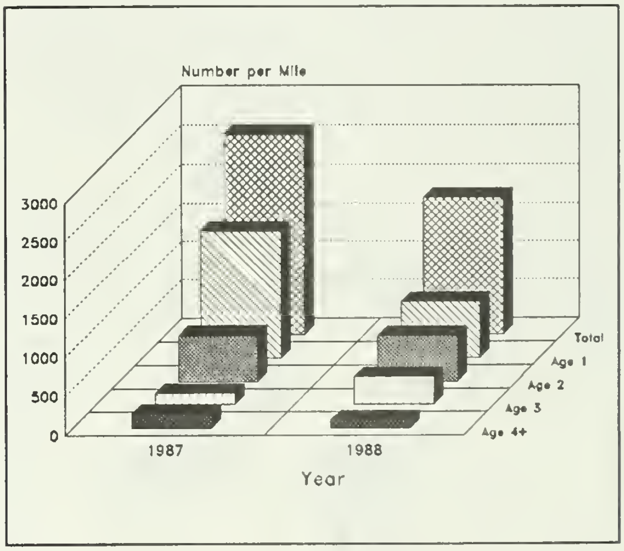


Figure 6. Fall rainbow trout populations in the Jerry Creek section of the Big Hole River, 1987 and 1988 (Oswald, Pers. Comm)[5]

Water Purchase

DFWP purchased 15,000 acre-feet of water from Painted Rocks Reservoir, a state water project, for release into the Bitterroot River (a major Clark Fork River tributary) to help maintain a flow of at least 100 cfs at Bell Crossing near Stevensville during the summer irrigation season. Although 100 cfs is only about 25 percent of the amount required in the channel, it is a significant improvement over previous summer flow conditions which often left the stream with almost no flow in this reach. Protection of the released water instream is dependent upon a water commissioner which DFWP hires to ensure the purchased water is not diverted for agricultural uses.

Protection of Water Rights and Reservations

DFWP has instream water rights on 12 major "blue ribbon" streams and on three smaller streams. It also has instream water reservations on 69 streams in the Yellowstone River Basin. During drought years, DFWP notifies water users who have junior priority dates that they may be asked to cease using their water if flows fall below the claimed rights or reservations. In 1988, junior users on most of those streams were notified to cease using their junior water so that the instream values could be protected. Despite this action, flows still dropped below the instream rights on some streams due to the natural water shortage and senior water rights, which are not affected by the DFWP instream rights and reservations.

Restrictive Fishing Regulations

Restrictive regulations of an emergency nature were implemented during the summer of 1988. These new regulations modified those which were in effect at the time. Their purpose was to protect wild adult trout stocks in streams and to compensate for severe dewatering of reservoirs which are managed with hatchery trout. They were the most extensive emergency regulations in the department's history. The general policy was to restrict creel limits on wild trout streams and to remove creel limits on reservoirs which were severely dewatered and which were likely to lose their fish populations.

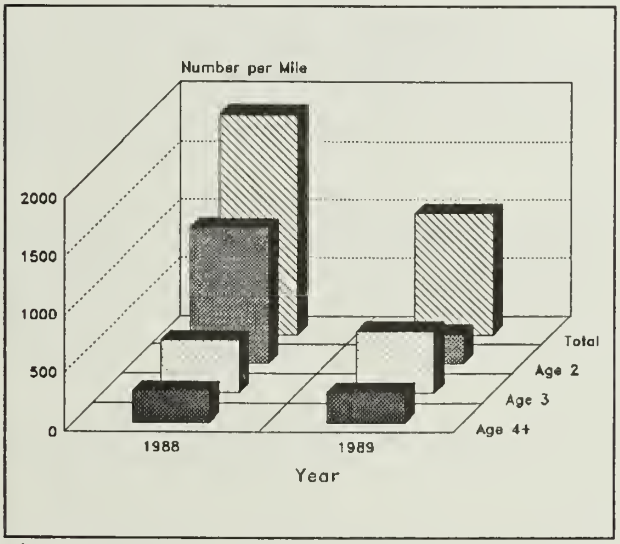


Figure 7. Spring brown trout populations in the Hog Back section of the Big Hole River, 1988 and 1989 (Oswald, Pers. Comm)[5]

In streams, the reduced creel limits were designed to protect adult trout which were becoming extremely vulnerable to a variety of environmental stresses in addition to angling pressure. Montana does not stock hatchery fish in its wild trout streams. Therefore, the remaining wild trout were essential to the natural rebuilding of trout populations during spring and fall spawning periods. In lakes and reservoirs, however, stocking can bring back a fishery within a year or two after water levels return to normal. (Fish were not stocked at all in some lakes and ponds where water levels were expected in 1988 to be too low to allow fish to survive the drought and the following winter.)

The Montana Fish and Game Commission ordered restrictive regulations on a number of streams and lakes on August 8, 1988. Wild trout streams with severe dewatering problems receiving these regulations included the Big Hole, Smith, Clark Fork, Little Blackfoot and Blackfoot rivers. On August 29, 1988, the Commission placed additional restrictions on some waters. Some of the restrictions continue in effect through February 28, 1990.

It should be noted that several trout streams already had some sections where special management regulations were in effect to protect the spawning populations. Additional site specific regulations are being considered for the 1990-1992 fishing seasons.

Reservoir Operation Coordination

DFWP coordinates with the BOR, COE and MPC concerning reservoir operations which can benefit downstream fisheries. This enables DFWP to contribute fishery information and recommend minimum releases that consider the life cycles of the trout inhabiting the streams below the dams. During low flow years like 1988, this coordination between agencies enabled reservoir releases to be maintained at levels higher than what would have occurred without cooperation. BOR projects at Hungry Horse, Canyon Ferry, Tiber, Clark Canyon, and Yellowtail reservoirs, a COE project at Libby Reservoir and the MPC project at Hebgen Lake are included in the coordination process. With the exception of Clark Canyon Reservoir, coordination was effective during 1988 in minimizing downstream fishery impacts, even though reservoir water supplies were not always available for full implementation of recommended releases.

Operation of Irrigation Diversions

DFWP distributed information to irrigators on how to shut down their diversions to save trout. In severely dewatered streams, trout will frequently leave the stream to reside in irrigation ditches which have more water. However, if the ditches are turned off suddenly, trout become stranded and die. Irrigators were asked to shut off their ditches gradually so trout could move back out of the ditches into the streams of residence. This relatively new program proved successful in several instances during 1988 and it is hoped wider publicity will encourage greater use of the program by irrigators, not only in extreme drought years but as a matter of regular practice.

SUMMARY

1988 was a significant drought year from both an agricultural and fisheries standpoint. Aggravated by two previous years of low precipitation and winter snowpacks, 1988 was a record year for low soil moisture and streamflows in most areas of the state. The most notable problems occurred on large reservoirs in the northwest part of the state and in reservoirs and streams in the southwest; however, many other waters suffered severe dewatering from lack of precipitation and increased irrigation demands.

A thorough understanding of the impacts of the 1988 drought on Montana lake and stream fisheries will likely not be known for several years. Although observable fish kills did occur in some streams and lakes, delayed fish losses of larger magnitude are evident on some waters where preliminary population studies have been conducted.

Note: The 1989 Montana legislature, after considerable public controversy, passed HB 707, a water leasing bill. The bill was passed in response to the 1988 drought's effect on stream fisheries. The bill enables DFWP to develop a pilot program to lease water from irrigators and convert the water to instream use. The purpose is to make additional water available for fishery use in times of low flows. This is the first authority ever obtained in Montana to legally change diversionary water uses to instream uses.

Wild Trout Management in the Eastern Megalopolis[1]

Robert A. Bachman, Howard J. Stinefelt, and Charles R. Gougeon[2]

Abstract.--Situated in the middle of the heavily-populated Baltimore-Columbia-Frederick-Rockville-Washington megalopolis, Maryland's wild trout fishery is showing dramatic improvement in the face of rapid increase in fishing pressure. Improved instream flows, cessation of stocking hatchery trout on wild trout populations, innovative restoration techniques, and implementation of regulations designed to reduce harvest of wild trout have resulted in extremely rapid increases in wild trout densities. A two to six fold increase in the standing crop of yearling-and-older brown trout at seven electrofishing sites in Gunpowder Falls near Baltimore was documented in just one year after intensive restoration efforts. Three case histories involving intensive monitoring efforts and complex management techniques are described together with the reasons that more information on hooking mortality of wild trout from different types of terminal tackle and varying angler experience is needed.

INTRODUCTION

Maryland is often referred to as "America in miniature", and nowhere is this attribute better exemplified than in Maryland's diversity of trout streams and trout angling opportunity. Ed Cooper, (1970) wrote:

"Many fishermen are gregarious and can enjoy pitting their skills against a conditioned hatchery fish in a confusion of crowds of people and tangled lines. Others are solitary souls longing for the opportunity of catching an occasional wild trout from a stream where man has deliberately not interfered with the natural course of events. Fish managers have a responsibility to provide these varied fishing opportunities where it is possible to do so, and to offer the public different options in their search for angling satisfaction. In fish management, as in animal evolution, versatility is likely to lead to success."

By this yardstick, Maryland's trout program can surely be termed successful. A small state, with only about 470 miles of wild trout water, Maryland offers an exceptionally diverse trout fishing experience. Trout fishing opportunity in Maryland includes wilderness trout fishing for indigenous "native" brook trout, wild brown trout in big, rough-and-tumble rivers such as the Youghiogheny in Garrett County, and in small, but very productive streams near the metropolitan areas of Baltimore and Washington. Maryland has naturally reproducing populations of brook, brown, and rainbow trout, and shares with West Virginia on the North Branch of the Potomac, a new and exciting

---

[1]Paper presented at the Wild Trout IV Symposium. [Mammoth Hot Springs, Yellowstone National Park, Wyoming, September 18-19, 1989].

[2]Robert A. Bachman is the Chief of the Freshwater Fisheries Program, Howard J. Stinefelt is a Trout Specialist, and Charles Gougeon is Region III Fisheries Manager, Maryland Department of Natural Resources, Annapolis, Md.

cooperative put-and-take tailwater fishery downstream of Jennings Randolph Reservoir.

The North Branch of the Potomac is an American success story in itself. Up until 1982, when the Jennings Randolph Reservoir filled, the North Branch was virtually devoid of all life in its upper reaches because of acid mine drainage. We now have a 200-ft-deep oligotrophic lake that supports brook, brown and lake trout, and by virtue of a multi-level water release capability, enjoy approximately 12 miles of spectacular tail-water trout habitat downstream of the dam.

Maryland stocks approximately a quarter of a million hatchery trout each year in lakes, ponds, and streams, but our general policy is to stock adult hatchery trout in waters that do not sustain wild trout fisheries. Some of our streams that get low and warm in summer and have prolific insect hatches, provide outstanding delayed harvest trout fishing. One such river, the Casselman in Western Maryland has such an abundant food supply that the early-stocked hatchery rainbows become nearly indistinguishable from wild rainbows by June 1, the date that harvest begins.

A number of our larger impoundments support trout year-round. Survival and growth of hatchery-reared adult rainbow trout stocked as part of our put-and-take program provide the opportunity to catch the occasional trophy trout such as the seventeen pound rainbow caught in Savage River Reservoir in 1987.

Rounding out Maryland's diverse trout fishing opportunities are six tail-water fisheries, two of which have recently been gaining a national reputation. Gunpowder Falls, in Baltimore County, is fed by releases from Prettyboy Reservoir, a Baltimore City water supply reservoir. A contract between the City of Baltimore and Trout Unlimited guaranteeing minimum flows between Prettyboy Dam and Loch Raven Reservoir and cooperative rearing and stocking projects between TU and Maryland DNR has led to Gunpowder Falls justifiably being listed this year by Trout Unlimited as among America's best 100 trout streams. This river, just 20 miles from Baltimore's famous Inner Harbor, now provides a year-round fishery for wild brook and brown trout, put-and-grow rainbow and brown trout, and in sections that will not support trout year-round, a popular put-and-take trout fishery.

Another tailwater fishery, and one that has extraordinary potential for native brook trout fishing is the Savage River in the western part of Maryland. It currently sustains a wild population of brook and brown trout, has excellent water quality, prolific insect hatches, and is being managed under trophy trout regulations. It was the site of the 1989 World-Championship Whitewater Races, and because the same conditions that make it an extraordinary trout stream also make it a superb setting for whitewater competition, the Savage River presents a unique management challenge.

As reflected in the sale of non-tidal fishing licenses, freshwater fishing in Maryland has become extremely popular within the past five years (fig. 1). Over 60,000 trout stamps were sold in 1988, and together with unlicensed anglers under the age of 16, and non-tidal anglers who do not need a trout stamp to fish (a trout stamp is required only to possess trout, or to fish in special management trout fishing areas), we estimate that on a state-wide basis our trout waters are exposed to a fishing pressure of approximately 240 resident anglers per mile of trout water. Thus the reason for the title of this paper--intensive trout management.

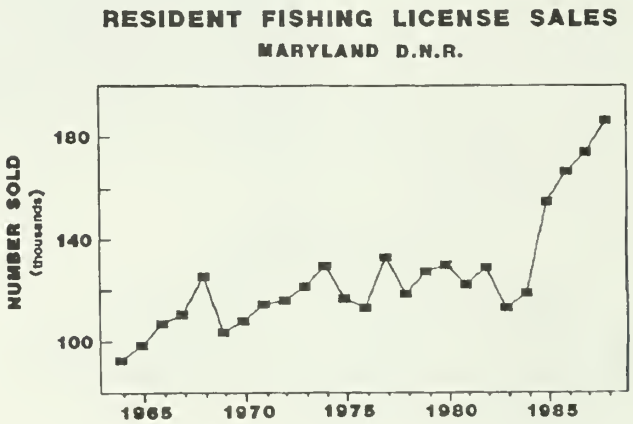


Figure 1.--Sales of Maryland resident non-tidal (fresh water) fishing licenses from 1964 through 1988.

METHODS

Population Inventories

We believe that our most important trout management tool is our state-wide inventory of wild trout populations. Our goal is to obtain an up-to-date assessment of all wild trout stream populations at least once every five years. Streams of special interest, under special management, or threatened by environmental assault are surveyed each year. Streams requiring less intensive scrutiny are sampled every other year, and the remainder are on a five year schedule. The number of sample stations per stream varies with size of stream and intensity of management, ranging from a single station of approximately 100 yards in length to as many as ten stations and as long as 400 yards.

Our basic assessment technique is the three-pass, depletion, electrofishing procedure. Equipment varies with stream size and habitat configuration. Small streams are sampled by regional teams with a single back-pack electrofishing unit. Larger streams, having a high gradient may require the use of two back-pack units working side-by-side, and still larger streams are sampled by large crews working two electrodes attached to a gasoline-powered DC generator mounted on a barge, or attached to two 325-foot leads to the generator on the bank. Only on very large bodies of water, where the electrofishing must be done by means of an electrofishing boat, do we use mark-and-recapture, or catch-per-unit effort sampling techniques.

Our standard depletion technique is to capture only trout on the first two passes, and other fish species as well as trout on the third pass. By this procedure we have been able to obtain extremely good trout population estimates with tight confidence intervals, and obtain point estimates of other fish species densities on a regular basis.

All trout captured are identified by species, measured for total length, and weighed. Population estimates are calculated by total number of trout per unit length of stream, number per unit area, weight per unit area, and ratio of young-of-year trout to yearling and older trout.

Management Objectives

Our statewide management objectives are prioritized as follows:

1. Protection of threatened or endangered wild trout populations. The threat may be in the form of housing development, highway construction, over harvest, adverse land use practices such as stream-bank degradation by livestock and farm pond construction, or improper timber harvest.

2. Protection and enhancement of wild trout fisheries.

3. Development and enhancement of put-and-grow trout fisheries in waters capable of sustaining year-round survival of trout but limited by natural reproduction.

4. Development and enhancement of a high-catch-rate trout fishery by means of stocking adult, hatchery-reared trout.

Current Regulations

Our fishing regulations are designed to meet the above management objectives by controlling or altering harvest, fishing pressure, hooking mortality, and angler perception. We believe that with the intense fishing pressure Maryland's trout fishery faces, and the speed with which fishing pressure can change in response to changes in fishing success, that fishing regulations and stocking procedures must be flexible and innovative. The following regulations are currently being used:

1. State wide regulations - two trout per day (brook, brown or rainbow) in aggregate. No closed season. No minimum size limit. (Unless preempted by special regulations.)

2. Special regulations:

a. Catch-and-return, fly-fishing only

b. Catch-and-return, artificial lures (and flies)

c. Trophy trout

1) Creel limit - five fish per day, artificial lures and flies only; minimum size -brown trout, 18 inches; brook trout, 12 inches; rainbow trout, no minimum size

2) Creel limit - five fish per day, no special tackle restrictions; minimum size -brown trout, 12 inches; brook trout, 9 inches; rainbow trout,no minimum size

d. Put-and-take

Creel limit - five trout per day, no special tackle restrictions. Open year-round, with closure periods in some areas to allow for stocking. (Some areas reserved for persons under 16 years of age, 65 years and older, and blind persons).

e. Delayed harvest

1) January 1 through May 31;

Catch-and-return, artificial lures and flies only

2) June 1 through December 31; Creel limit - two fish per day, no special tackle restrictions

The state-wide creel limit for trout reflects the limited productivity of the state's wild trout habitat. The more generous five-fish-per-day creel limit in put-and-take areas is intended to underscore the fact that the hatchery trout program is a special fishery, and not typical of Maryland's wild trout populations. As such, the put-and-take areas are really special regulation areas and they, as well as all of our other special regulations areas, are clearly marked by stream-side posters.

CASE HISTORIES

Gunpowder Falls

Gunpowder Falls rises in York County, Pennsylvania, and flows southeasterly into Baltimore County, Maryland, where it and twelve other tributaries (ten of the twelve contain wild trout populations) are impounded by Prettyboy Dam to form Prettyboy Reservoir, one of two Baltimore City water supply impoundments on Gunpowder Falls (fig. 2). Water is drawn from Loch Raven Reservoir, 17.7 miles downstream of Prettyboy Reservoir, and water is released as needed from Prettyboy to supply Loch Raven. Twelve small tributaries feeding Gunpowder Falls between Prettyboy Dam and Loch Raven Reservoir sustain naturally reproducing brook trout populations, as do most of the small headwater streams in this gently-rolling Piedmont section of Maryland.

The upper five miles of Gunpowder Falls between Prettyboy Dam and Loch Raven Reservoir have been stocked in the spring of the year with catchable-sized brown and rainbow trout for well over two decades on a put-and-take basis. Although the occasional wild brook and brown trout was caught along with the hatchery trout, no self-sustaining wild trout fishery existed in the mainstem of the river because water quality criteria for trout was not considered in the release regime from Prettyboy Dam.

In 1986 Trout Unlimited negotiated a contract with the City of Baltimore to obtain a guaranteed minimum flow from Prettyboy Dam. From fall 1985 through the fall of 1987, in cooperation with the Maryland Chapter of Trout Unlimited, wild brown trout eggs were obtained by

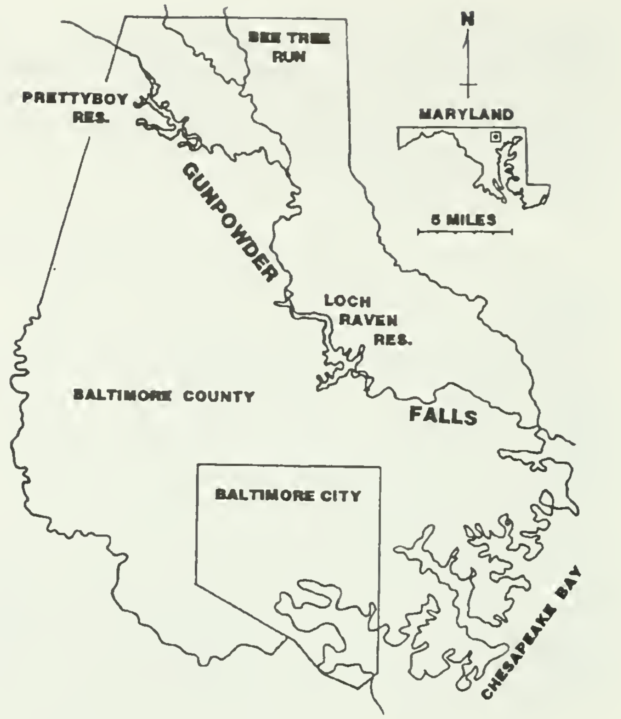


Figure 2.--Map of Baltimore County showing the location of Gunpowder Falls, Prettyboy Reservoir, Loch Raven Reservoir, and Bee Tree Run.

electroshocking wild brown trout in Jones Falls, a nearby, highly productive stream. These eggs were fertilized on site by milt from wild male brown trout, hatched and reared to fingerling size, and stocked in Gunpowder Falls between Prettyboy Dam and Falls Road, the first road crossing below the dam. These trout survived, spread throughout the upper reaches of the tailwater area, but because of limited numbers, and perhaps because the area was also heavily stocked with catchable-sized rainbow trout, the adult brown trout population remained relatively low.

In January, 1987, 10,000 Bitterroot-strain eyed brown trout eggs were planted in redds prepared in a method fashioned after Gustafson-Marjanen and Moring (1984). Later in the spring of 1987, 1500 Jones Falls fingerlings were stocked in the vicinity of Falls Road. Electrofishing surveys at seven stations in September 1987 indicated that the Bitterroot eggs had hatched very well, and 3-to-4-inch fingerling brown trout had spread throughout approximately eight miles of the river below the dam. The relatively high standing crop of fingerling brown trout at station E (fig. 3), where the eyed eggs had been planted was a strong indication that most, if not all, of the trout at that station were from the Bitterroot egg implant, and the second highest standing crop, near station B (fig. 3), suggested that the Jones Falls fingerlings were doing well also.

In 1988, 1000 (4 to 5 inch) fingerling brown trout from the Greensprings hatchery in Pennsylvania were stocked at four locations between Falls Road and Bluemount Road, and 10,000 Bitterroot eyed eggs were implanted near Masemore Road. In addition, 7000 (one to two inch) Bitterroot-strain brown trout fingerlings were stocked upstream of Falls Road. Electrofishing surveys conducted in September 1988 showed that hatch and survival of the January 1988 egg implant was poor, but survival of the stocked Bitterroot fingerlings was excellent at station B (fig 3.). The number of yearling and older brown trout had increased from 1987 to 1988 by 2 to 6 fold at seven stations in the eight miles below Prettyboy Dam (fig. 4). Fingerling brown trout, assumed to be mostly from the Bitterroot egg implant, had grown from a mean of 110 mm (4.3 inches) total length in September 1987, to a mean length of 220 mm (8.6 inches) by September 1988, and the number of brown trout exceeding 304 mm (12 inches) had increased by approximately 400% (fig. 5 and fig. 6).

Four-inch fingerling rainbow trout stocked in June 1987 had more than doubled in length by October and by fall were contributing substantially to the catch. The growth rate of rainbow fingerlings was slower in 1988 than it had been in 1987, possibly because of the greater standing

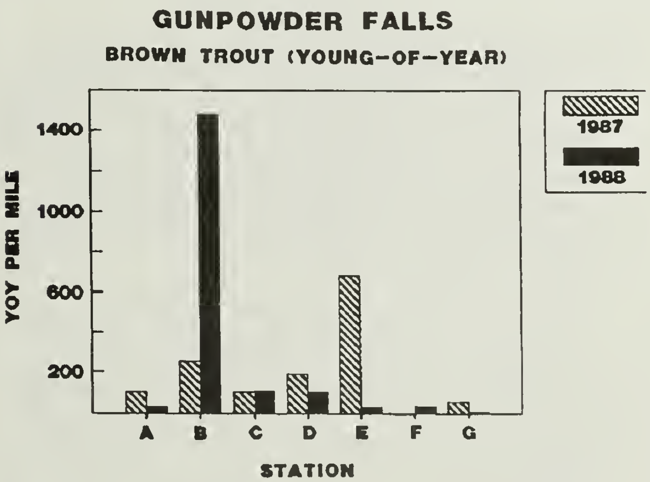


Figure 3.--Standing crop of brown trout fall-fingerlings (YOY) at seven electrofishing stations on Gunpowder Falls, 1987 and 1988.

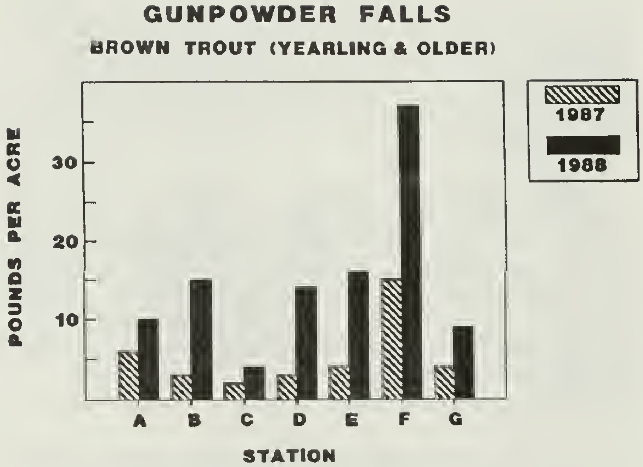


Figure 4.--Population estimates of yearling-and-older brown trout at seven electrofishing sites on Gunpowder Falls, 1987 and 1988.

crop of trout in the river, but they nevertheless still had an excellent condition factor.

The evolution of fishing regulations on Gunpowder Falls presents an interesting example of how sociological, environmental, and biological factors can combine to produce a top-rate trout fishery. In 1987, the statewide creel limit for trout was reduced from five trout per day to two trout per day, but the creel limit for put-and-take fishing areas remained at five per day. As a result, the creel limit from Prettyboy dam downstream to York Road remained at five fish per day (the put-and-take area), but downstream of York Road, the creel limit became two fish per day. In 1988, no adult trout were stocked above Falls Road (station B), and in 1989, the section between the dam and Falls Road came under catch-and-release, artificial lures only regulations (fig. 7).

Summer water temperatures become marginal in the lower sections of Gunpowder Falls. To provide for more put-and-take fishing, and relieve the fishing pressure on the developing put-and-grow and wild trout fishery, an additional 10.4 mile section of put-and-take fishing was established on Gunpowder Falls above Loch Raven Reservoir (fig 7.). In 1989, 3.0 miles of the 10.4 mile put-and-take area were stocked with hatchery reared trout. The result was a complex series of different regulations--1.3 miles of catch-and-release, followed by 2.8 miles of put-and-take, five fish per day, followed by 3.2 miles of two fish per day, followed by 10.4 miles of five fish per day. Angler acceptance of these complex regulations was nothing short of amazing. The secret seems to lie in the diversity of angling opportunity (a little of something for everybody), and the easily understood signs posted along the various sections of the stream.

In 1989 all fingerling brown trout stocked were marked by an adipose fin clip, so that any unmarked young-of-year could be positively identified as coming from natural reproduction. In May 1989, swim-up brown trout fry were observed at two sites within in the eight mile section below Prettyboy Dam, confirming that natural reproduction had occurred.

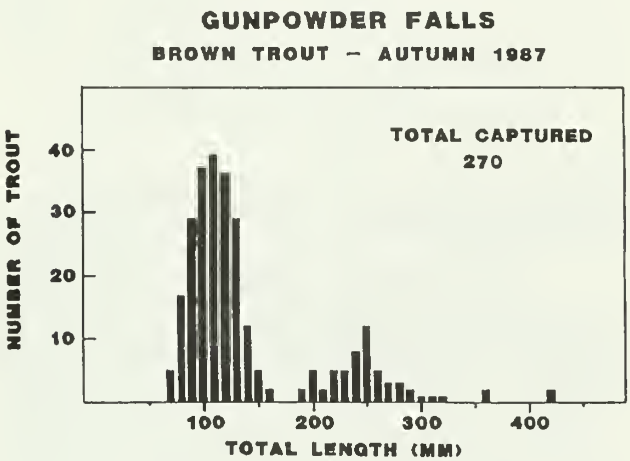


Figure 5.--Length frequencies of 270 brown trout captured in Gunpowder Falls, 1987.

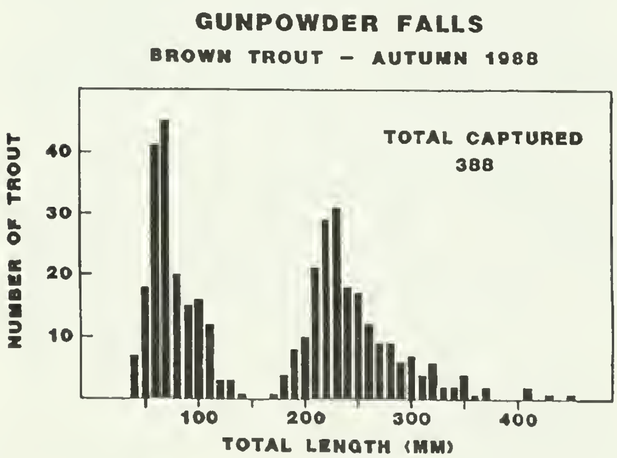


Figure 6.--Length frequencies of 388 brown trout captured in Gunpowder Falls, 1988.

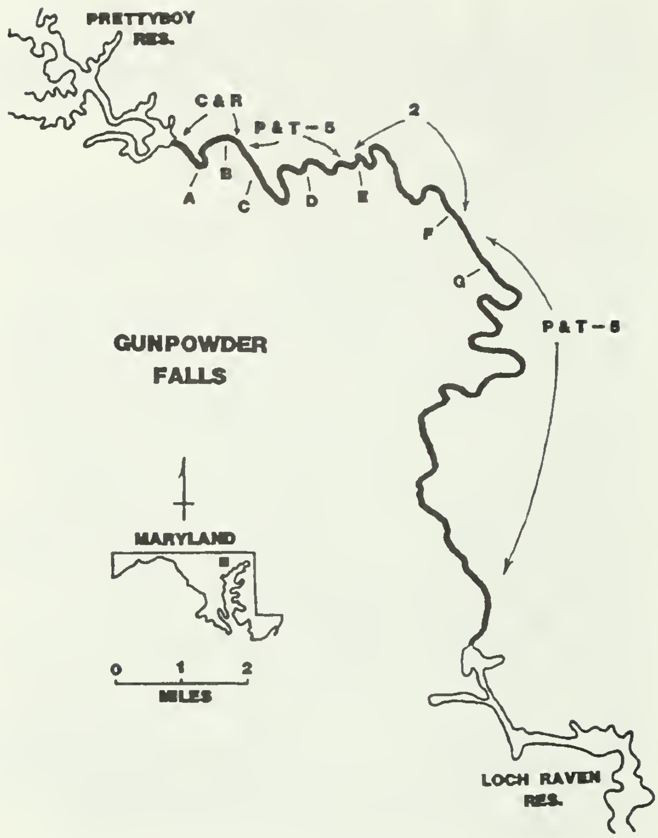


Figure 7.--Map of Gunpowder Falls showing sections under catch-and-release (C&R), put-and-take (P&T-5), and state-wide (2) regulations, and locations of survey stations (A through E).

Bee Tree Run

Bee Tree Run is a medium-sized freestone stream averaging 13 to 17 feet in width that originates in Pennsylvania and flows in a southerly direction for 6.3 miles through the northeast corner of Baltimore County, Maryland (fig. 2). Bee Tree Run is a tributary of Little Falls which in turn flows into Gunpowder Falls near Bluemount Road.

For many years, Bee Tree Run has been known to support a wild brown trout population but was stocked by the State of Maryland with hatchery-reared brown and rainbow trout for well over two decades as part of the annual spring put-and-take trout program. Most of the stocking took place in a 1.7 mile section from Bee Tree Road downstream to the mouth.

Fishing access along the entire stream has recently improved by State acquisition of property previously owned by the North Central Railroad. As a result, a total of 35 miles of high quality trout water consisting of Bee Tree Run, Little Falls, and Gunpowder Falls now flows through a large, state-owned complex known as Gunpowder Falls State Park and Gunpowder Falls State Park Trail. A gated hiker/biker path, and state-maintained parking at road crossings provides easy non-motorized access to this serene, wilderness-like recreational area.

With the 1987 implementation of a statewide two-trout-per-day creel limit, the creel limit in the unstocked upper section of Bee Tree Run dropped from five to two, but the creel limit for the put-and-take section downstream of Bee Tree Road remained at five trout per day. Increased emphasis on management for wild trout and growing concern about the adverse impacts of stocking hatchery trout on top of wild trout populations led to the initiation of a study of the Bee Tree Run brown trout population in 1984. In order to compare the stocked and unstocked portions of the stream, two electrofishing stations were established, one within the put-and-take area and another approximately 1.5 miles upstream of the put-and-take area. An additional station was added in 1987 in the unstocked portion 0.3 miles upstream of Bee Tree Road.

Young-of-the year brown trout were captured at all three electrofishing sites each year, but the stocked, put-and-take section of Bee Tree Run consistently had a lower standing crop of wild brown trout than the upstream, unstocked areas. Each year virtually all of the hatchery rainbow trout were harvested within the first few weeks after stocking (Fedler, 1989a).

Stocking of rainbow trout was discontinued in Bee Tree Run in 1989, and the entire stream was placed under the state-wide two-trout-per-day limit. By the end of the first season under no-stocking, wild trout management, the biomass of yearling-and-older brown trout was 360% higher than in previous years in the down-stream, previously stocked, section, 91% higher in the adjacent (middle) section, and 44% higher in the upper section (fig. 8). Creel studies (Fedler, 1989a) documented that illegal harvest of wild trout in the unstocked section was occurring when fishing pressure generated by put-and-take stocking was high, and although there was no significant change in the number of yearling and older wild brown trout per mile in the upper section, the average size increased as a result of the decreased fishing pressure.

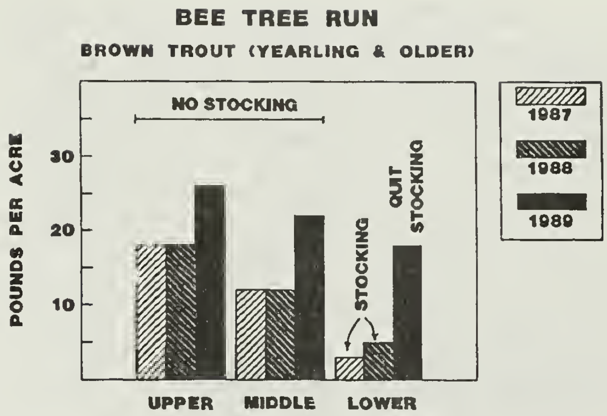


Figure 8.--Population estimates of yearling-and-older brown trout at three electrofishing stations on Bee Tree Run in 1987, 1988, and 1989 before and after wild trout regulations were implemented.

Savage River

The Savage River lies tucked away in the forested mountains of western Maryland's Garrett County. It is one of Maryland's most scenic big rivers. Rising at an elevation of over 2800 ft, it flows southwesterly through steep-sided stands of mixed hardwoods and scattered evergreens to the Savage River Reservoir, a 150-ft-deep, 350-acre water supply impoundment. Calcareous formations within this mostly undeveloped watershed contribute to its excellent water quality. Most of the watershed lies within the Savage River State Forest. Five large tributaries, all of which contain self-sustaining populations of brook trout, and the mainstem of the Savage River feed the Savage River Reservoir.

The principal uses of the reservoir are water supply, pollution abatement, and low-flow augmentation of the North Branch Potomac River. Releases from the reservoir are regulated by the Upper Potomac River Commission (UPRC) following recommendations from the U.S. Army Corps of Engineers.

Below the dam, the Savage River flows southeasterly through a high-gradient, boulder-strewn valley lined with thick stands of rhododendron and bushy undergrowth for 4.5 miles to its confluence with the North Branch of the Potomac River. A paved road parallels the Lower Savage River mainstem for most of its length.

Despite the presence of wild brook trout, and excellent water quality, the Savage River was heavily stocked with hatchery-reared rainbow trout for decades. During spring run-off, the Savage River provided excellent habitat for put-and-take trout fishing, but water supply and flow augmentation requirements over-rode fishery considerations, and extremely low flow conditions prevailed for very long periods during most summers. Prior to 1982, periodic surveys of the Lower Savage River in late summer, below the dam, often produced no trout at all, even though several thousand hatchery-reared brown and rainbow trout had been stocked in the spring.

The recently-built Jennings Randolph dam on the North Branch of the Potomac River, approximately 8.5 miles upstream of the mouth of the Savage River, has vastly improved water quality in the North Branch of the Potomac, and has allowed greater flexibility in water release requirements from the Savage River Reservoir. Recognition of this increased flexibility prompted the Maryland Department of Natural Resources to form an in-stream flow committee to establish water release guidelines designed to improve year-round water quality for trout, and to provide for releases for whitewater boating activities. Factors considered in establishing these guidelines were low flow considerations (trout and macroinvertebrate habitat), water temperature, thermal shock, displacement of fish and aquatic invertebrates by high flows, and stranding of aquatic organisms when flows were reduced. The recommendations of the in-stream flow committee were adopted, and made a part of the operational procedures for Savage River Reservoir in 1983.

Two aspects of the new release recommendations understandably led to a dramatic increase in the number and size of wild brook and brown trout below the Savage River Dam. Minimum flows that maintained cold water habitat throughout the summer undoubtedly were important, but so too, was the provision of maintaining the reservoir low in winter and allowing it to fill with somewhat warmer spring runoff. The result was a more natural flow and temperature regime, and the biota of the stream, macroinvertebrate and fish, responded.

Electrofishing surveys during the period 1983 through 1986 confirmed that wild brook and brown trout were increasing in the Lower Savage River. Population estimates were obtained at two stations by the mark-and-recapture method from 1983 through 1986. One station was located in the one-mile section above a structure known as the "Piedmont Dam" and another was located about 2.5 miles further downstream. The results of these surveys suggested that the Lower Savage River should be managed for wild trout. Concern about the effect of stocking adult hatchery rainbow trout on the wild trout populations, and the attendant fishing pressure generated by such stocking led to the establishment of Maryland's first wild trout regulations in 1987.

Local opposition to the new regulations was intense, especially on the Savage River, but in 1987 the Department of Natural Resources ceased stocking any trout in the first mile of water above the Piedmont Dam and established trophy trout regulations on the Lower Savage River. In the one mile section from Savage River Dam downstream to the Piedmont Dam, no trout were to be stocked, terminal tackle was restricted to the use of artificial lures and artificial flies, and a minimum size limit for brown trout was set at eighteen inches, twelve inches for brook trout, and no minimum size for rainbow trout. The creel limit was set at five trout in the aggregate.

Partially as a concession to local anglers, accustomed to the spring put-and-take fishery, and partially to evaluate the effectiveness of different regulations, the remaining four miles of the Lower Savage River was managed as follows: spring stocking of adult hatchery rainbow trout, no special tackle restrictions, creel limit of five trout in the aggregate, twelve inch minimum size for brown trout, nine inch minimum size for brook trout, and no minimum size for rainbow trout.

In order to better assess the effects of these new regulations, another electrofishing station was added below the Piedmont Dam in 1987, and the sampling method was changed to the three-pass-depletion method at all three stations.

The effects of the special regulations on the brook trout population were spectacular. Within two years of implementation, the number of yearling and older brook trout in the upper, artificial-lures-and-flies, no-stocking section increased from 200 trout per mile to over 1100 trout per mile (fig. 9). A slight increase was also documented in the lower section where put-and-take stocking persists, and the use of bait is permitted, but the message is clear: <u>the Savage River is capable of sustaining an exceptional tailwater brook trout fishery under restrictive regulations and no stocking of hatchery trout</u>.

Interestingly, there was little or no change during this same period of time in the size or number of wild brown trout either above or below Piedmont Dam. Young of the year brook trout outnumbered young-of-the-year brown trout thirty to one throughout the Lower Savage in 1989. The cold water may favor conditions for brook trout reproduction, and the low susceptibility of brown trout to angling may account for the relatively stable, but low, brown trout population in both trophy trout sections.

As mentioned earlier, the same flexibility in releases from Savage River Reservoir that produced conditions favorable for wild trout also provided exceptional whitewater boating opportunity. In 1988, the Savage River was the site of the "Pre-World" Maryland Whitewater Canoe and Kayak Races, and in June, 1989, approximately 600 athletes from 30 countries converged on the Lower Savage for a two-week "World Championship Canoe and Kayak" whitewater event.

The effects of these events on the trout population have been difficult to assess, since so many changes were taking place at the same time. Some departures from the in-stream flow recommendations were made in order to assure that sufficient water would be available for this "world-class" event. "Ramp up" and "ramp down" times were shortened to conserve water, and the reservoir was filled earlier, with colder water, and allowed to top prior to the start of the whitewater event. In addition, the races were held earlier than recommended by the in-stream flow guidelines.

Early qualitative observations of swim-up fry suggested that 1989 produced a good hatch of brook trout in the Lower Savage. Patrols along the river after each day's 1989 whitewater event revealed stranded young-of-year and adult trout, some of which were dead. Others were stranded in pools that became flooded again the next day. The first day's release resulted in a precipitous drop in water temperature from 22 C to 5 C in less than one hour. The maximum number of dead and stranded trout occurred after the first day's release, and the high number of stranded fish is suspected to have been partly due to thermal shock. Nevertheless, young-of-the-year brook and brown trout survived throughout the Lower Savage after the races.

Our work is not over on the Savage River. We already have an excellent wild trout fishery, but it is clear that it can get even better. We have come a long way in just seven years, but the mix of

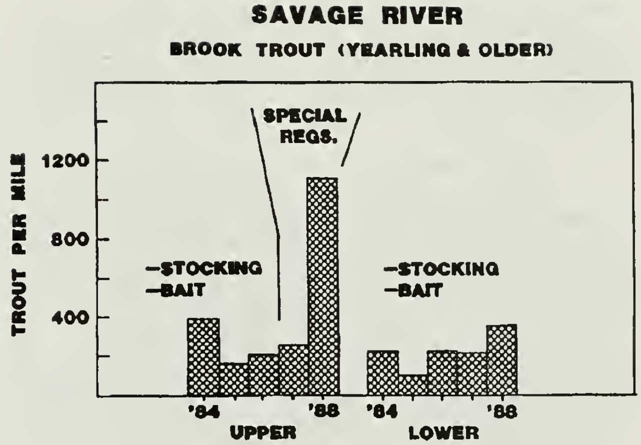


Figure 9.--Population estimates of wild brook trout in the upper and lower sections of the Savage River Trophy Trout Management Area Under different management options before and after special regulations were implemented. Upper section; artificial lures and flies, no stocking--lower section; stocked with hatchery trout, bait permitted.

sociological, biological, environmental, and economic factors that come together on this river presents an exciting challenge.

DISCUSSION AND CONCLUSIONS

Most of Maryland's wild trout waters are within an easy drive of the Baltimore-Columbia-Rockville-Washington megalopolis. Over 21% of the trout anglers that reside in this heavily populated region can be classified as "technique specialists" (Bryan 1979, Fedler 1989b) or "purists" as defined by Clawson (1965). This segment of the trout angling population is characterized as being highly informed about the species of fish they catch, the waters they fish, their methods of fishing, and they are willing to spend considerable amounts of money and travel long distances to engage in their sport.

In a state-wide mail survey of Maryland's trout anglers, Fedler (1989b) found that 58.8% of the anglers reported that they fished with a combination of bait, artificial lures, and artificial flies, 25% responded that they fished only with bait, 11.4% said they fished only with artificial flies, and 4.9% said they fished only with artificial lures.

Our experience in Maryland in instituting wild trout management--reduced creel limits, high minimum size, catch-and-release, and terminal tackle restrictions--has shown us that most anglers are willing to accept changes if they are based on sound rationale and accurate data.

Most anglers consider the prospect of catching a large trout important. This is especially true of those anglers who fish for wild trout. Under the intense fishing pressure we have in Maryland, the chances of a wild trout becoming big (old) without some type of special regulation--read catch-and-release--is fairly remote. As word of our improving wild trout fishery spreads, fishing pressure on this resource is bound to increase. We want to protect this valuable resource in a wise, responsible way. To do so we need the most up-to-date information regarding hooking mortality. We think that we have a problem in this regard.

A review of the literature reveals, we think, a discrepancy between the data that have been published on the hooking mortality of trout, and the way that these data have generally been interpreted. For example, Wydoski (1977) reported a mean hooking mortality of fish caught on bait as 25% (**range 3.3 to 61.5%**), on barbed artificial lures, 6.1% (**range 1.7 to 42.6 %**) and on barbed flies 4.02 % (**range 0.0 to 11.3 %**). Although he clearly pointed out that there was substantial variance due to species of fish, size of fish, hook size, angling technique, and the voracity of the fish, many fisheries agencies currently consider these differences biologically insignificant or not serious.

If we consider only the data published on brown trout, we find **zero** hooking mortality for brown trout caught on artificial flies, (Shetter and Allison, 1955; Shetter and Allison, 1958) and 3% mortality for brown trout on artificial lures (one paper) (Shetter and Allison, 1955).

The average hooking mortality of brook trout caught on artificial flies was reported by Wydoski (1977) to be about 2.5% (three papers), and only one paper was cited for hooking mortality of brook trout caught on artificial lures, (3.9%) (Shetter and Allison, 1958).

In reviewing essentially the same material as Wydoski, Mongillo (1984) concluded that wild salmonids suffer 2 to 4 times higher hooking mortality than hatchery fish when caught on artificial lures and flies, but that "there are no differences in hooking mortality between any artificial lures or flies, with or without barbless hooks on any salmonid species." (Emphasis added.)

A review of the data and methodologies of the studies cited by Mongillo (1984) and Wydoski (1977) reveals that most of these studies were undertaken to assess the hooking mortality of sub-legal trout and salmon (small fish) with terminal tackle commonly used to catch legal sized fish. In these reviews the hooking mortality of landlocked Atlantic salmon on tandem-hook streamers (Warner 1978) was averaged with that of wet and dry flies (Shetter and Allison 1955) and the hooking mortality of worm-hooked trout that were intentionally deep-hooked (Mason and Hunt 1967) with worm-hooked landlocked Atlantic salmon that "took worms gingerly and rarely ingested the bait deeply" (Warner 1976). Other authors then have taken these averages, and averaged **them** to conclude that the hooking mortality of artificial lures and flies is about 5%. The result, we think, is a loss of important information concerning the relative hooking mortality of different species of salmonids on different types of terminal tackle.

In his paper "The Future of Fisheries Management: Managing the Fisherman" Larkin (1988) notes "we all know that the technologies of angling improve as time goes by. Hooks, lures, lines, rods, reels--everything but live bait, is better than it used to be." Data on the relative hooking mortality of large wild trout on especially effective, modern tackle is woefully lacking. In our review we found no studies that assessed the hooking mortality of wild trout caught on the very effective spinners that are so popular today, or the multiple-hook, minnow-like lures that are notorious for catching large brown trout.

Even though the practice of averaging averages in the reviews cited above tends to blur substantial differences, it appears that what data does exist shows there **is** a difference, albeit small, in the hooking mortality of brook and brown trout on flies and artificial lures.

The two species of wild trout we primarily manage for in Maryland are brook and brown trout. Even if the hooking mortality for artificial lures and flies is low in comparison to that for bait, and if the difference in hooking mortality between artificial lures and artificial flies is small, when fishing pressure is high, and when especially valuable resources are involved, these differences may attain substantial significance.

A recent study regarding the hooking mortality of walleye (Fletcher 1987), and our own experiences with brook trout on the Savage River gives us cause for alarm. Although the overall hooking mortality reported by Fletcher (1987) was only 1.11% (two dead fish out of a total of 180 collected), he cautioned that "the terminal gear used in this study was entirely lead-head jigs with rubber tails and hooks baited with night crawlers,... other fisheries in Washington State which rely on different gear types reportedly experience higher mortality of hooked walleye...many of the walleye caught in Banks Lake and the lower Columbia River are caught on trolled spinners, and it seems as though the fish ingest the spinner much more deeply than they do the slowly moving jig. There are indications [that] the mortality of these spinner-caught fish may be as high as 50%,"(emphasis added).

Fletcher's anecdotal observation is very similar to our own experiences with brook trout in the Savage River. In the fast water of this high gradient stream, brook trout strike a fast moving spinner aggressively, and take the hook deeply, with resultant damage to the gills and gill arches. Both observations seem to be associated with the "voracity" variable mentioned by Wydoski (1977).

We believe that as fishing pressure increases in Maryland, we will have to have more information on hooking mortality in order to manage our wild trout fisheries wisely. Factors such as size-selective effectiveness of specific terminal tackle, lure type, fly type, fishing technique, the relative effectiveness of different tackle and variance due to angler experience have hardly been addressed at all. This is understandable, because of the difficulty of obtaining sufficient sample sizes of wild fish, and the inherent difficulties in establishing adequate controls in field studies. Nevertheless, it is vital that we, as fisheries managers, make the distinction between an absence of evidence and evidence of absence. We cannot simply say there is no difference because we don't have the data to document the differences that may exist.

Is all this information really necessary? Already we read of ideas such as limited entry in catch-and-release trout fisheries (Griffith 1987) and "lighter tackle, smaller and barbless hooks, and very dry fly fishing" (Larkin 1988). Is it necessary for us to determine the differential hooking mortality between different types of artificial lures and different types of flies? What really is the hooking mortality of large trout caught on large streamers compared to that of trout caught on small dry flies? Is it large enough to make a difference? Can we afford not to look?

At the last catch-and-release symposium Bob Behnke (1987) said "a fishery agency must establish expertise and credibility on which to base a strong leadership role for public acceptance and trust." If future studies fail to document important differences in hooking mortality among different types of terminal tackle, we will be on much firmer ground than we are today. In the meantime, it serves little purpose to refer to our well-informed trout angling constituency with emotion-laden terms. We must get the data, and manage our resources from a sound, unemotional perspective. Only then will we have the public acceptance and trust that Bob Behnke so rightly insists we must have.

LITERATURE CITED

Behnke, Robert J. 1987. Catch-and-release-the last word. Pages 291-299 in R.A. Barnhart and T.D. Roelfs, Editors. Catch-and-release Fishing, A Decade of Experience: a national sport fishing symposium. Humboldt State University, Arcata, California.

Bryan, H. 1979. Conflict in the great outdoors: toward an understanding of diverse sportsmen preferences. Sociological Studies No. 4. University of Alabama, Bureau of Public Administration.

Clawson, M. 1965. Economic aspects of sport fishing. Canadian Fishery Report No 4: 12-24.

Cooper E.L. 1970. Management of trout streams. In A Century of Fisheries in North America. N.G. Bensen, (editor). American Fisheries Society Special Publication Number 7, p. 153-162.

Fedler, A. J. 1989a. Bee Tree Run trout fishing study. University of Maryland, College Park, Md. 20pp.

Fedler, A. J. 1989b. Trout fishing in Maryland, an examination of angler characteristics, behaviors and economic values. University of Maryland, College Park, Md. 101 pp.

Fletcher, D. H. 1987. Hooking mortality of caught-and-released walleye. Pages 170-174 in R.A. Barnhart and T.D. Roelfs, Editors. Catch-and-release

Fishing, A Decade of Experience: a national sport fishing symposium. Humboldt State University, Arcata, California.

Griffith, Jack. 1987. Is limited entry needed in catch-and-release trout fisheries? Pages 112-125 in R.A. Barnhart and T.D. Roelfs, Editors. Catch-and-release Fishing, A Decade of Experience: a national sport fishing symposium. Humboldt State University, Arcata, California.

Gustafson-Marjanen, K. I. and J. R. Moring. 1984. Construction of artificial redds for evaluating survival of Atlantic salmon eggs and alevins. North American Journal of Fisheries Management 4:455-461.

Larkin, P.A. 1988. The future of fisheries management: managing the fisherman. Fisheries 13:3-9.

Mason, J.W. and R.L. Hunt. 1967. Mortality rates of deeply hooked rainbow trout. The Progressive Fish Culturist 29:87-91.

Mongillo, P. 1984. A summary of salmonid hooking mortality. Mimeo rep. Fish Management Division, Washington Department of Game.

Shetter, D.S. and L.N. Allison. 1955. Comparison of mortality between fly-hooked and worm-hooked trout in Michigan streams. Michigan Dep. Conserv., Inst. Fish Res., Misc. Publ. No. 9. 44 p.

Shetter, D.S. and L. N. Allison. 1958. Mortality of trout caused by hooking with artificial lures in Michigan waters, 1956-1957. Michigan Dep. Conserv., Inst. Fish. Res., Misc. Pub. No. 12. 15 p.

Warner, K. 1976. Hooking mortality of landlocked Atlantic salmon, Salmo salar, in a hatchery environment. Transactions of the American Fisheries Society 105:365-369.

Warner, K. 1978. Hooking mortality of lake-dwelling landlocked Atlantic salmon, Salmo salar. Transactions of the American Fisheries Society 107:518-522.

Wydoski, R.S. 1977. Relation of hooking mortality and sublethal hooking stress to quality fishery management. Pages 43-87 in R.A. Barnhart and T.D. Roelfs, Editors. Catch-and-release fishing as a management tool: a national sport fishing symposium. Humboldt State University, Arcata, California.

Rainbow Trout Populations in Silver Creek, Idaho, Following a Decade of Catch-and-Release Regulations[1]

Michael D. Riehle, Blaine L. Parker, and J. S. Griffith[2]

Abstract.--Fish population and creel census data from 1986-87 were compared with those from 1976-77 to assess possible changes in the rainbow trout population on a portion of Silver Creek, Idaho, following 10 years of catch-and-release regulations. Growth increased slightly, total mortality declined, and the proportion of large fish in the population increased in that time interval. Fishing effort nearly doubled, and effort in a nearby section managed under general regulations declined by nearly half. The rainbow trout population in the general regulations section also showed some positive changes in the past 10 years.

INTRODUCTION

Silver Creek, a tributary of the Little Wood River in Blaine County, Idaho, is recognized as one of the more esteemed western trout streams. Its abundant surface-feeding rainbow trout *Oncorhynchus mykiss* and mayfly hatches draw anglers from all areas of the country. In 1975, The Nature Conservancy purchased land surrounding 2.4 km of Silver Creek and its tributaries, and catch-and-release regulations were initiated there by the Idaho Department of Fish and Game (IDFG) in 1977. The IDFG conducted an investigation (Thurow 1978) in 1975 through 1977 to assess the condition of the fishery.

Our study, conducted in 1986 and 1987, focused on evaluation of the effects of catch-and-release regulations at the end of the ten year period. Changes in adjacent general regulations waters were also assessed, and angler use of the stream was evaluated in light of its increasing popularity. A detailed description of methods and results of the entire study appears in Riehle et al. (1988); this report reviews a portion of those results. Our specific objectives were to:

1. describe the distribution and population structure of trout and evaluate the fishery on portions of Silver Creek managed under catch-and-release and general regulations, and

2. assess changes in the rainbow trout population and in the fishery in both areas during the past decade.

STUDY SITES

Silver Creek is largely a spring-fed system formed by the confluence of Grove and Stalker creeks. Loving Creek, the only other major tributary, enters about 3 km downstream. The IDFG Hayspur Fish Hatchery is located at the head of Loving Creek. Silver Creek flows southeasterly 42 km to its junction with the Little Wood River. The upper valley is pasture and farmland, and the lower valley is predominantly sagebrush steppe.

Peak flows in Silver Creek occur in late summer due to decreased irrigation activities and influxes of groundwater recharge. From 1975 to 1983, mean discharge ranged from 3.4 to 6.2 m^3/s. Specific conductance ranged from 275 to 434 umhos/cm. The pH varied from 7.9 to 8.7, and total alkalinity ($CaCo_3$) averaged 195 mg/l (U.S. Geological Survey 1975-1983). Summer water temperatures ranged from 10 to 22°C during the summer months, and winter temperatures ranged from 0.5 to 7.0°C.

Game fish present in Silver Creek in addition to rainbow trout included mountain whitefish *Prosopium williamsoni*, brown trout *Salmo trutta*, and brook trout *Salvelinus fontinalis*. Nongame

---

[1]Paper presented at the Wild Trout IV Symposium. Mammoth, Wyoming, September 18-19, 1989.

[2] Michael D. Riehle and Blaine L. Parker were Research Assistants, and J. S. Griffith is Professor, Department of Biological Sciences, Idaho State University, Pocatello, Idaho.

species include bridgelip sucker Catostomus columbianus, redside shiner Richardsonius balteatus, longnose dace Rhinichthys cataractae, speckled dace R. osculus, and the Wood River sculpin Cottus leiopomus. No hatchery-reared trout were stocked in the study sections during 1986-87.

Silver Creek was divided into five study sections during the 1976-1977 IDFG study (Thurow 1978). The five sections were used for creel census, and electrofishing sites were located within those sections. We used the original creel census sections for this study, and 1986-1987 electrofishing sites 500 to 1,00 m in length were located within the areas electrofished in 1976-1977. In this paper, results from two sections (referred to as Section C&R for catch-and-release and Section GR for general regulations) are reported.

Section C&R, which was located entirely within the boundaries of The Nature Conservancy Preserve, began at the confluence of Grove and Stalker creeks and extended 3.4 km downstream to Kilpatrick Bridge. Two electrofishing sites, referred to as Upper and Lower, were located within the section. Deep silt deposits characterized the majority of the substrate, but some exposed gravel and marl areas were present. Stream gradient averaged 0.8 m/km, width was typically 20 to 30 m, and depth 1 to 3 m. The dominant macrophytes were Chara spp. and Potamogeton spp. and the riparian zone contained predominantly willow Salix spp., birches Betula spp., sedges Carex spp. and grasses Poa spp..

Section GR extended from the upper Highway 20 bridge west of the town of Picabo (2.7 km below the lower end of Section C&R) 5.8 km to the Picabo Bridge. Some land is privately owned but public access is permitted, and the remainder is administered by state and federal agencies. The two electrofishing sites ranged from 10 to 45 m in width and contained some pools up to 3 m in depth. Gradient was similar to Section C & R. The substrate was primarily gravel, with silt occurring in depositional areas. The banks in the upper site supported dense growths of willows, birches, and wild roses Rosa spp.. and those in the lower site were largely open with some willow and wild rose. Potamogeton spp. was the dominant macrophyte at both sites.

METHODS

Fish Populations

Game fish populations were sampled by electrofishing at night in 1986-87. A 4.3-m-long raft was equipped with a 3500 watt generator and a variable voltage pulsator with output of 200-230 volts of pulsed D.C. at 4-6 amperes. The electrical field was established using a single boom-mounted positive and six side-mounted negative electrodes. Illumination was provided by two bow-mounted 150 watt floodlights.

Electrofishing runs were started immediately after dusk and continued for three to five hours. Sampling was done at night due to the high angler densities during the day, particularly in the catch-and-release area. Total lengths of fish collected were recorded to the nearest millimeter and weights to the nearest gram. A scale sample was removed from the area just below and posterior to the dorsal fin from all fish collected. Fin clips were used to mark fish for population estimates.

Estimates of population size were made for all electrofishing sites sampled in the summer of 1986. Upper sites only were sampled in the fall of 1986 and all sites were sampled in the spring of 1987. Population estimates were calculated using the Chapman modification of the Schnabel estimate. With this technique, multiple mark and recapture runs are made through a study site over a number of days. We utilized five to six runs for each population estimate when possible. Ninety-five percent confidence intervals were calculated for each estimate using Ricker (1975). The following equation was used to estimate population size:

$$N = \frac{C_t M_t}{R+1}$$

Where:

C_t = total sample taken on day t.
M_t = total marked fish at large at the start of the tth day or any other interval.
R = total recaptures during the experiment.
N = the estimate of the population present throughout the experiment.

Population estimates were not made in 1976-77.

Since electrofishing in 1976-1977 was conducted during the day, we conducted matched day and night electrofishing runs in both study sections in the spring of 1987. Comparisons of length frequency and numbers of fish captured were made for rainbow and brown trout. Night sampling was the more efficient method of electrofishing for rainbow trout and brown trout in the slow-moving water that characterized the sites. Approximately three times more rainbow and brown trout were captured during the night sampling. Comparisons of length frequencies between matched day and night samples indicated only minor differences for both species.

Scales from 957 rainbow trout were read for age-growth analysis. Samples were dry mounted on glass microscope slides and a glass coverslip was taped in place over the scales. All scales were magnified 50.3 times and projected onto a Houston Hipad DT11A digitizing pad. Measurements were taken along the median anterior radius from the focus to each annulus. These data were directly entered into an Apple microcomputer and analyzed using the Disbcal program (Frie 1982).

Condition factors were calculated to assess possible changes between 1977 and 1987 samples. Survival rates were calculated from the frequency of fish in age classes, as determined by scale analysis. The Heincke method, which does not require as much strength in the age determinations of the older ages as does the catch curve (Ricker 1975), was used to calculate survival (S).

Angler Effort and Catch

Creel census was conducted for the entire angling season from late May through November 1987 in the same sections surveyed in 1977. We patterned our creel census after the one conducted by Thurow (1978), but used the cluster method with three counts per day as opposed to the four that Thurow utilized. The days and count times were selected at random using a random number generator. Counts were done on two weekdays and two weekend days in each 14-day interval. All holidays were counted, with the exception of Thanksgiving Day. The count schedule was reduced to one weekend day and two weekdays after Labor Day weekend.

Angler effort was estimated using the method used in 1977, where angler effort for each interval is $XWD(H) + X_1WE(H)$, with

$X_1(X)$ = or the mean number of anglers:

$$X_1 = \frac{\text{total anglers counted on weekends}}{\text{total number of counts}}$$

$$X = \frac{\text{total anglers counted on weekdays}}{\text{total number of counts}}$$

WD = The total number of weekdays in the interval.

WE = The total number of weekend days in the interval.

H = The mean daylight hours per interval, taken from the sunrise and sunset timetable for Twin Falls, Idaho.

The same procedure was utilized for holiday counts.

Angler catch and harvest information was calculated for each interval from the interview data. Catch per hour and harvest per hour were estimated by dividing the total number of hours fished (from interviews) by the total number of fish captured or harvested for that interval. The resultant values were then multiplied by the total estimated hours of effort for that interval to calculate the estimated catch and harvest.

RESULTS

Fish Populations

Species Composition

For fish longer than 100 mm, the proportion of wild rainbow trout captured by electrofishing within Section C&R increased from 57% in 1976 to 80% in 1986-87 (Table 1). Hatchery rainbow trout accounted for 1% of the numbers in 1976, and fish that escaped from the Hayspur Hatchery comprised that same percentage in 1986-87. Mountain whitefish made up 40% of the 1976 sample but only 8% in 1986-87. We are uncertain whether this change is due to a reduction in density of whitefish or an increase in trout. Brown trout, which were first observed on the Conservancy

Table 1.--Species composition in percent of total catch of game fish captured by electrofishing during the 1976 and the 1986-87 field seasons on Silver Creek, Idaho. Data for 1976 from Thurow (1978).

Study site and sample period	Wild trout			hatchery	mountain	sample
	rainbow	brown	brook	rainbow	whitefish	size
Section C&R						
Apr, Jul, & Nov 1976	57	0	2	1	40	504
Jul & Oct 1986, May 1987	80	6	5	1	8	1220
Section GR						
Apr, Jul, & Nov 1976	65	0	2	28	4	199
Jul & Oct 1986, May 1987	62	34	1	3	<1	656

Preserve in 1981, increased to 6% of the fish population in the C&R section in 1986-87. Brook trout increased from 2% to 5%.

In Section GR, the proportion of wild rainbow trout decreased slightly from 65% in 1976 to 62% in 1986-87. Hatchery rainbow trout stocked in the section made up 28% of the 1976 sample. Hatchery escapees accounted for 3% in 1986-87. Brown trout increased from zero in 1976 to 34% of the population in the GR section in 1986-87.

Size Composition

In the summer and fall of 1976, 3% of the rainbow trout collected by electrofishing in Section C&R exceeded 400 mm (Thurow 1978). In 1986, 16% and 23% of the electrofishing sample consisted of this size class in summer and fall, respectively (Table 2). There was a consistently higher percentage of rainbow trout longer than 400 mm in each of the 1986 and 1987 samples for the upper site of Section C&R as compared with the 1977 sample.

Section GR had a lower percentage of rainbow trout longer than 400 mm in 1986-87 than did Section C&R, but the latter did show an increase from 1977. The largest percentage, 14%, occurred in the fall of 1986. In fall 1977, 4% of the rainbow trout there were over 400 mm in length.

Seventeen percent of the brown trout electrofished in Section C&R exceeded 500 mm in length, although about three-fourths of the fish were smaller than 300 mm. Samples for Section GR were dominated by large fish. The summer 1986, fall 1986, and spring 1987 samples had 23, 33, and 25% of brown trout greater than 500 mm in length, respectively.

Trout Density and Biomass

Estimates of wild rainbow trout density for fish longer than 100 mm were generally at the level of 200-300 fish/hectare in both sections (Table 3). Densities increased in spring 1987 due to full recruitment to our sampling gear of yearling trout and, in the C&R Section, an apparent influx of fish that had reared upstream.

Brown trout densities were generally 20-40 fish/hectare (Table 3). The upper site in Section GR experienced a substantial increase in the concentration of brown trout in the fall of 1986, with densities increasing from 30 to 189 brown trout/hectare from the summer to the fall as fish congregated for spawning.

The highest rainbow trout biomass, 169.6 kg/hectare, was estimated for the upper site in Section C&R in the spring of 1987 (Table 4). Section C&R maintained a rainbow trout biomass twice or more of that of Section GR at all sample periods. Because mean weight of brown trout consistently exceeded that of rainbow trout, brown trout biomass in the upper site of Section GR often was similar to, or exceeded, the biomass of rainbow trout.

Age and Growth

In 1976-77, back-calculated length of rainbow trout at ages 1-4 was consistently greater at Section GR than at Section C&R (Table 5). Ten years later, length at ages 1-4 on Section C&R increased by 5-14 mm (not statistically significant), and length in Section GR was less than in 1976-77 (change significant for age-1 fish).

Table 2.--Length frequencies of rainbow trout in catch-and-release and general regulations sections of Silver Creek in 1977 (data from Thurow 1978) and 1986-87. Values shown are percentages of the electrofishing samples for each section.

Study site	Date	Length class in millimeters					Sample size
		100-199	200-299	300-399	400-499	>500	
Section C&R							
	Fall 1977	26	37	34	3	0	202
	Summer 1986	37	28	19	16	0	234
	Fall 1986	40	20	17	23	0	180
	Spring 1986	48	18	24	11	0	530
Section GR							
	Fall 1977	22	50	24	4	0	105
	Summer 1986	66	10	20	4	0	90
	Fall 1986	11	53	22	13	1	71
	Spring 1986	53	17	25	5	0	236

Table 3.--Density estimates (fish/hectare) for wild rainbow trout and brown trout >100 mm in Silver Creek study sections, values in parentheses are 95% confidence limits.

Study site	Area, hectares	Rainbow trout Summer 86	Rainbow trout Fall 86	Rainbow trout Spring 86	Brown trout Summer 86	Brown trout Fall 86	Brown trout Spring 86
Section C&R							
upper	2.9	305 (197-469)	281 (185-423)	804 (615-1048)	__a	__a	44 (22-88)
lower	6.6	253 (161-392)			4 (2-7)		
Section GR							
upper	2.0	172 (97-294)	__a	323 (235-443)	30 (19-47)	189 (114-309)	44 (33-57)
lower	1.4	234 (111-451)			__a		

—[a] insufficient recaptures for valid estimate

No rainbow trout older than age 4 were collected in the 1976-77 study. Samples collected in 1986 and 1987 from both sections showed an additional age class, with a total of fourteen age-5 rainbow trout captured in both years. In Section GR, three age-5 fish were found in the spring 1987 sample only.

Differences in condition factors of rainbow trout between 1977 and 1987 samples (Table 6) and between sections in 1987, were not significant using the Mann-Whitney test and length-weight regression analysis.

Brown trout mean length at age was substantially higher than that of rainbow trout in respective sections. In Section GR, mean length at age 1 was 157 mm, as compared with 122 mm for rainbow trout. For all ages, brown trout were larger than rainbow trout of the same age. Also, brown trout exhibited greater longevity than rainbow trout, attaining a maximum of 7 years.

Table 4.--Estimates of biomass (kilograms/hectare) based on densities and average weight of rainbow and brown trout larger than 100 mm in Silver Creek. Values in parentheses are 95% confidence limits.

Study site	Rainbow trout Summer 86	Rainbow trout Fall 86	Rainbow trout Spring 87	Brown trout Summer 86	Brown trout Fall 86	Brown trout Spring 86
Section C&R						
upper	79.3 (51.2-121.9)	84.6 (55.7-127.3)	169.6 (129.8-221.1)	__a	__a	23.7 (10.8-47.4)
lower	105.8 (67.3-196.0)			3.8 (1.9-6.6)		
Section GR						
upper	31.0 (17.5-52.9)	__a	55.9 (40.7-76.6)	29.0 (18.4-43.6)	205 (123.9-335.9)	33.0 (24.7-42.7)
lower	40.5 (19.2-78.0)			__a		

—[a] no valid population estimate

Table 5.--Back-calculated lengths for rainbow trout in Silver Creek in 1976-77 and 1986-87. Asterisk denotes a significant difference between samples using a two sample t-test (P < 0.05). Data for 1976-77 from Thurow (1978). Number of fish per age class is given in parentheses.

Study site and source	Sample size	Estimated length at age, mm 1	2	3	4	5
Section C&R						
1976-77	77	112(13)	208(27)	280(24)	349(3)	
Oct 1986 and May 1987	505	126(262)	213(69)	294(79)	358(81)	389(14)
Section GR						
1976-77	52	139(9)*	212(26)	297(9)	361(8)	
Oct 1986 and May 1987	256	122(133)*	205(47)	268(36)	347(37)	426(3)

Table 6.--Condition factors (K) of Silver Creek rainbow trout for 1976-77 (from Thurow 1978) and 1986-87 sampling periods.

Sampling period and size classes	Mean condition factor 1976-77	1986-87	Sample size 1976-77	1986-87
Section C&R				
Fall				
<200 mm	1.00	1.04	5	32
200-299 mm	0.99	1.01	15	33
300-380 mm	1.01	0.99	13	18
>380 mm	1.01	0.97	4	52
Spring				
<200 mm	0.89	1.02	1	244
200-299 mm	1.03	1.01	4	96
300-380 mm	0.96	0.98	4	94
>380 mm	0.94	0.93	2	67
Section GR				
Fall				
<200 mm	1.28	1.10	6	8
200-299 mm	1.06	1.11	6	37
300-380 mm	0.93	1.05	2	14
>380 mm	1.02	1.04	6	11
Spring				
<200 mm	0.91	0.91	2	94
200-299 mm	0.97	0.98	13	35
300-380 mm	1.06	0.96	8	43
>380 mm	1.05	1.03	2	10

Table 7.--Total estimated effort on Silver Creek for the 1977 and 1987 angling seasons. Data for 1977 from Thurow (1978).

Study section	Surface area (hectare)	Total estimated effort, hours 1977	1987	hours/hectare 1977	1987
Section C&R	13.1	7,772	14,514	594	1,110
Section GR	22.2	11,963	6,417	538	289
Total	35.3	19,735	20,931		

Mortality

Annual mortality of adult rainbow trout age 3 and older was reduced in both sections in 1986-87 from that of 1977. Annual mortality (A) in our study ranged from 0.44 to 0.53 for various time intervals in Section C&R, a decrease from 0.67 in 1977.

For Section GR, both 1986 and 1987 annual mortality estimates (0.67 and 0.42, respectively) were also less than the 0.72 value determined in 1977. The exploitation rate (E) of age 3 and older rainbow trout there was 0.38.

Angler Effort and Catch

Total angling effort for the two sections of Silver Creek increased slightly from 1977 to 1987, from 19,735 to 20,931 hours (Table 7). The distribution of effort changed dramatically, however, with that of Section C&R nearly doubling (to 1,110 h/hectare) and that of Section GR decreasing by nearly half to about 290 h/hectare.

Catch rates for rainbow trout in Section C&R increased from 1.13 fish/h in 1977 to 1.81 fish/h during the 1987 season (Table 8). Catch rates of trout $\geq$ 300 mm increased from 0.42 fish/h in 1977 to 0.74 in 1987. The increase in catch rate and effort resulted in a threefold increase in estimated number of rainbow trout caught from 8,803 in 1977, the first year of catch-and-release, to 26,213 in 1987 (Table 7).

The length frequency (based on angler recall) of angler-caught rainbow trout in Section C&R was similar to that generated from electrofishing samples for trout up to 400 mm. For fish over 400 mm, however, anglers captured a smaller fraction (9%) in the section than did electrofishing (19%). There was no substantial change in size of rainbow trout caught by anglers in the 10 year period; fish longer than 300 mm comprised 41% of the 1987 catch, as compared with 37% in 1977 (Table 9). Brown trout and brook trout in Section C&R comprised 8% and 2.5% of the catch, respectively.

In Section GR, the proportion of fly fishermen increased from 38% in 1977 to 61% (38% bait and 1% lures) in 1987. Only 28% of fish caught in Section 3 in 1977 were wild rainbow trout, as compared to 86% in 1987 (Table 8). The total catch rate for rainbow trout in Section GR increased over the last 10 years from 0.24 fish/h in 1977 to 1.38 fish/h in 1987.

Table 8.-- Estimated catch of rainbow trout in the 1977 (from Thurow 1978) and for all trout species the 1987 angling seasons. Catch rates (fish/h) are in parentheses.

Study section	1977 rainbow	1987 rainbow	1987 brown	1987 brook
Section C&R	8,803 (1.13)	26,213 (1.81)	1,221 (0.08)	688 (0.05)
Section GR	2,846 (0.24)	8,886 (1.38)	1,356 (0.21)	141 (0.02)

Table 9.--Mean lengths of angler-caught wild rainbow trout and percentages of the catch that exceeded 300 mm and 400 mm for the 1977 and 1987 angling seasons. Data from section C&R from angler recall and from section GR from measurements of harvested fish. Data for 1977 from Thurow (1978).

Stream section	1977 mean length, mm	1977 % > 300 mm	1977 % > 400 mm	1977 sample size	1987 mean length, mm	1987 % > 300 mm	1987 % > 400 mm	1987 sample size
Section C&R	285	37	8	898	255	41	9	1168
Section GR	280	44	8	146	286	49	6	55

The proportion of rainbow trout exceeding 300 mm harvested by anglers in Section GR also increased from 44% to 49% during the ten years (Table 9). Our creel census indicated that 15% of the rainbow trout caught (regardless of whether they were released or harvested) in Section GR were larger than 300 mm in 1987. Harvest rates of rainbow trout in the section have almost doubled since 1977, from 0.16 to 0.28 fish/h. The number of rainbow trout harvested in 1987 decreased slightly to 1,805 from 1,924 fish in 1977, due to the reduction in effort and an increase in the percentage of rainbow trout released from 32 to 80%.

Brown trout in Section GR accounted for 13% of the catch in 1987. The total estimated catch during the season was 1,356 brown trout, of which an estimated 437 were harvested.

DISCUSSION

In evaluating the effects of catch-and-release regulations on Silver Creek, both biological and sociological changes may be evaluated. The former would be reflected in a response of the fish populations, and the latter would be evident in the fishery.

Our study demonstrates sociological changes in the past decade that were much stronger than the biological changes. Although angler effort on Silver Creek as a whole has remained quite similar since 1977, effort in the catch-and-release section has more than doubled. This increase is not solely due to an increase in nonresident use, as little change in residence of anglers occurred (Riehle et al. 1988). Effort in the section that continued under general regulations declined by nearly half. This decline was unfortunate from a research perspective because it confounded analysis of trout population dynamics in that section.

The biological indicators of change that we had the opportunity to evaluate for both study sections were the frequency of large fish in both the electrofishing sample and in the catch, and the angler catch rate. These indicators, with one possible exception, suggest success in the catch-and-release portion of Silver Creek during the past ten years of special regulations.

Because our evaluation depends upon point estimates made at the beginning and end of the interval and not periodically through it, drastic fluctuations in population levels caused by extrinsic factors such as floods and droughts could mask any effects of regulation change. As a spring-fed system, Silver Creek is largely immune from those effects and, we believe, its population dynamics are similar to those in spring streams such as Lawrence Creek, Wisconsin, where trout populations remained relatively stable over a number of years (Hunt 1974 and 1976).

One important question that this study cannot definitively address is whether the number of rainbow trout, especially the number of large trout, has increased during the period in either study section. Since no population estimates using electrofishing were made in the 1976 and 1977 field seasons, only inference based on catch rates is possible, and this requires the assumptions that angler ability and susceptibility of trout to capture have not changed in the 10-year period. If that is the case, rainbow trout populations in the catch-and-release section may have increased at a level commensurate with the 160% increase in catch rate, and those in the general regulation section may also have increased, as discussed below.

Rainbow trout in the 400-499 mm size class in the catch-and-release section increased from 3% to 23% of the electrofishing sample. An increase in size in the angler catch was not evident. One possible explanation is that the larger trout were becoming less vulnerable to repeated hooking. Our data indicate that, on average, each rainbow trout was captured about three times during each angling season (Riehle et al. 1988). Another possible explanation is that larger rainbow trout were more vulnerable to electrofishing.

The increase in the proportion of larger fish in the population appears to reflect changes in both growth and survival. We found a decrease by about one-third in total annual mortality for rainbow trout of ages 3 and older. A similar reduction in summer season mortality (0.47-0.50 in a catch-and-release area and 0.71 in a general regulations area) has been documented for rainbow trout in the Madison River of Montana (Vincent 1980). In the Big Wood River of Idaho, annual mortality rates for rainbow trout were 0.70 in a catch-and-release area and 0.76-0.78 in a general regulations area (Thurow 1988). From these and other studies, it is becoming evident that total annual mortalities over 40% may be typical for rainbow trout in catch-and-release fisheries. There are several possible reasons for this. One, suggested by Thurow (1988), is that natural mortality is elevated in a compensatory manner over that of a population where harvest is substantial. Other possibilities are that mortality from hooking may be greater than expected and/or the impacts of repeated hooking may be synergistic.

The presence of age-5+ rainbow trout in the Silver Creek population in 1986-87 reflects the increase in survival. Increases in longevity among salmonids protected by catch-and-release regulations have been documented in studies by Johnson and Bjornn (1978), Vincent (1980), and Jones (1985).

Growth of rainbow trout in the catch-and-release section of Silver Creek has increased from estimates made in 1977. The increase, although not statistically significant, may be biologically significant. Increases in growth may have occurred from the protection afforded to fast growing individuals, assuming that these individuals would have otherwise been harvested, or may reflect a reduction of hatchery catchable rainbow trout from the section. Vincent (1987) found an increase in growth of wild brown trout in O'Dell Creek, Montana, after the elimination of hatchery catchable plantings. An ongoing program of The Nature Conservancy to reduce sediment input from the upper tributaries may have also increased the productivity of Silver Creek and increased trout growth.

The moderate response of Silver Creek rainbow trout to special regulations may be due to inherent characteristics of the stock. As discussed by Thurow (1978), random introductions over the past 80 years of fish from numerous hatcheries have altered the genetic makeup of the original McCloud River stock established in the nineteeth century.

The rainbow trout population in the general regulations section has also shown improvement over the last 10 years. Total annual mortality of age-3 and older fish has fallen to a degree similar to that in the catch-and-release section, and a few age-5 rainbow trout were present. Although growth has declined since 1977, there has been a small increase in the percentage of fish exceeding 399 mm in length. The probable cause of these changes is the 46% decrease in angler effort and the substantial increase in the percentage of fish released. Harvest of rainbow trout was reduced by 37% from 1977. Another possibility, which also influenced the reduction in effort, is the cessation of rainbow trout stocking. During the 1976 and 1977 study years, approximately 12,000 catchable-sized rainbow trout were planted in the section.

The number of rainbow trout caught by anglers in the general regulations section has tripled and the catch rate has increased nearly six-fold in the interval. Although the percentage of fish released has increased to 80% of that caught, the fishery continues to provide substantial harvest. We found that in 1987, anglers harvested an estimated 41% and 28% of the rainbow trout present in the spring that exceeded 300 and 400 mm, respectively.

Considering that in 1977 brown trout were not found above the Picabo Bridge, the brown trout population has made strong advances in the ten years. Few anglers were successful in catching them. A few successful anglers fished at night, and they were probably not adequately covered in the interviews, but too few trips were involved to affect the harvest values. Brown trout in the catch-and-release area have become more than a novelty. Although few brown trout were caught by anglers, electrofishing and snorkel surveys in the upper portion of the section indicate a relatively high density of juvenile brown trout. With undercut banks, brushy submerged and overhead cover, and deep pools, the habitat there is well suited for brown trout, and the population should continue to expand.

ACKNOWLEDGEMENTS

Funding for this study was provided by Federal Aid in Fish Restoration, the Idaho Department of Fish and Game, and The Nature Conservancy. Special thanks go to Virgil Moore, David Ortmann, Guy Bonnivier, and Russ Thurow for the valuable assistance they provided.

LITERATURE CITED

Frie, R.V. 1982. Measurement of fish scales and back-calculation of body lengths using a digitizing pad and microcomputor. Fisheries 7(5): 5-8.

Hunt, R.L. 1974. Annual production by brook trout in Lawrence Creek during eleven successive years. Technical Bulletin 82, Wisconsin Department of Natural Resources, Madison.

Hunt, R.L. 1976. A long-term evaluation of trout habitat development and its relation to improving management related research. Transactions of the American Fisheries Society 105: 361-364.

Jones, R.D. 1985. Fishery and aquatic management program in Yellowstone National Park. Technical Report for Calendar Year 1984. U.S. Fish & Wildlife Service.

Johnson, T.H. and T.C. Bjornn. 1978. The St. Joe River and Kelly Creek cutthroat trout populations: An example of wild trout management in Idaho. In J.R. Moring, editor. Proceedings of the Wild Trout-Catchable Trout Symposium, Research and Development Section, Oregon Department of Fish and Wildlife, Eugene.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin 191 of the Fisheries Research Board of Canada.

Riehle, M.D., B.L. Parker, and J.S. Griffith. 1988. Silver Creek fisheries evaluation. Final Report, Project F-71-R-12, Subproject III, Job 5. Idaho Department of Fish and Game, Boise.

Vincent, R.E. 1980. Southwest Montana fisheries investigations, Job Progress Report, F-9-R-28, Montana Department of Fish, Wildlife and Parks, Fisheries Division, Helena.

Vincent, R.E. 1987. Effect of stocking catchable-size hatchery rainbow trout on two wild trout species in the Madison River and O'Dell Creek, Montana. North American Journal of Fisheries Management 7: 91-105.

U. S. Geological Survey. 1975-83. Water resources data for Idaho. Water Resources Division, Boise.

Thurow, R. 1978. Silver Creek fisheries investigations. Federal Aid in Fisheries Restorations, Job Completion Report, F-66-R, Idaho Department of Fish and Game, Boise.

Thurow, R. 1988. Effects of stream alterations on rainbow trout in the Big Wood River, Idaho. pp. 175-188 In: Proceedings of the 68th Conference of the Western Association of Fish and Wildlife Agencies.

Salmonid Geomorphology[1]

William J. Trush[2]

Abstract.--Several physical factors at different spatial and temporal scales affect salmon and steelhead trout spawning in headwater tributaries. An alternate bar morphology in low gradient channels produces salmon and steelhead spawining habitat within a band of frequently mobilized bedload. Steeper tributary channels lose the systematic pattern of alternating bars, but continue to provide spawning habitat with a different channel morphology. Spawning habitat in the downstream margins of boulder steps and the tails of bedrock pools is located in highly mobile gravels. The interaction of channel gradients at river confluences and the shape of winter hydrographs limit anadromous access to headwater tributaries. The timing and magnitude of storm discharges also determine weekly and annual habitat availability.

INTRODUCTION

A watershed's anadromous salmonid population is dependent on the interaction of many spatial and temporal physical factors. Each factor may exert an influence on salmonid population dynamics at several spatial and temporal scales. For example, daily, annual and inter-annual patterns of stream discharge each have the potential to affect different stages in an anadromous life cycle. The distribution of rocks in a pool may determine the quality of juvenile cover, while larger spatial scales including an entire river basin, and ultimately the open ocean, clearly are important influences on adult growth rates and migration. Year-to-year persistance of an anadromous population requires (1) adequate adult upstream migration and (2) adequate smolt production and successful outmigration. Each salmonid population must overcome (or adapt to) constraints at several spatial and temporal scales in order to satisfy both requirements. The purpose of this paper is to demonstrate the importance of several temporal and spatial scales influencing the migration and spawning of anadromous salmonids, particularly steelhead trout (*Oncorhynchus mykiss*), in the headwaters of the South Fork Eel River, California.

[1]Paper presented at the Fourth Wild Trout Symposium, Mammoth, Wyoming, September 18-19, 1989.

[2]William J. Trush is a fisheries instructor at Humboldt State University Arcata, Calif. and biologist at Trinity Fisheries Consulting, Arcata, Calif.

INFLUENCE OF SPATIAL SCALE

A larger watershed, such as the Eel River basin in Northern California, presents a variety of channel sizes and shapes to migrating adult salmonids. Headwater tributaries of the South Fork Eel River (fig. 1) support chinook salmon (*Onchorhynchus tshawytscha*), coho salmon (*O. kisutch*) and steelhead trout. The limited occurrence of an extensive terrace within an otherwise narrow, bedrock-confined channel, is a major influence on species utilization of first through fourth order tributaries. Tributaries entering the main channel of the South Fork Eel River that do not pass through a river terrrace typically range in gradient from 2.0 to 15 percent and support only steelhead with an

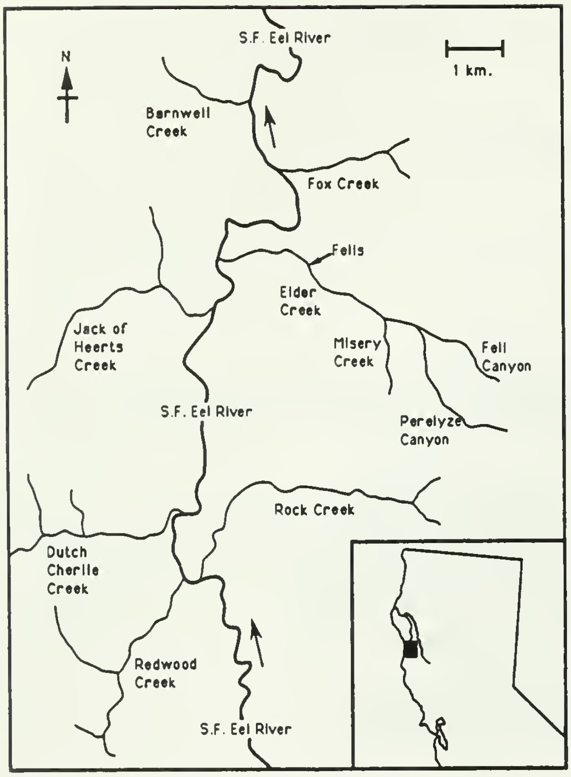


Figure 1. Upper South Fork Eel River, Mendocino Co., California

occasional stray coho salmon. Elder and Fox Creeks (fig. 1), two pristine Douglas-fir watersheds, have steep channels and never supported salmon migrations, though steelhead are abundant. In contrast, Dutch Charley and Rock Creeks (fig. 1) pass through a river terrace, creating a gradient near one percent in the lower portion of their channels. Chinook salmon utilize the low gradient channels; steelhead are common in the lower and headwater reaches of both streams. Redwood Creek has a channel gradient near its mouth of less than one percent, supporting a large run of coho salmon. The longitudinal profile of tributary main channels, therefore, can be a critical spatial factor determining species utilization.

Gradient differences within the same tributary and among different tributary channels of similar drainage areas lead to several distinct channel morphologies, creating a variety of spawning environments that satisfy a range of species preferences. Salmonids spawn in gravels easily entrained by high discharges. The dynamics of bedload movement and storage determine the amount, particle size, location and availability of spawnable habitat.

The majority of bedload moves along a sinuous pathway, alternating from one point bar to the next, downstream point bar in a typical alluvial channel (fig. 2). Successive point bars are not spatially isolated depositional features, but rather are exposed portions of temporarily stored alluvium along a continous 'band' of bedload movement. The development of an alternate bar morphology is a precursor to the establishment of a meandering alluvial channel.

Chinook salmon and steelhead in low gradient channels spawn in this bedload pathway, primarily at channel cross-overs where the channel changes meander direction (fig. 2). The upwelling of subsurface gravel flows and favorable gravel composition in the tail of pools immediately upstream of the channel cross-over produce high quality spawning habitat. Geomorphically, the pool represents a frequently scoured portion of the alternate bar morphology, with the pool's tail being the upstream face of a mobile alluvial bar (fig. 2). The riffle represents the downstream side of the alluvial bar. On larger rivers, such as the lower portions of the main Eel River, chinook salmon also spawn in the low gradient riffles during mild winter flows.

Channel features for steep tributaries, such as Elder Creek (with an average main channel gradient of 2.2 percent), deviate from the regular occurrence of point bars in an alternate bar morphology typical of less steep, meandering channels. Mean particle size in riffles increase, causing the abundance and types of spawning habitat in steep channels to change.

Many Elder Creek riffles had sets of boulders arranged in rows at various angles relative to the channel flow (fig. 3) in stream bed gradients ranging from 1.5 to 5.0 percent. Boulders comprising the rows were larger than the average particle size for the entire riffle by a factor of two. Boulder sets produced a stepped appearance to many riffles, creating a series of deep runs between each boulder set. Simple critical shear stress calculations indicated that the boulders in the sets could have been mobilized only by very large storm flows such as the December 1964 flood. Bankfull discharge, occurring on the average of once each year, would not have initiated boulder movement.

The location and abundance of potential spawning habitat was

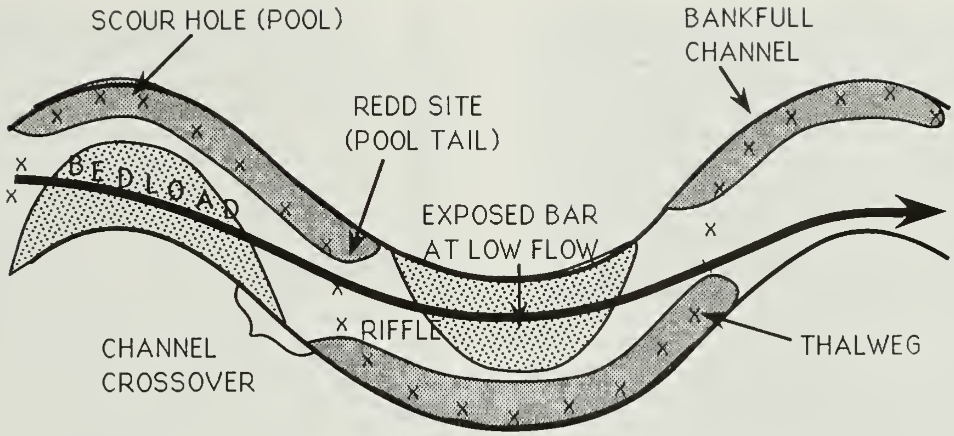


Figure 2. Idealized bedform morphology, for an alluvial channel.

influenced by boulder step formation. Small gravel patches just upstream of the gap between two boulders in the set were utilized by steelhead, especially at lower discharges. These small patches were mini 'pool tail' habitats, the habitat type heavily favored by spawning steelhead. Limited spawning habitat also was found along the margins of boulder steps. Features created by infrequent events, such as the arrangement of boulder sets, function as the structural framework for storing spawnable gravels.

Pools in Elder Creek differed from typical alluvial pools in several ways. Outer pool banks were generally composed of bedrock. The alternate bar morphology was fragmented, only occasional reaches of 100 to 300 meters had successive gravel point bars. The finer gravels in the bedrock pool tails overtopped a much coarser subsurface layer. The disparity in particle size distribution indicates that the finer surface gravels are a secondary depositional feature scoured and shaped at considerably lower discharges. As found in the alternate bar morphology, steelhead spawn in alluvium mobilized by bankfull discharges. The particles less frequently mobilized form the structural framework for gravel storage in the steep, relatively narrow channel of Elder Creek.

INFLUENCE OF TEMPORAL AND SPATIAL SCALE

The arrangement of headwater tributaries within a river basin demonstrates the combined effects of spatial and temporal scale on steelhead populations. Junctions of first (1 km^2 watershed) and second order channel (3 km^2 watershed) typically do not exhibit sharp breaks in slope. Although storm discharge in a first order channel peaks slightly earlier than in a second order channel, the timing of their respective storm hydrographs is sufficiently similar to allow migrating adults to swim from the second order channel into the first order channel during most winter flows. The junction of a first and fourth order channel (15-20 km^2 watershed), however, often does exhibit a sharp slope break, with the first order channel rapidly dropping to the fourth order floodplain. This steep portion of the first order channel often

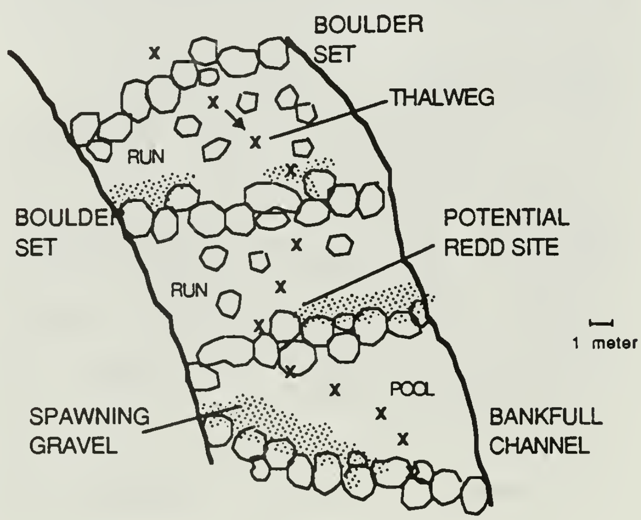


Figure 3. Planimetric map of a typical Elder Creek riffle (2.5% gradient).

must be partially flooded by the rising stage of the fourth order channel before adults can negotiate the junction. However, by the time the fourth order channel flow is peaking, flow in the first order channel already has been declining. The effect of stream junctures on adult migration, mediated by differences in channel slope and flood hydrographs, is diagramed in Figure 4 for two channels differing by only one or two stream orders, given the following terminology:

Q_{S1}...range of flows allowing steelhead to reach favorable spawning habitat in Watershed #1 (the smaller channel);
Q_{S2}...range of flows (in the larger channel, WSHD #2) needed by steelhead to negotiate the mouth of Watershed #1 (flows below this range in WSHD #2 are a barrier to WSHD #1);
T_A ...number of hours to negotiate the stream junction;
T_S ...number of hours for reaching upper regions of WSHD #1.

As size differences between watersheds (or stream order) increase, T_A and T_S decrease because greater flows are needed in the larger channel to flood the junction. A first order stream joining a fourth order stream greatly limits T_A and T_S. Partial stream barriers, acting in a similar fashion to stream junctions, also can affect migration depending upon their structure, location and sequence within the stream channel network.

The mouth of Fox Creek (fig. 1) provides an example. The junction of the South Fork Eel River (fifth order) and Fox Creek (second order) presents a sharp break in channel slope to migrating fish at baseflow conditions. Only during storm conditions can fish enter Fox Creek. In a dry year, a single storm produces a steep hydrograph greatly limiting access to Fox Creek. The upstream limit of rearing fry and observed spawnings occur at a small cascade 0.75 km above the mouth. If fish were present at the cascade during the peak of the storm hydrograph, I do not think migrating fish would be stopped by the cascade. Parr were found above the cascade in 1983, a particularly wet year with multiple, overlapping storm peaks.

INFLUENCE OF DISCHARGE TIMING

As adult steelhead in the South Fork Eel River migrate upstream, channel morphology changes. The limited alternate bar morphology of the main channel, in lower portions of tributaries flowing through terraces, evolves into boulder sets and bedrock pools found in steeper headwater channels. The abundance and type of spawning habitat also changes with this evolution of channel morphology. In addition, discharge magnitude and timing influence spawning habitat abundance and availability. The temporal influence of stream discharge on spawning habitat will be examined for Elder Creek.

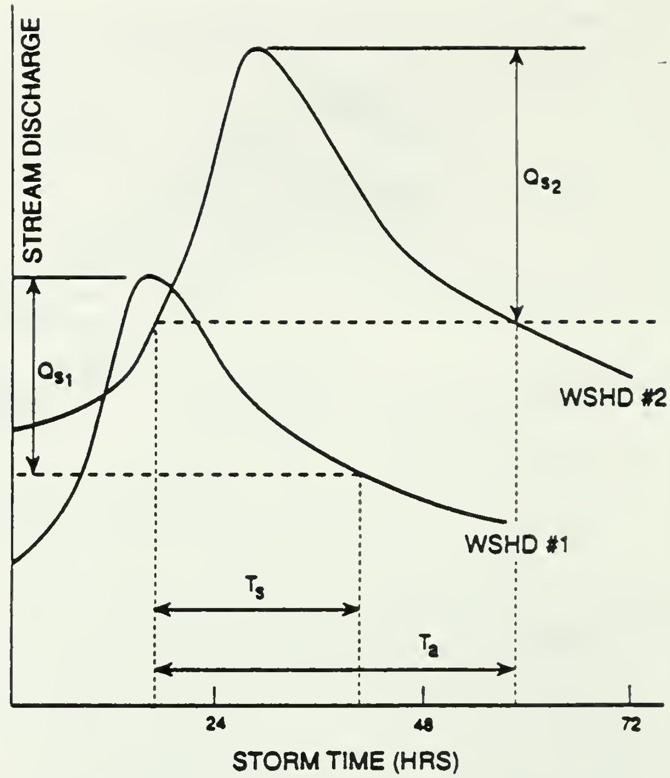


Figure 4. Temporal window of access for migrant adult steelhead

In the 1960's, the Nature Conservancy purchased an old growth tract along the South Fork Eel River. The Northern California Coast Range Preserve, managed jointly with the U.S. Bureau of Land Management, includes the Elder Creek watershed, the largest undisturbed Douglas-fir watershed in California. The U.S. Geological Survey has maintained a hydrologic benchmark station (Sta.No. 11475560) 0.60 km upstream of the mouth, monitoring stream discharge and precipitation at 15 minute intervals since 1968.

The main channel bed is composed of coarse grained median particle sizes ranging from 25 to 50 cm in steep riffles and 3 to 10 cm in point bar deposits. Bedrock is exposed on the floor of all major pools and comprises 10 to 90 percent of the exposed banks in typical channel reaches. In Rosgen's (1975) stream classification system, most channel segments on Elder Creek would be 'B1' stream types. Multiple terrace sets 3 to 15 m above the present channel indicate an extensive period of downcutting; major alluvial features are limited to very few, less confined channel reaches. Stream gradient for the entire main channel averages 3.3 percent, though the channel gradient below a major knickpoint (2.3 km from the mouth) is 2.4 percent. The low sinuosity of the channel exhibits depositional features typical of alluvial channels, though modified by bedrock outcrops and boulders. Coarse point bars are found at more acute channel bends associated with the larger pools.

Under saturated soil conditions, winter storms generated intense periods of high runoff in Elder Creek watershed. Approximately 18 percent of an average spawning season (22 of 120 days) exceeded an average daily discharge of 2.27 cms (80 cfs). Over half the days had average discharges under 0.85 cms (30 cfs). Individual storms with steep ascending and descending hydrograph limbs produced a very limited duration of higher discharges. Even closely spaced storms did not produce high sustained daily discharges, but rather a series of peaks with considerable fluctuation of flows between peaks. The 1983 season was the wettest since 1968 (first year of USGS records) with 7 distinct storm peaks. Individual storm hydrographs overlapped to maintain relatively high discharge between storms. A decrease to 4 peaks in 1986 significantly reduced hydrograph overlap. To keep daily discharge above 0.85 cms (above MODERATE discharge), a storm sequence of 6 to 8 days would be needed to provide sufficient hydrograph overlap. Storm frequency may be as important as storm magnitude in determining flows available for escapement and spawning. Extended periods of discharge below 1.13 cms (40 cfs), interrupted by spikes of storm discharge with instantaneous peaks near or above 5.66 cms (200 cfs), is the norm for an Elder Creek spawning season.

The effect of flow timing on upstream migration would be particularly pronounced during a season with very few storms separated by long periods of dry weather. Steelhead cannot move gradually up the watershed during low flows; instead they must remain in the lower watershed, waiting for the next storm. The 1989 season is a good example. A minor storm peak in February induced few fish up Elder Creek (approximately 7 redds in 2.5 km of channel below a bedrock falls). Normally a flow of this magnitude at this time of the season would produce a large migration run (resulting in 30 to 40 redds), but conditions in January of 1989 were dry. Steelhead during years with distinct rainfall events may move up large river basins in pulses, as Snyder (1933) observed in the Shasta River. In contrast, a season with overlapping storm hydrographs (roughly a storm every 10-15 days) would permit an extended migration window.

Elder Creek falls is a partial barrier to migration that cascades in two steps. After negotiating the first step (midway), steelhead encountered no slack region before attempting the second step, making passage difficult. Thirty minute observation periods (n=90) narrowed the range of passable flows to 1.7 cms (60 cfs) through 4.8 cms (170 cfs). On a daily average flow duration curve, 19 percent of the days in an average spawning season (23 of 120 days) have flows ranging from 1.7 cms to 4.8 cms. This percentage varied from year to year. In 1984 the number of days with passable discharge totaled 12; 14 of 72 redds were constructed above the falls. In 1985 only two days had passable discharges; 15 of 105 redds were constructed above the falls. Depending on storm magnitude, the steep recession limb of storm hydrographs limits an individual steelhead to only a few days (from 2 to 5 days) for clearing the falls.

Individual steelhead usually ascend the channel, spawn, and emigrate within the time frame of a single storm hydrograph. The first storm in 1985 (early February) had an isolated storm hydrograph with a typical base of 19 days. Average daily discharge increased from 0.17 cms (5.5 cfs) to 5.75 cms (203 cfs) in two days. Instantaneous peak discharge was 9.26 cms (327 cfs) (unpbl. U.S.G.S. records, Eureka office). Three days following the storm peak, average daily discharge was 1.53 cms (54 cfs); redd construction already had been active for 24 hours. Eleven days later, daily average discharge was 0.57 cms (20 cfs); most adults had completed spawning and emigrated.

Spawning in Elder Creek began in earnest 2 to 5 days following peak discharge. Each spawning site was occupied by a single spawning pair (usually including a supporting cast of additional males) at any given time regardless of site area. Redds were constructed with an average area of 1.45 m^2. However, a spawning pair ranged over an area several times greater than the area physically disturbed by the cutting female. At pool tails, dominant males utilized the entire pool and lower riffle to fend off other males. Territorial defense by the dominant male and female often extended up to 30 m above and below the redd. Construction time from site selection to final covering of the eggs was not estimated, specifically. Needham and Taft (1934) noted spawning could be completed in 12 hours, but a week was common. Steelhead in a tributary of the Clearwater River (Idaho) averaged 15.8 days for their entire length of stay and 1.6 days at a single redd site (Reingold 1965). In Elder Creek, initially undisturbed sites often had large, well-developed redds within 30 hours.

Not all spawning habitat types (eg. the tail of pools, isolated deposits on the margins of riffles) were equally available for spawning in each migration season. Square meters of spawnable gravel in each habitat type on Elder Creek changed with stream discharge. For example, pockets of gravel in riffles were spawned almost exclusively at low winter flows while pool tail alluvium provided habitat at all but the greatest flows. The magnitude, frequency and timing of winter storms were important factors in determining habitat availability for individual spawning seasons. Upper Elder channel was most accessible in spawning seasons with frequent, overlapping storms of moderate magnitude (below 4.81 cms). Another factor was the steep recession limbs in Elder Creek flood hydrographs. An innate drive to reach the highest possible watershed elevation during, and somewhat after, each storm peak caused steelhead to under-utilize spawning habitat suited only for higher flows in the upper half of the recession limb. Many fish were 'too busy' negotiating migration barriers instead of spawning on the lower channel reaches. While a channel may contain the same surface area of spawning gravels between spawning seasons (i.e. habitat abundance), annual flow regime will determine overall habitat availability. Consequently, the relative importance of each spawning habitat type on Elder Creek shifted from year to year.

The gravel patches most utilized for spawning were those frequently mobilized during winter discharges. Evidence of frequent movement can be found in the field. First, spawning gravels were located within the active channel where stream depths are greatest. Greater water column depth produces a greater shear stress on the channelbed, considering other factors such as water surface slope. Second, the most frequented spawning sites had gravels that were easily excavated by hand or the toe of your chestwaders. Larger regions of the streambed with marginal spawning habitat had a shallow layer of small gravels (a few centimeters deep), but a tightly interlocked subsurface layer of larger gravels and smaller cobbles; steelhead were able to break-up this subsurface but often abandoned these sites in favor of others. Typical channel locations with these substrate characteristics were the tail regions of pools. Higher frequency storms (i.e., lower magnitude discharge peaks) should mobilize the less interlocked substrate with greater ease and, therefore, greater frequency. In an extreme case, you could push your arm, up to the elbow, into pockets of fine gravel in the lee of boulders positioned downstream of riffle boulder sets; steelhead rarely utilized this channel location. Gravel deposits in the boulder eddies are highly mobile, formed well into the declining limb of storm hydrographs of relatively low magnitude.

If spawning habitats are subject to frequent scour, do storms threaten egg survival in selected redds or an entire annual generation of eggs? The Valentine Flood in 1986 had a major detrimental impact on redds constructed in January and early February on Elder Creek. A field survey 4 days after the storm recorded almost total scour of several major spawning sites and complete burial of other sites. But the potential impact of less extreme storm events, particularly below bankfull discharge, is less clear. Bedload rating curves would be helpful in an analysis, but not conclusive in determining potential impacts unless particles sampled in the bedload could be associated with the vertical extent of redd scouring (i.e., sampled bedload could be originating from other parts of the channel).

Even an experimental approach, associating redd scour or egg mortality to flood magnitude, would not provide a complete story on the significance of flooding on spawning habitat. Steelhead in Elder Creek may be strongly dependent on gravels with a high turnover and low in-channel storage (high relative gravel import and export rates). Deep scour of spawnable gravel could have major detrimental impact on total annual egg survival in certain years, but a highly favorable impact on the longer term survival of the population. Major storm flows would (1) maintain the supply of gravels into the active channel, (2) allow steelhead to reach the upper headwaters, (3) maintain present channel morphology, (4) clear the channel of barriers and (5) keep the accumulation of fine material to a minimum within the subsurface gravels.

The negative impact of flooding on egg survival in a given year would be tempered by life history traits. A watershed's steelhead population may have individuals collectively representing up to 27 or more variations in life cycle (Shapovalov and Taft 1954; Jones 1977). Individuals from a single cohort may spend from one to four years in freshwater before smolting and one to four years in the ocean before returning on their maiden migration run. The influence of a single generation on the age composition of a migration run would be represented in several migration runs. The overlap of several generations in each annual migration run would modify major fluctuations in the number of migrants caused by years with poor or highly successful egg (or smolt) survival.

It would be difficult to imagine a healthy steelhead population without frequent disturbance to the channel. Even the 100 year flood event might not be considered a disturbance, but rather a necessary element of the steelhead's environment for guaranteeing population survival over many generations.

SUMMARY

Steelhead spawning habitat is the product of an interaction between two basic physical factors at several scales. The first factor, channel morphology, determines the location, abundance, quality and availability of spawning gravels. Streamflow magnitude and timing, as the second factor, directly interact with channel morphology and spawning salmonids. Gravels must be covered by water to a sufficient depth, at a reasonable velocity, and for a favorable inundation period before qualifying as spawning habitat. Flows interact with the channel in a more dynamic role. Gravel abundance, channel cross section shape, and substrate composition are the products of an interaction between basin geomorphology, lithology, and the magnitude and timing of stream flows.

LITERATURE CITED

Jones, D.E. 1977. Life history of steelhead and life history of sea-run cutthroat trout. Sport Fish. Div.; Alaska Dept. Fish. Game., Study AFS 42, Compl. Report vol. 18. U.S. Army Corps Engr., Contract DACW57-74-F-0621, 75 pp.

Reingold, M. 1965. A steelhead spawning study. Idaho Fish and Game Comm., Idaho Widl. Rev. 17(4):8-10.

Rosgen, D.L. 1985. A stream classification system. In: Riparian ecosystems and their management: reconciling conflicting uses. 1985 April 16-18; Tucson, AZ. Gen. Tech. Rept. RM-120. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Dept. of Agriculture; 91-95.

Shapovalov, L. and A.C.Taft. 1954. The life histories of the steelhead rainbow trout (Salmo g.gairdneri) and silver salmon (Oncorhynchus kisutch) with special reference to Waddell Creek, California, and recommendations regarding their management. California Dept. Fish and Game, Fish. Bull. No. 98:375 pp.

Snyder, J.O. 1933. A steelhead migration in Shasta River. California Dept. Fish and Game 19:252-254.

Relation of Geomorphology to Stream Habitat and Trout Standing Stock in Small Rocky Mountain Streams[1]

Thomas A. Wesche[2] and Wayne A. Hubert[3]

Abstract.--Evidence that drainage basin morphology and trout standing stock are related through a functional link between geomorphic features and stream habitat quality is presented. Numerous significant univariate correlations were found between geomorphic variables, stream habitat variables, and trout standing stock in both high-elevation forest and low-elevation rangeland streams. Canonical correlations between geomorphic variables and stream habitat variables provided in-sight into the form of the functional link. Multiple-regression equations predicting trout standing stock were dominated by geomorphic variable. When geomorphic variables alone were incorporated into regression models they predicted trout standing stock as accurately as did stream habitat variables.

SUMMARY OF RESULTS

Relations between measures of drainage basin geomorphology, stream habitat quality, and trout standing stock were demonstrated in this study by numerous univariate correlations between geomorphic and stream habitat variables, high canonical correlations between geomorphic variates stream habitat variates, and the extent to which geomorphic variables accounted for variance the standing stock of trout. Platts (1979) and Parsons et al. (1981) also looked at the relations between drainage basin geomorphology stream habitat. Platts (1979) found that as stream order increased, stream width, depth, and the percent of rubble substrate also increased, whereas the percent of pool habitats, channel gradient, and the percent of gravel substrate. Parsons et al. (1981) correlated a habitat condition score generated from measured features of stream habitat to four measures of drainage basin geomorphology. All of these relations combine to provide substantial evidence that stream habitat is a function of geologic processes within the drainage basin.

Geomorphic variable dominated our multiple-regression models where both variable types were incorporated. In addition, when used separately, trout standing stock was predicted as accurately with geomorphic variables as it was with stream habitat variables. Other studies have successfully used measures of drainage basin geomorphology to predict salmonid standing stock or abundance in streams (Ziemer 1971; Burton and Wesche 1974; Swanston et al. 1977). These observations suggest that geomorphic variables are useful in predicting the potential habitat quality of trout streams.

Our data confirm that small, gently sloping drainage basins produce the best trout habitat.

[1]Paper presented at the Wild Trout IV Symposium, Yellowstone National Park, Wyoming, September 18-19, 1989. For additional detail, the reader should consult the following citation:
Lanks, R.P., W.A. Hubert and T.A. Wesche. 1987. Relation of geomorphology to stream habitat and trout standing stock in small Rocky Mountain streams. Transactions of the American Fisheries Society 116:21-28.

[2]Thomas A. Wesche is an Associate Professor, Wyoming Water Research Center and Department of Range Management, University of Wyoming, Laramie, WY.

[3]Wayne A. Hubert is the Assistant Leader, Wyoming Cooperative Fishery and Wildlife Research Unit, and Associate Professor, Department of Zoology and Physiology, University of Wyoming, Laramie, WY. The Unit is jointly supported by the University of Wyoming, Wyoming Game and Fish Department, and United States Fish and Wildlife Service.

Basin relief, relief ratio, and gradient indicate (by their negative relation to trout standing stock) that a large drop in elevation over the drainage basin leads to reduced trout habitat quality. Branson et al. (1981) stated that high basin relief resulted in greater channel slope and increased drainage density, both of which were negatively related to trout standing stock in our study. The combined effect of watershed features, such as increased basin slope (basin relief and relief ratio), increased channel slope (gradient), and a more dendritic drainage pattern (drainage density), may tend to decrease response time of stream discharge to rainfall events. Drainage basins with these characteristics, when subjected to high-intensity, thunderstorms (which are common in Wyoming), generally have greater flow variability, decreased storage of water in depressions and as groundwater, and lower base flows (Viessman et al. 1977). Low base flows and high flow variability result in poor habitat quality for trout (Binns and Eiserman 1979).

Highest trout biomass was associated with the transition zone between forest and rangeland stream types, which occurred between elevations of 2,100 and 2,455 m in forest streams and 2,100 and 2,224 m in rangeland streams. Platts (1979) found a similar situation in Idaho, and Elser (1968) observed the best habitat quality at the transition between high-gradient, boulder-substrate habitat (characteristic of forest streams) and lower-gradient, gravel-substrate habitat (characteristic of rangeland streams).

Increasing stream size, as reflected by geomorphic variables, resulted in reduced trout density in our study. This relation may be the result of a decrease in relative abundance of riparian cover or an increase in human impact with increasing stream size. Data presented by Conder (1982) indicated that as stream order increased in the Bighorn Basin of Wyoming human impact on the aquatic and riparian resources increased.

Statistical evidence leads us to the conclusion that the relation between drainage basin geomorphology and trout standing stock is the result of a functional link between measurable features of a drainage basin and stream habitat. This linkage may enable the use of simple measures of drainage basin geomorphology to predict potential habitat quality for trout.

LITERATURE CITED

Binns, N.A., and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108:215-228.

Branson, F.A., G.F. Gifford, K.G. Rendard, and R. F. Hadley. 1981. Rangeland hydrology. Society for Range Management, Range Science Series 1, Denver, CO.

Burton, R.A., and T.A. Wesche. 1974. Relationship of duration of flows and selected watershed parameters to the standing stock estimates of trout populations. University of Wyoming, Water Resources Series 52, Laramie.

Conder, A.L. 1982. Instream flow investigations on selected streams: Wyoming. Completion Report (Contract YA-512-CT9-226) to the Bureau of Land Management, Denver, CO.

Eiser, A.A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Transactions of the American Fisheries Society 97:389-397.

Parsons, M.G., J.R. Maxwell, and D. Heller. 1981. A predictive fish habitat index model using geomorphic parameters. Pages 85-91 *in* N.B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society. Western Division, Bethesda, MD.

Platts, W.S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho river drainage. Fisheries (Bethesda) 4(2):5-9.

Swanston, D.N., W.R. Meehan, and J.A. McNutt. 1977. A quantitative geomorphic approach to predicting productivity of pin and chum salmon streams in southeast Alaska. U.S. Forest Service Research Paper PNW-227.

Viessman, W., Jr., J.W. Knapp, G.L. Lewis, and T.E. Harbaugh. 1977. Introduction to hydrology. Harper and Row, New York.

Ziemer, G.L. 1971. Quantitative geomorphology of drainage basins related to fish production. Alaska Department of Fish and Game, Information Leaflet 162, Juneau.

A Perspective on Artificial Fishery Systems for the Great Lakes[1]

Randy Eshenroder[2]

Abstract. The loss of key fish species in the Great Lakes during the 1940s and 1950s necessitated massive planting programs. Managers are formally committed to establishment of self-sustaining fish stocks in the Great Lakes. However, issues associated with maintaining artificially-supported fishery systems (artificial systems) have tended to dominate decision making. Also, because of success with planted trout and salmon, the incentive to invest in more natural, self-sustaining systems is diminished. Fishery managers are under more pressure to provide stable fisheries with artificial systems than they would be with natural systems. Artificial systems are vulnerable to instability because it may be difficult to maintain fitness of the planted trout and salmon without importations. If these artificial systems destabilize, managers will likely be urged to take actions that tend to promote systems that are even more artificial. Such controversial actions could lead to disintegration of the consensus approach to interagency management on the Great Lakes. Proposals that inhibit the chances for self-sustainability of the native lake trout and that seek importations are being voiced. The risks associated with perpetuation of the artificial systems need to be considered in decision making and communicated to constituencies.

INTRODUCTION

Lake trout (Salvelinus namaycush), once abundant in all the Great Lakes except Lake Erie, were reduced to extinction in Lakes Ontario and Michigan, near extinction in Lake Huron, and scarcity in Lake Superior, during the 1940s and early 1950s. Predation by sea lamprey (Petromyzon marinus) has been strongly implicated in the declines, although overfishing is thought by some to have been partly responsible (Smith 1968). The sea lamprey, eel-like in appearance and native to the Atlantic Ocean, feeds by attaching itself to other fish and sucking out the body fluids, often killing the victim. It entered Lake Ontario at least as early as 1830, (Christie 1974) but did not spread to the upper lakes (Huron, Michigan, and Superior) until the 1930s. Several other fish species declined dramatically at the same time as did the lake trout, and probably for the same reasons; among them was the burbot (Lota lota). The losses of lake trout and burbot, both key predators, resulted in an ecological void (Smith 1972) and, in the case of the lake trout, the collapse of extremely valuable fisheries. The loss of the lake trout fisheries was largely responsible for the creation of the bi-national (U.S. and Canada) Great Lakes Fishery Commission, the primary responsibility of which (at least in the beginning) was the coordination of efforts to control sea lamprey and rehabilitate lake trout.

Sea lamprey control was initiated in the late 1950s and was successful enough by the mid 1960s that heavy stocking of lake trout for rehabilitation purposes was begun (Pearce et al. 1980; Smith and Tibbles 1980). Large scale stocking of several other species of trout, and also salmon, to provide more-or-less immediate fishing opportunities, began in

---

[1]Paper presented at Wild Trout IV, Yellowstone National Park, September 18-19, 1989.

[2]Randy L. Eshenroder is Senior Scientist, Great Lakes Fishery Commission, Ann Arbor, Mich.

the mid 1960s to early 1970s depending on lake. By 1984 over 430 million salmon and trout had been stocked (Margaret Dochoda, Great Lakes Fishery Commission, personal communication). Four species besides lake trout are extensively planted: rainbow trout (*Oncorhynchus mykiss*), chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and brown trout (*Salmo trutta*).

All of the agencies with management responsibilities on the Great Lakes are formally committed to securing "...fish communities, based on foundations of stable self-sustaining stocks..." as a long-term goal (Great Lakes Fishery Commission 1980). Of the five species of salmonids extensively planted in the Great Lakes, only the lake trout is native and has the potential to reach self-sustainability in all the lakes. Therefore, most of the issues relevant to progress in reaching the self-sustainability goal focus on lake trout. This fish is in considerable demand by angler and commercial fisheries, and a major question relating to self-sustainability involves deferment of present fishing opportunities to allow for expansion of lake trout spawning stocks (Clark and Bin Huang 1985). Exploitation rates on lake trout are affected by planting rates, which are impacted by hatchery priorities. Selection of planting sites and catch regulation, including control of bycatch, also influence exploitation. Competition for forage between lake trout and other trout and salmon may occur (Eck and Wells 1987) so total planting of all species is an issue relevant to the self-sustainability goal. Therefore, the traditional management activities, fish planting and fishery regulation, markedly influence the prospects for a more self-sustaining fish community in the Great Lakes.

Despite the mandate for developing self-sustaining stocks, fishery management in the Great Lakes is often most involved with maintaining artificially-supported fishery systems (hereafter called artificial systems). The annual large plantings of various trout and salmon are made mainly without regard to development of self-sustaining stocks. The plantings have been so successful in generating fishing opportunities that many fishery managers now consider the maintenance of fish stocks through artificial propagation as a long-term solution to degraded fish communities. Unfortunately, certain risks are associated with such a management philosophy. A clear understanding of these risks would help establish what it being traded off when management actions discourage self-sustainability. The purpose of this paper is to identify these risks.

THE NEED FOR STABILITY

In the Great Lakes angling has to a large extent replaced the commercial fisheries prevalent before the large-scale planting programs began in the late 1960s (Eshenroder 1987). Fishery managers are under tremendous pressure to maintain economic benefits and meet expectations. Based on estimates of angling effort in 1980 (Talhelm 1988a) and per trip expenditures in 1985 (Talhelm 1988b), annual angler expenditures on the artificially-propagated trout and salmon fisheries in the Great Lakes may be as high as $1 billion. Inevitably, decision makers must consider regional aspects in the distribution of such large amounts. Constituents would be intolerant of any major shifts in this distribution, and such shifts would best be avoided by maintenance of stable stocks. Paradoxically, managers may be under more pressure to provide stability in artificial systems than they would be with natural systems.

Constituent intolerance for depressions in stocks of artificially propagated trout and salmon in the Great Lakes appears to have several causes. Anglers correctly perceive that the fisheries are products of technology. For them it is not illogical to assume that all stock fluctuations result from adjustments in technology. In general, anglers probably believe that managers have more control over fishery dynamics than they actually do, or would have with natural systems. This belief is abetted by some managers who foster an exaggerated appearance of being in control. This appearance may be harmless when stock sizes are stable or increasing, but not when they are depressed, as they inevitably are from time to time. Gale (1987), illustrating with contemporary fishery issues for Lake Michigan, warned managers that unrealistic constituent expectations can lead to revolts.

The intolerance of anglers may be exceeded by that of other constituent groups. Experienced anglers undoubtably have seen prospects in other fisheries vary and probably have alternative opportunities when a particular fishery declines. However, the service industry for the fishery is less flexible. Restaurant and motel owners, for instance, may have little appreciation for variations in ecological systems and may also find it difficult to compensate for lost revenue associated with depressions in fish abundance. Avoiding economic disruption of the service industry is obviously important. The scale of the artificial trout and salmon systems in the Great Lakes leads to development of powerful constituencies, who tend to measure satisfaction in relation to recent events. During periods of stock declines planting schedules are examined closely and changes in planting that might conceivably have accounted for a decline are automatically assumed to have done so. This association would be more difficult to make for natural systems.

IMPEDIMENTS TO STABILITY

Continuation of artificial propagation as a long term solution to mitigate fishery losses in the Great Lakes presupposes that fitness of the planted stocks can be maintained. Direct evidence concerning fitness of these stocks is not available, but an inferential analysis raises questions concerning the long term prospects for stability. This analysis considers that fitness will be eroded by cultural practices, that diversity and adaptability are limited, and that adaptability is important because of environmental changes in the Great Lakes.

Cultural practices can diminish fitness directly by eroding genetic diversity or indirectly by inhibiting local adaption. Coho and chinook salmon have been propagated throughout the Great Lakes from only a few egg collection facilities. Eggs collected from Lake Michigan by the State of Michigan supplied the other lakes for many years. Dependence on a few egg supplies increases the probability that unintended selection will occur (Hynes 1981) with consequences for fishery programs beyond those supported by the donor stock. For example, genetic bottlenecks may occur in years such as in 1988 when coho salmon runs were so weak in Lake Michigan that eggs were taken from relatively few fish. Natural mishaps and inappropriate cultural practices such as nonrandom matings will tend to erode gene pools. Leary et al. (1989) showed that genetic variability was lost in rainbow trout progeny from early and late spawners because these spawners were under represented in past egg collections. Local adaption, effected by reproduction of anadromous forms in tributary streams, may be inhibited by mixing of hatchery and wild fish as occurs in Great Lakes tributaries (Carl 1982; Stauffer 1987; Seelbach and Whelan 1988), a problem discussed by Chilcote et al. (1986) for west coast rainbow trout.

Mass rearing from feral broodstocks, a common practice in culture of anadromous species, reduces fitness by making the role of pathogens more important. Great Lakes fishery experts are becoming increasingly concerned about the vulnerability of propagated trout and salmon to pathogens. During 1988-1989 three hatcheries on the upper lakes were completely disinfected and their broodstocks destroyed as a result of lake trout mortalities associated with a newly-isolated virus (McAllister and Herman 1989). Managers hope to keep destructive west coast diseases, particularly infectious hematopoietic necrosis and viral hemorrhagic septicemia from being introduced in the Great Lakes. The growing aquaculture industry poses risks for the artificial systems in the Great Lakes, because private trout growers in the midwest obtain eggs from west coast suppliers and fish from these eggs have access to the Great Lakes. Whirling disease probably entered the Great Lakes through this process (Yoder 1972). Mortalities of chinook salmon in 1988 and 1989 in southern Lake Michigan were associated with clinical signs of bacterial kidney disease (BKD). Managers want to determine if this mortality accounts for the weak runs of chinook salmon reported recently for Lake Michigan. These observations represent only a smattering of the disease issues in the Great Lakes. Salient points are that well known diseases like BKD are still a major problem, and that new diseases such as caused by the lake trout virus can be anticipated.

It may be difficult to maintain stability in species that naturally exist as multiple breeding populations, but in the Great Lakes are propagated from a few donor stocks. Keller et al. (1989) identified 3 sources for the coho salmon and 2 sources for the chinook salmon introductions in the Great Lakes. Fish from the different sources were allowed to hybridize so that each species came to be propagated from a single genotype. Likewise, lake trout are planted from a few captive broodstocks and do not provide the genetic diversity of the former wild stocks (Ihssen 1988). It is not clear how adaptable the planted trout and salmon are, but the greater diversity as is characteristic of natural populations would seemingly favor resilience to environmental change and consequently foster stability.

It cannot be demonstrated that the planted trout and salmon lack adaptability, but the necessity for the characteristic is evident in view of the continuing changes in the Great Lakes ecosystem. In Lake Michigan, which is particularly well studied, major changes are occurring in the forage base. Of particular concern are changes among forage species important to trout and salmon. Adult alewives are the most preferred food of trout and salmon (Jude et al. 1987). Two other forage species the bloater (Coregonus hoyi) and yellow perch (Perca flavescens) became much more abundant probably in response to the alewife decline (Jude and Tesar 1985; Scavia et al. 1986; Eck and Wells 1987). To replace adult alewives in their diet with these species, trout and salmon will need to forage either in colder, deeper water (for bloater) or warmer, shallower water (for yellow perch). Food habitats of juvenile trout and salmon are less well known, but the trophic changes in Lake Michigan are so extensive that they would affect the energetics of planted fish throughout their life in the lakes.

DISCUSSION

The major premise in this paper, that it will be difficult to maintain fitness of the artificially propagated trout and salmon in the Great Lakes and therefore to provide stable fisheries, is very speculative. Larkin (1981) argued the opposite position that biologists have exaggerated the significance of genetic differences between populations within a species and that species like rainbow trout remain very adaptable despite extensive culture. However, the impetus for this paper is not a belief in impending disaster, but a desire to see fishery policies examined thoroughly for potential long-term consequences. Prudent managers should consider uncertainties in policy making and communicate well the risks involved. The rationale for such values as the desire for natural systems (Scarnecchia 1988) should be well understood by clients.

It may be profitable to speculate on what might occur as responses to fishery destabilization in the Great Lakes. Development of natural propagation offers little immediate relief to a depressed artificial system. When chinook salmon declined in Lake Michigan in 1987-1988, catches of lake trout increased dramatically and liberalization of lake trout creel limits and season restrictions were sought. These actions tend to promote instability by making the prospects for lake trout rehabilitation less likely. It is noteworthy that depression in a species stocked for put-grow-take purposes did not arouse demands for increased emphasis on developing natural stocks, but produced the opposite effect. Thus, the connection between the problem (instability) and the long term solution (self-sustainability) is not being made.

If the large, artificial systems in the Great Lakes destabilize, it may be very difficult for the managers to resist remedies that lead to systems even more artificial. Actions such as abandoning lake trout rehabilitation for lake trout put-grow-take, introducing new fish species and new strains of the existing species, or stocking seriously diseased fish may be considered. Managerial responses to destabilization may sorely test existing institutional arrangements. Under tremendous pressure to quickly rejuvenate the artificial systems, some managers may feel compelled to abandon the existing commitment to a consensus approach and undertake unilateral actions that have potential to destabilize aquatic systems even more. Hopefully, the chances for institutional disintegration are remote. However the ingredients, wide swings in stock abundance and calls for importations[3] have already materialized. Thus, a more explicit recognition of the risks associated with artificial systems needs to be communicated so that decision-making reflects established long-term goals.

Acknowledgements

I thank L. Wells and G. Fleischer for reviewing the manuscript.

LITERATURE CITED

Carl, L. M. 1982. Natural reproduction of coho salmon and chinook salmon in some Michigan streams. North American Journal of Fisheries Management 4: 375-380.

Chilcote, M. W., S. A. Leider, and J. J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Transactions of the American Fisheries Society 115:726-735.

Christie, W. J. 1974. Changes in the fish species composition of the Great Lakes. Journal of the Fisheries Research Board of Canada 31:827-854.

Clark, D. R., Jr., and Bin Huang. 1985. Conflict between sportfishing, commercial fishing, and rehabilitation of lake trout in Lake Michigan. North American Journal of Fisheries Management 5:261-276.

Eck, G. W., and L. Wells. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of the alewife (Alosa pseudoharengus). Canadian Journal of Fisheries and Aquatic Sciences 44 (Suppl.2): 53-60.

Eshenroder, R.L. 1987. Socioeconomic aspects of lake trout rehabilitation in the Great Lakes. Transactions of the American Fisheries Society 116:309-313.

Gale, R. P. 1987. Resources miracles and rising expectations: a challenge to fishery managers. Fisheries 12(5): 8-13.

Great Lakes Fishery Commission. 1980. A joint strategic plan for Great Lakes fisheries. 23 p. Ann Arbor, MI.

Great Lakes Fishery Commission. 1985. Great Lakes Fishery Commission Annual Report for 1983. 164 p. Ann Arbor, MI.

Hynes, J. D., E. H. Brown Jr., J. H. Helle, N. Ryman, and D. A. Webster. 1981. Guidelines for the culture of fish stocks for resource management. Canadian Journal of Fisheries and Aquatic Sciences 38: 1867-1876.

---

[3]Dick Swan. Addressing Great Lakes woes long overdue (Part 1). Great Lakes Fisherman. May 1989. p. 67-73.

Ihssen, P. E., J. M. Casselman, G. W. Martin, and R. B. Phillips. 1988. Biochemical genetic differentiation of lake trout (Salvelinus namaycush) stocks of the Great Lakes region. Canadian Journal of Fisheries and Aquatic Sciences 45: 1018-1029.

Jude, D. J., and F. J. Tesar. 1985. Recent changes in the inshore forage fish of Lake Michigan. Canadian Journal of Fisheries and Aquatic Sciences 42: 1154-1157.

Jude, D. J., F. J. Tesar, S.F. Deboe, and T. J. Miller. 1987. Diet and selection of major prey species by Lake Michigan salmonines, 1973-1982. Transactions of the American Fisheries Society 116: 677-691.

Keller, M., K. D. Smith, and R. W. Rybicki. 1989. Summary of salmon and trout management in Lake Michigan. Michigan Department of Natural Resources Fisheries Division Technical Report 89-1. 27 p. Lansing, MI.

Larkin, P. A. 1981. A perspective on population genetics and salmon management. Canadian Journal of Fisheries and Aquatic Sciences 38:1469-1475.

Leary, R. F., F. W. Allendorf, and K. L. Kundsen. 1989. Genetic differences among rainbow trout spawned on different days within a single season. The Progressive Fish-Culturist 51:16-19.

McAllister, P. E., and R. L. Herman. 1989. Epizootic mortality in hatchery-reared lake trout Salvelinus namaycush caused by a putative virus possibly of the herpesvirus group. Diseases of aquatic organisms 6:113-119.

Pearce, W. A., R. A. Braem, S. M. Dustin, and J. J. Tibbles. 1980. Sea lamprey (Petromyzon marinus) in the lower Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 37: 1802-1810.

Scarnecchia, D. L. 1988. Salmon management and the search for values. Canadian Journal of Fisheries and Aquatic Sciences 45: 2042-2050.

Scavia, D., G. L. Fahnenstiel, M. S. Evans, D. J. Jude, and J. T. Lehman. 1986. Influence of salmonine predation and weather on long-term water quality in Lake Michigan. Canadian Journal of Fisheries and Aquatic Sciences 43: 435-443.

Seelbach, P. W., and G. E. Whelan. 1988. Identification and contribution of wild and hatchery steelhead stocks in Lake Michigan tributaries. Transactions of the American Fisheries Society 117: 444-451.

Smith, B. R., and J. J. Tibbles. 1980. Sea lamprey (Petromyzon marinus) in Lakes Huron, Michigan, and Superior: history of invasion and control, 1936-78. Canadian Journal of Fisheries and Aquatic Sciences 37:1780-1801.

Smith, S. H. 1968. Species succession and fishery exploitation in the Great Lakes. Journal of the Fisheries Research Board of Canada 25(4): 667-693.

Smith, S. H. 1972. Factors of ecological succession in oligotrophic fish communities of the Laurentian Great Lakes. Journal of the Fisheries Research Board of Canada 29: 717-730.

Stauffer, T. M. 1977. Numbers of juvenile salmonids produced in five Lake Superior tributaries and the effect of juvenile coho salmon on their numbers and growth 1967-1974. Michigan Department of Natural Resources Fisheries Research Report No. 1846. 29 p. Ann Arbor, MI.

Talhelm, D. R. 1988a. The international Great Lakes sport fishery of 1980. Great Lakes Fishery Commission Special Publication 88-4. 70 p. Ann Arbor, MI.

Talhelm, D. R. 1988b. Economics of Great Lakes fisheries: a 1985 assessment. Great Lakes Fishery Commission Technical Report No. 54. 54 p. Ann Arbor, MI.

Yoder, W. G. 1972. The spread of Myxosoma cerebralis in native trout populations in Michigan. Progressive Fish-Culturist 34: 103-106.

Dissolved Gas Supersaturation and the Fishery in the Bighorn River, Montana[1]

George A. Liknes and Robert G. White[2]

Abstract.--Excessive dissolved gas pressures resulting from natural factors or man-caused activities, have long been known to adversely affect aquatic life. River systems chronically affected by gas supersaturation include the Snake and Columbia drainages in the Pacific Northwest and the Bighorn River in Montana. On the Bighorn River water passing through the automated sluicegates of Afterbay Dam entrain air which is forced into solution, producing high gas tensions and severe gas bubble trauma (GBT) in fish. Operational and physical modifications to Afterbay Dam, which would reduce gas entrainment, are discussed.

INTRODUCTION

The deleterious effects of excessive dissolved gases on aquatic organisms has long been recognized. Symptoms of the condition were described as early as the nineteenth century (Weitkamp and Katz 1980). Causes of gas supersaturation include biological activity, waterfalls and rapids, hydroelectric dams, thermal discharges from power generating or industrial plants, and pumping of water or groundwater.

Dissolved gas problems resulting from hydroelectric operations became apparent in the Columbia River system more than two decades ago. Migrating adult and juvenile salmonids exposed to supersaturated water often developed emphysema in soft tissues, exophthalmia (pop eye), and\or emboli in the cardiovascular system. These lesions, collectively referred to as gas bubble disease or gas bubble trauma (GBT), reduced the physiological condition of the fish and in severe cases resulted in mortality.

These symptoms have been observed in resident brown and rainbow trout of the Bighorn River in south-central Montana (Swedberg 1973, Curry and Curry 1981, and White et al. 1986, 1987, and 1988). The first documentation of GBT in the Bighorn River occurred in 1973 (Swedberg 1973), and a fish kill in 1979 was attributed to the problem (Porter and Viel 1980). This problem is of special concern since the Bighorn River, designated as a blue ribbon trout stream by the Montana Department of Fish, Wildlife, and Parks (MDFWP), is a highly productive water with combined brown and rainbow trout population estimates approaching 10,000 fish per mile (Fredenberg 1987 and 1988; Fig. 1).

As we would expect from a blue ribbon trout stream, the Bighorn River attracts substantial angling use, estimated as high as 21,724 man-days in 1986 on the upper 12 river miles (MDFWP 1987). Duffield et al. (1987) estimated the 1985 net economic value of the fishery resource at $4,210,000.

We monitored dissolved gas levels and examined the influence of gas supersaturation on aquatic organisms in the Bighorn River downstream from Afterbay Dam. The Bureau of Reclamation operates Afterbay Dam as a reregulating facility for Yellowtail Dam. This paper describes the gas supersaturation problem and considers potential solutions.

---

[1]Paper presented at the Wild Trout IV Symposium, Yellowstone National Park, Wyoming, September 18-19, 1989.

[2]George A. Liknes, fisheries biologist, and Robert G. White, Leader, U.S. Fish and Wildlife Service, Cooperative Fishery Research Unit, Montana State University, Bozeman, Mont.

METHODS

Total dissolved gas pressures were measured manually using a Bouck gasometer (Bouck 1982) and a pocket altimeter-barometer. We determined partial pressures of individual dissolved gases by measuring water temperature and determining the dissolved oxygen level using the azide modification of the Winkler method (APHA 1976).

In cooperation with the Bureau of Reclamation, we also installed and maintained continuous recording water quality monitoring equipment at two sites downstream of Afterbay Dam. Measurements taken by the instruments every 30 min, 24 h per day were relayed through a Sutron Satellite system to a Bureau of Reclamation computer in Billings, Montana. The equipment included Common Sensing tensionometers, which provided the same data we gathered manually. The Bureau of Reclamation provided Afterbay Dam operation records for use in relating operating regimes to changes in dissolved gas pressures and the incidence of GBT in salmonids.

Dissolved gas levels were calculated using formulas presented by Colt (1984). Although much of the previous work reported total gas levels as percent saturation, we report results in terms of delta P (mm Hg), which is the difference between total dissolved gas pressure and absolute barometric pressure. Delta P, the excessive gas pressure which results in emphysema and emboli growth in fish, is a more meaningful unit of measure than percent saturation. Compensating

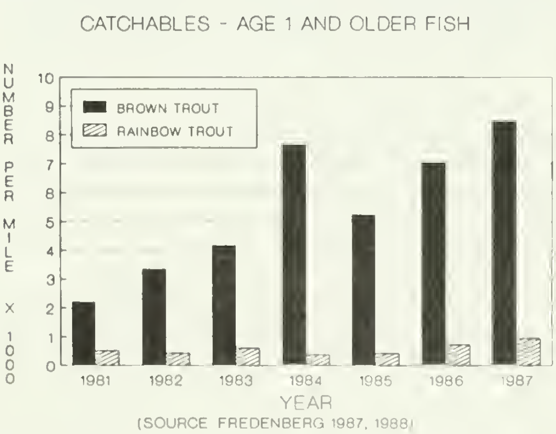


Figure 1. Fall brown and rainbow trout population point estimates on the upper Bighorn River, Montana from 1981-1987.

pressures, which counteract positive delta P's and prevent GBT from developing, include barometric, hydrostatic, and tissue or blood pressure. We present partial pressures of individual gases in mm Hg.

We monitored the incidence of GBT among larger salmonids using a boom-mounted electrofishing system. Affects of gas pressures on trout embryo and fry survival were examined through field bioassays.

RESULTS AND DISCUSSION

Studies have shown adult brown trout to be more visibly affected than rainbow trout and the problem is usually most severe during May or June (Curry and Curry 1981; White et al. 1986, 1987, 1988). Life stages show variation in tolerance to dissolved gas supersaturation. A greater percentage of the longer, older catchable-sized fish in electrofishing samples displayed external symptoms of GBT (White et al. 1988). Also, both brown and rainbow trout fry in the Bighorn River developed severe buoyancy problems at delta P's larger than 83 mm Hg while adult fish display only minimal symptoms at this gas level. Differences in habitat utilization by individual fish also influence the effects of hyperbaric pressure. Change in hydrostatic pressure associated with each 1 m of water depth reduces gas saturation by 10% or about 73.5 mm Hg. In contrast to other life stages, eggs appear able to withstand high gas pressures (White et al. 1988).

In an attempt to solve the dissolved gas problem, the Bureau of Reclamation installed deflector plates (flip lips) on the face of Afterbay Dam in fall 1982. Although delta P's were reduced, turbulence resulting from the plates caused rocks to be pulled into the base of the dam and initiated erosion of footings. Consequently, the deflectors were removed in July 1983.

Additional methods considered to reduce gas entrainment at Afterbay Dam include: 1) raising the sluiceway floor, 2) constructing a cascade downstream from the sluiceway, 3) building a powerhouse or bypass structure, and 4) changing the operational regime of the sluicegates. Raising the sluiceway basin floor would probably reduce saturation levels 6-8% and be the most economical method involving construction[3]. The cascade option was predicted to lower gas supersaturation 10-13%[3]. The only option capable of completely eliminating gas entrainment is construction of a powerhouse or bypass penstock which would divert water away from the sluice and spillways. Operational modes which avoid sluicegate mid-range openings and maximize discharge from the spillway could decrease dissolved gas tensions to similar levels as raising the sluiceway basin floor or installing a cascade during at least part of the year. Although changing the operational mode of Afterbay Dam would not require construction, it may interfere with peaking power production at Yellowtail Dam and increase river level flucuations. This option would eventually require installation of equipment to automate the spillway radial gates.

Although reduced dissolved gas levels will decrease the frequency of GBT symptoms, the exact response of the trout population is difficult to predict. Other factors such as predation, recent fishing regulation changes, the lack of a forage base, and density dependent or hooking mortality may limit or mask the response of any one species. However, the reduction in gas pressures will benefit the angler and the fishery in addition to providing additional challenges to the professionals responsible for managing the salmonid populations.

LITERATURE CITED

APHA 1976. Standard methods for the examination of water and wastewater, 14th edition. American Public Health Association, Washington, D.C.

Bouck, G.R. 1982. Gasometer: an inexpensive device for continuous monitoring of dissolved gases and supersaturation. Transactions of the American Fisheries Society 111:505-516.

Colt, J. 1984. Computation of dissolved gas concentrations in water as functions of temperature, salinity, and pressure. Special Publication 14. American Fisheries Society, Bethesda, Maryland.

Curry, R.L. and K.B. Curry. 1981. Bighorn River nitrogen supersaturation study, final report, February-August 1981. USDI, Fish and Wildlife Service, Hardin, Mont.

Duffield, J., J. Loomis, and R. Brooks. 1987. The net economic value of fishing in Montana. Montana Department of Fish, Wildlife, and Parks, Helena, Mont.

Fredenberg, W. 1987. South central Montana fisheries investigations, Bighorn Lake and Bighorn River post-impoundment study. Job Progress Report, Montana Department of Fish, Wildlife, and Parks, Project F-20-R-31, Job IV-a, Helena, Mont.

Fredenberg, W. 1988. Statewide fisheries investigations, survey and inventory of coldwater streams, upper Bighorn River investigations. Job Progress Report, Montana Department of Fish, Wildlife, and Parks, Project F-46-R-1, Job I-h, Helena, Mont.

MDFWP 1987. Upper Bighorn River Fisheries Management Plan. Montana Department of Fish, Wildlife, and Parks, Helena, Mont.

Porter, J.F. and T.J. Viel. 1980. Progress Report: Bighorn River nitrogen supersaturation study, July-September 1980. USDI, Fish and Wildlife Service, Hardin, Mont.

Swedberg, S. 1973. South-central Montana fisheries study, Bighorn Lake, Bighorn River, and Bighorn River post-impoundment study. Job Progress Report, Montana Department of Fish, Wildlife, and Parks, Project F-20-R-18, Job IV-a, Helena, Mont.

Weitkamp. D.E. and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:659-702.

White, R.G., G. Phillips, G. Liknes, and S. Sanford. 1986. The effects of supersaturation of dissolved gases on the fishery of the Bighorn River downstream of the Yellowtail afterbay dam. 1985 Annual Report. Montana Cooperative Fishery Research Unit and Montana Department of Fish, Wildlife, and Parks, Bozeman, Mont.

[3]Houston, K.L. 1984. Additonal model studies of Yellowtail Afterbay Dam sluiceway and spillway - recommended alternatives for reducing supersaturation. Unpublished report. USDI, Bureau of Reclamation, Research and Laboratory Services, Denver, Colo.

White, R.G., G. Phillips, G. Liknes, C. Sprague, J. Brammer, W. Connor, L. Fidler, T. Williams, and W.P. Dwyer. 1987. The effects of supersaturation of dissolved gases on the fishery of the Bighorn River downstream of the Yellowtail afterbay dam. 1986 Annual Report. Montana Cooperative Fishery Research Unit and Montana Department of Fish, Wildlife, and Parks, Bozeman, Mont.

White, R.G., G. Phillips, G. Liknes, C. Sprague, J. Brammer, W. Connor, L. Fidler, T. Williams, and W.P. Dwyer. 1988. The effects of supersaturation of dissolved gases on the fishery of the Bighorn River downstream of the Yellowtail afterbay dam. 1987 Annual Report. Montana Cooperative Fishery Research Unit and Montana Department of Fish, Wildlife, and Parks, Bozeman, Mont.

Dollars and Sense in Montana[1]

Patrick J. Graham[2]

There are many ways to use and abuse economic values as they relate to managing or protecting a fishery. To be successful we must understand the need for using economics and the potential roles economic and other values can have when making resource decisions.

Standing at the headwaters of the fabled Yellowstone River, surrounded by all this grandeur, it is difficult to imagine how anyone could question the value of fisheries or fishing? Nevertheless, the debate continues in board rooms and bar rooms as the people of Montana, in this state's centennial year, struggle with their future and the future of their natural resources.

Like some of you, I would rather take the high ground and just go fishin'. But before we do, let's examine this issue a little more closely. My own interest in economics and values evolved because I saw things I cared deeply about threatened by decisions based on economic analyses that, to me, appeared unsound and misleading. I felt if we were to be effective resource advocates, we had to understand economics. I also wanted to understand more about people's values, how those values change, and how they are shaped.

I also had another question nagging at me. What if all those jokes about economists were true?

By chance you may have read an article recently about the problems a research laboratory in California was encountering. The lab was under siege by a group of animal rights activists opposed to the use of animals in the lab's experiments. Specifically, the animal rights folks wanted the scientists to stop using rats in their experiments. They pelted the lab with rotten tomatoes, tossed bricks through windows and chanted outside. The scientists, fearing for their lives, knew they had to do something. So they made an announcement. They would stop using rats in their experiments. Instead, they would use economists. The economists were just as prolific, but you didn't get so attached to them, and, besides -- there are some things that a rat just won't do.

DOLLARS AND SENSE

You probably expect me to expound upon Montana and to tell you that the Big Sky Country offers some of the finest quality fishing opportunities in the country, if not the world. You probably expect me to tell you about the state's deep water fishing for trophy lake trout, or about peering into a wilderness stream for native cutthroat, stocking largemouth bass in pothole lakes, trolling for a tasty walleye, or losing your sense of time and perspective casting to a pod of trout during a mid-July trico hatch. But I'm not.

I will tell you that as diverse as these fisheries are, so, too, are the fishermen who pursue them. Some fish for relaxation, some for excitement, still others to test their skills, to get away from it all, to be out in nature, for meat or trophies. Some fishermen travel hundreds of miles to fish for a certain species during the select season on a favorite water. Others cast into a water scarcely knowing what they might pull out, and possibly not even caring.

[1]Paper presented at the Wild Trout Symposium, Mammoth, Wyoming, September 1989.

[2]Patrick J. Graham, Administrator, Fisheries Division, Department of Fish, Wildlife and Parks, Helena, Mt.

How do we place a value on these experiences and what does it mean? These are questions our department has been wrestling with for a number of years. They are also questions many other individuals and groups have had to address in recent years. To help answer them, the Montana Department of Fish, Wildlife and Parks has conducted several economic surveys including one statewide survey on the economic value of fishing and hunting. I won't bore you with a lot of numbers that you would probably forget by the time I sit down, but I will give you one -- $16.47. That's how much I spent on beer and tackle at Bob's Bait and Beer here Saturday.
(I thought 47 cents for tackle was extravagant!)

I won't try to convince you that money spent on fishing is more important than revenue raised through logging or agriculture. Such generalizations are of limited use and, for reasons I'll discuss later, such arguments are often difficult to win.

However, that is not to say that what we spend is not important. From the backyard bird feeder to the outfitted fishing or hunting trip, national expenditures related to wildlife have increased from $2.8 billion in 1955 to nearly $56 billion in 1985. The pursuit and enjoyment of fish and wildlife touches nearly every person in the nation -- whether that pursuit involves a walk in the park, a nature program seen on TV, or a wilderness encounter. Yet, the issue, it seems to me, is not so much what we spend but the relationship of fisheries to the economic decisions made by society. This paper also offers me an opportunity to discuss some uses and misuses of economic values.

I wonder whether we would be talking about this subject at all if we were more self-assured about the importance of fishing to the economy. Many people still look at fishing and fish as possessing only amenity values and, like apple pie and motherhood, who can be against them? Clearly the cities and towns of Montana recognize the importance of fishing because you find it mentioned in every travel promotional brochure sent to prospective out-of-state visitors. Yet the basic issue remains: How are these values taken into account when decisions are made that will affect the future of fishing opportunities?

Clearly things are changing. I grew up in Bozeman, Montana, and I remember driving through Ennis, a community on the renowned blue-ribbon Madison River, 20 years ago. Today it stands in stark contrast to the town I remember. The economic impact of tourism and fishing on that community is obvious. But in larger communities such impacts are more difficult to observe and may even be overlooked by community leaders.

CAN WE AFFORD THEM?

Most people would agree that fish and fishing have value, but a question often raised is -- Can we afford them? That reminds me of a caption to a cartoon I saw long ago of a southern Senator defending his opposition to busing as a way to integrate schools. He said, "Some of my best friends are buses."

Robert Alison, a Canadian naturalist, noted that throughout history, "societies could rarely afford the luxury of insight into future dilemmas . . . " While ". . . conservation enthusiasm emerges early in the evolution of a particular society, its incorporation into the behavior of citizens is restricted to the advanced stages of the society, since only then can it afford the luxury of concern."

Clearly, most people today in North America can afford to think about the consequences their actions will have on future generations. Few of us are concerned about where our next meal will come from or where we will sleep tonight (although some of us probably should be).

In fact our society shows many signs of excess. Everybody must own at least one diet book and comedian Richard Pryor's commentary rings true when he says, "cocaine is God's way of telling you you make too much money."

We North Americans have taken many actions to conserve wildlife at home and abroad by establishing refuges, through international treaties, and more. Still the questions are repeated, "how much is it worth and can we afford it?"

The difficulty in answering these questions is compounded by the role into which fisheries advocates have been cast. Joseph Wood Krutch captured it by saying, "the campaign to preserve Montana's wild land and wildlife has at times been characterized as a battle between man and nature. In some respects, that has been an unfortunate characterization. Nature never really fought man and some of his intemperate schemes. Nature usually just endures our heavy hand and at times extracts a form of retribution from mistakes we have made." Still, we are often dismissed as obstructionists to economic progress. I say that because now, possibly more than at any recent time, there is great confusion about where our economy stands and where it is going.

WHAT IS AN ECONOMY?

In defining the role of fisheries in the economy the first step we must take is to decide which economy we are addressing -- the economy of the nation, the west, of Montana or Bob's Bait and Beer? There is no single economy. California and other western states look for trade to the Pacific Rim countries, Florida looks to South and Central America. Montana looks to her neighboring states and Canada. Bob's Bait and Beer looked to me -- Bob must be the same guy selling screwdrivers and toilet seats to the Pentagon.

Recognizing that these different sectors of an economy exist, we must learn to communicate values in terms that people understand and in a context that has meaning in their world. Rural communities are much more likely to see the benefits of fishing expenditures, but it is people from urban and suburban areas who are pushing up the demand for fish and wildlife often beyond our ability to supply them.

When extolling the benefits of fisheries, we must recognize that benefits to one group are likely to be a cost to another. Maximizing expenditures is certainly no benefit to the angler. It is not enough to have good values, we must know how to use them.

A second important feature of today's economy is its short-term focus. Fortunes are won and lost in the stock market on quarterly profit statements. Unfortunately, the short-term economic gain from a one-time harvest of minerals, coal, oil, gas and now perhaps even trees is often more attractive than the economic benefits provided by a fishery. Increasingly, laws have been passed to minimize the damage to fish or wildlife. Nonetheless, the pressure to compromise these values always lurks. These problems are compounded by government subsidized programs to exploit natural resources. In fact, the terrible abuse of economic principles used to justify these projects has contributed to a general disdain and mistrust of economics.

A third feature of today's economy is a demand for quality and diversity of products. People appear to be willing to pay for quality and they demand many choices. Quantity is no longer a substitute for quality.

This is reflected in fishing in different ways. For example, people are willing to travel long distances to find quality experiences in Montana. Montana ranks fourth in the number of non-resident fresh water fishing licenses sold in the country. Two of the top states, Wisconsin and Michigan, are bordered by the Great Lakes and have large population centers nearby.

But people do not come here simply to catch fish. If they did we could line them up at a hatchery raceway. They come for more diverse reasons.

Other aspects of the public's changing perception of quality and diversity are an increased interest in non-game wildlife and outdoor photography. In sport fishing there appears to be a significant trend away from consumptive use of fish. Many more fishermen are releasing fish today, not because they have to by law, but because they want to as conservationists. While this is not entirely a non-consumptive use, (as some of their catch do undoubtedly die) the trend is refreshing if not essential. In spite of success in habitat conservation and improvement, we find an increasing need to encourage less consumptive use of fish and wildlife to maintain quality opportunities.

Regardless of the motive, these people come and spend money and that's what it is all about -- right? The one thing we often forget is that you need somebody else's money to stimulate your own economy. Everybody, that is, except the federal government; they just print more.

FISHERIES ROLE IN ECONOMICS

It has been said that it is better to know some of the questions than all of the answers, and one question we have to answer is --how do fish and wildlife contribute to society? Economists, among others, have been accused of knowing the price of everything and the value of nothing. To an economist your lunch today had a value measured by the price you paid for it. To the nutritionist its value is measured in calories, percent of fat and fiber, minerals and vitamins. Values for fisheries include market, recreational, scientific, aesthetic, cultural, historical, religious, genetic diversity, therapeutic and intrinsic. These different values are why many of us find it uncomfortable to talk about fishing in economic terms. Dollar values seem to isolate us from what we perceive as the real values of fisheries.

In fact, maximizing economic return of fisheries has never been the mandate for our management. The objective has instead been to conserve fisheries while providing recreational opportunities to as many people as possible.

Fisheries, like many other goods and services, are provided outside the marketplace. Society, through its many institutions, provides such services as our national defense, social security and protection against crime. The natural environment provides clean air and water and the opportunity for quality outdoor recreation.

People in small towns and rural areas, common in much of the West, tend to make less money and to have fewer job opportunities; but these areas usually offer a high quality of life. University of Montana economist Tom Powers noted that this relationship is no coincidence.

What's more, one need not use fisheries to hold them in high value. Many of us are willing to pay to have the option for use in the future and simply to know that wildlife and wild lands exist. An analogy can also be drawn to the plight of the family farm. Many people are concerned about the family farm not because they are concerned about what will be produced or even how much. They are concerned about who will produce it. It is not about preserving lives but lifestyles. Maybe even Bob's Bait and Beer.

CASE STUDIES

Increasingly we are finding uses for economic values in making our management decisions. The legislature has mandated that our department conduct economic impact analyses on major land acquisitions for wildlife habitat. This includes assessing impacts on local taxes and the economic trade-offs from converting lands from agriculture production to wildlife and recreational use. We also use economic values to portray the value of instream flows for fisheries. The recent passage of a water leasing law by the Montana legislature will now take the use of economics into another dimension. Until now we used economics to illustrate a demand and value for instream flow. We will now have to use economics to determine market values for instream flows. Until today there has been no "market" for instream flows in Montana.

We can also use economic values to assess differences in providing diverse fishing opportunities through the recognition of various types of anglers. In one study we evaluated the value of trout fishing in the Swan River and Lake in northwestern Montana. The majority of users targeted no specific trout -- 67%, compared to only 10% who targeted trophy-size bull trout (Dolly Varden). However, the price for targeting bull trout per party visit was $450.00 or 15 times higher than those targeting unspecified trout per party visit ($30.00). An analysis that looks only at the average price for fishing opportunities would not have recognized the high value of the more limited bull trout fishery.

In addition to an economic valuation study we conducted a preference survey of trout stream/anglers during the spring of 1987. We identified four major subgroups of anglers on trout streams. These user groups ranged from generalist to specialist and net economic values per trip varied considerably across user groups. The averages ranged from only $7.56 per trip for a generalist to $170.00 for a specialist. This suggests specialized anglers place a much higher value on their fishing than more generalized anglers.

Unfortunately, agencies such as the Department of Agriculture often ignore these differences in values in their analyses. To them, fishing is fishing. However, they seem to have no problem distinguishing between two different species of trees. We have provided our economic values to the U.S. Forest Service and BLM and we have encouraged these agencies to utilize them in their decision-making process. We believe we have made progress in this area, but there is still some distance to go.

Economic values also can be used to frame and evaluate policies and management decisions. An economic valuation study was conducted on Rock Creek to determine whether the department needed to further limit fishing from floating craft. The study found that to bank anglers the value of an average trip was $212. This compares with $289 for floating anglers. Floating anglers would suffer significant losses in value ($80-$100 per trip) if present conditions deteriorated to the point where either total catch or the chance of catching large trout were reduced to one-half their present levels. However, if float fishing were eliminated on Rock Creek, the increased value to bank anglers would be only $27 compared to the loss of $243 per trip for float anglers. The resulting management recommendation was to maintain float fishing, but limit it to the popular high-water season in an attempt to avoid further conflicts with bank anglers later in the summer.

ON COMMON GROUND

As you can see there are many ways to use and to abuse economics. Describing fisheries or fishing opportunities in economic terms can be difficult to understand or even accept. Some values people might associate with a fishery such as intrinsic cultural, religious, or scientific can not be measured in economic terms. That does not mean you dismiss these values, it means you must address them along with economic values.

Therefore, developing an understanding and acceptance of fishery's values will be an evolutionary rather than a revolutionary process. Yet, by using economics properly we have an opportunity to broaden the debate about fishery's values and include them in a decision-making process that has traditionally excluded fishery's resources.

Through the economic studies conducted in Montana we have tried to put fishing and hunting on common ground with market activities that can affect the quality and quantity of fishing and hunting opportunities. In using economic terms to describe fish and wildlife we must also be mindful not to encourage misperceptions that might threaten the long-held public doctrine that fish and wildlife are held in trust for all the people.

Success in this arena brings increased responsibilities. It will no longer be enough to simply find fault, we must also be part of the solution to resource issues. The prospect of maintaining or enhancing our fisheries resources is both exciting and demanding. The prospect for failure is unthinkable, and as we survey the bounty of fisheries resources, during this our centennial year, the prospect for success is clearly within our grasp.

Why, Why, Why?: The Human Dimensions of Trout Angling Motivations and Satisfactions[1]

Robert M. Jackson[2]

Abstract -- Fisheries professionals today need to accept that their work includes human as well as resource management. This paper presents a psychology of angler development and behavior with an emphasis on satisfaction and motivation. Basic principles and concepts are illustrated and supported with data based on an assessment of Wisconsin trout anglers as collected through creel surveys, post-season mailed surveys and group interviews. Findings suggest that major determinants of motivations and satisfactions include: expectations; socialization sources and models; time and experience; and an evolving sense of stewardship as expressed through non-consumptive utilization of the resource. The paper concludes that a user inventory and a resource inventory are both needed to fully capitolize on angler motivations and to maximize satisfaction.

The future of fish and wildlife resources, as well as sport fishing, depends on the attitudes and behaviors of the user as well as on the biological management of the species. While theorists (Knopf, et al 1973) have long contended that "a behavioral approach has been applied too infrequently as a basis for fishery and wildlife management", it is only recently that resource managers came to understand this principle and accept that their work is one of human, as well as resource, management.

Researchers have been slow to evidence interest in recreational development and behavior, particularly that of fishing and hunting. Studies of sports, recreation, and leisure by behavioral scientists have bypassed fishing and hunting activities, with few exceptions (Hummel, 1983). In part, this can be attributed to the fact that disciplines like psychology and sociology often manifest an urban, liberal bias. This is notable because other researchers (Roberts, 1970) have pointed to evidence that individuals can center their lives around leisure activities. As Roberts noted, "it can be argued that for many people leisure has become such a central and dominant part of their lives that it is their behavior and attitudes toward work that are determined by their leisure rather than the other way around."

Since the early 1970's, however, interest in the so-called "human dimensions" of outdoor recreation has increased steadily. Evidence includes a "human dimensions" group of researchers and managers, their publication of a quarterly newsletter, and a growing number of conferences and paper sessions focusing on the users of the resource, both consumptive and non-consumptive.

A broad range of participant orientations and behaviors accompanies any recreational activity. Actually, managers can engineer user groups by the type of recreational environment they provide (Bultena and Field, 1978; Heywood, 1987). For example, income, education, occupation and socioeconomic status are attracted to natural and undeveloped areas; preferred river recreation experiences are related to the size and composition of the social group of participation; by offering non-consumptive, rather than consumptive experience, we can recruit more women and people with higher education. It has been illustrated on Wisconsin streams (Hunt, 1988) that habitat improvement can attract trout anglers. In contrast, recreation that becomes too expensive limits usage to purists and more elite user groups. In short, facilities, regulations, and other aspects of management all affect user behavior. To be effective, the manager must correctly assess that cause-and-effect behavior.

Developing policies based on both biological and human dimensions, Bryan (1976) notes, can be particularly difficult. Research on trout anglers suggests that those who fish trout may have the broadest range of individual differences of any angling sub-group, (Jackson, 1988) creating obvious problems for the manager who seeks to please and satisfy those who fish for trout. Newly approved angling regulations in Wisconsin reflect the motivation of managers to provide a variety of fishing opportunities and satisfactions for this diverse clientele.

To illustrate the complexity of this task, this paper will review the major theoretical dimensions of trout angler motivations and satisfactions. Support and illustrations for these con-

[1]Paper presented at Wild Trout IV Symposium, Yellowstone, Wyoming.

[2]Robert M. Jackson, B.S., M.S., Ph.D., Department of Psychology, University of Wisconsin-La Crosse, La Crosse Wisconsin.

cepts will be drawn from the research of the author and his research colleagues, Larry Clagget and Ed Nelson, both of the Wisconsin Department of Natural Resources (DNR).

RESEARCH METHODS

Stream trout are a significant part of Wisconsin angling opportunities. Currently the trout resource is maintained on 9,650 miles of streams, 443 spring ponds, and 200 lakes. Five streams were chosen for this research. In the summer of 1986, stream census activities were already planned by DNR fish managers for Rowan Creek and Timber Coulee Creek, both located in the "Southern Zone" as designated by angling regulations. Angler samples for these DNR surveys are stratified very carefully to represent fishing activities on a season-long basis. When a mailed survey was sent after the season's close to a randomly drawn sample of these trouters, 85% (N=256) responded to the 21 page questionnaire.

These methods were repeated in 1987 when the researchers again sampled trout anglers, using creel census studies being conducted on three northern Wisconsin streams: the Namekagon River, Prairie River, and the North Branch of the Pem Bon Won. In addition anglers were identified whose primary interest was fishing on small northern streams with native brook trout populations. All were contacted by mail and again over 80% responded (N=495). Finally 162 members of Trout Unlimited met with the principal investigator in seven chapter units, responding first to the identical questionnaire used with the stream selected anglers, and later to a series of open-ended questions posed in a group interview (i.e, "Why do you fish trout?, etc.). The percentage of returns throughout the study was unusually high, particularly for such a lengthy questionnaire. We suggest that this is probably a measure of the unusual intensity and commitment of trout anglers to their sport.

SATISFACTIONS AND MOTIVATIONS

Management practices have historically focused on increasing yield. However, as more information was gathered concerning the desires of sport anglers, it became evident that many other factors were also important to angler motivation and satisfaction. For example, Wisconsin studies (Avery, 1981) indicate that over half of all trout trips produce no catch. Later, managers began to measure recreationists' satisfaction by counting "man days" in the field. Hendee (1973) suggested that the concept of multiple satisfaction should be a fundamental assumption for understanding, predicting, and managing outdoor recreation behavior and conflict. Given the individual difference among the anglers already cited, a multiple satisfaction approach to fish management makes it possible to increase human benefits, even where fish populations are fixed or declining, through better management of angler-resource relationships and surrounding conditions. Good management, using Hendee's position, implies providing a range of experiences for recreationists with different motives and satisfactions.

Expectations

Psychologists theorize that expectations of an angler are critical to satisfaction. Success and satisfaction depend on congruence between the expectation one takes into the field and the actual experience. Thus, the key to participant satisfaction is principally determined by, and carried in the head of the individual recreationist; change expectations and one changes the degree of satisfaction experienced. The implications of this are that an angler can catch four trout in the summer where low water and other conditions make fishing particularly difficult and feel more satisfaction than he might in catching 30 on opening day; he took different (lower) expectations into the field in the summer.

To illustrate this, at one end of a continuum among trout anglers we might place the angler who visits a Missouri trout park (Hicks, et al, 1983). Within this setting, trout are stocked daily and the individual anglers must pay a daily permit fee to participate. Fifty-seven percent of these anglers said that this was more enjoyable than other trout angling settings or opportunities within the state. Their primary stated objective (expectation) was to catch one fish; the next highest rated goal was to catch a limit. Crowding by other anglers, or the nature of the environmental setting was not important, as reported for these anglers.

In contrast, our studies of Wisconsin trout anglers indicated that satisfaction was indeed based on more than yield. When our samples of Wisconsin trout anglers were asked to rate 20 fishing satisfactions, (Table 1) these six were given the highest overall ratings: (1) being in the out of doors; (2) nature appreciation; (3) opportunity to utilize skills; (4) seeing trout feeding; (5) solitude; and (6) escape. Catching trout ranked seventh. (Eighth for Trout Unlimited members.) It is evident that opportunities to practice preferred angling methods and the trout angling setting were of great interest to these Wisconsin anglers. The rank orders for the four different angler populations were remarkable more for their similarities than differences.

Our Wisconsin studies also searched out individual differences among this population of trout anglers. Predictably we found variations of satisfactions among those with preferences for different species or different angling methods. Those who fish brown trout in Wisconsin were significantly more likely to get satisfaction from seeing trout feeding, using fishing skills, nature appreciation, releasing their catch, and using the equipment they

TABLE 1

MEAN RATINGS OF SATISFACTION FOR TROUT ANGLER POPULATIONS

Stream initial angler location and ratings of angler satisfaction

T.U.	Southern Zone	Northern Zone	Small Streams Specialists	Categories
4.75	4.79	4.76	4.74	Being in the out of doors
4.63	4.54	4.57	4.66	Nature appreciation
4.40	4.47	4.28	4.34	Beauty of the trout itself
4.39	4.34	4.27	4.55	Solitude
4.21	4.31	4.09	4.16	Utilizing fishing skills
4.01	4.25	4.06	4.00	Escape from routine
4.00	3.79	3.71	3.91	Seeing trout feeding
3.84	4.08	4.03	3.96	Catching a trout
3.81	3.49	3.08	2.88	Releasing the catch
3.46	3.38	3.26	2.99	Companionship with friends
3.35	2.37	2.44	2.34	Using special fishing equipment you made (flies, rods, etc.)
3.05	3.18	3.27	3.05	Associated outdoor activities (boating, camping, etc.)
2.76	2.99	2.79	2.92	Telling fishing stories/experiences
2.41	2.86	2.67	2.52	Watching fishing movies/TV programs
2.32	3.16	3.03	3.33	Catching fish to eat
2.30	2.98	2.81	2.70	Companionship with family
2.07	2.27	2.19	2.19	Having the best of fishing/boating equipment
1.91	1.68	1.55	1.61	Competitive activities
1.89	2.76	2.44	2.76	Showing fish I caught to family and friends
1.68	1.96	1.68	1.92	Trophy display

made. Those who fished brook trout, in contrast, were more likely to eat their fish, show it to others, and just enjoy being in the out of doors. Fly fishing anglers were more likely to prefer brown trout, and cited appreciations similar to those preferring to angle for brown trout. Fly fishermen were also more likely to enjoy "the beauty of the trout", and more likely to select their fishing setting based on its beauty and the chance for a large or trophy fish.

Michigan studies (Fenske, 1983) show that regional differences are associated with trout angler expectancies and behaviors. This makes management more complex because these anglers can choose to travel anywhere to fish. From our Wisconsin studies we can generalize that those anglers identified while fishing a southern stream much prefer to catch brown trout (61.5%). In contrast, 55% of those first contacted on a northern river preferred brook trout and this figure rose to 77.6% for the small stream specialists who were all residents of the north. (Anglers reported spending most of their fishing times in the zones where they were identified as subjects through creel census; i.e., northern zone anglers fished predominately on northern streams, etc.) Yet our surveys and our group interviews provided many cases of anglers who drove hundreds of miles to the north to fish large browns on large streams, using their preferred method, the fly rod. (Probable dates for the "hex hatch, for example, is a conspicuous entry in many a Trout Unlimited member's pocket calendar.)

Socialization

Social characteristics and motivations are clearly different among anglers, and also among different recreational groups. In surveying 12 different recreational activities, Knopf (1973) found that trout anglers were lowest in their need and desire for affiliation. Canoeists using the same streams as trout anglers are higher in their needs and motivations for affiliation. However, these individuals are often participating with organized groups which may skew the results.

For some anglers and hunters, the social experience is the dominant motivation for participation. In researching deer-gun hunters, one 17 member hunting party being interviewed by this presenter had only five guns in the camp. They were there to socialize, play poker and to drink beer, they stated. Smelting and walleye runs in the midwest can be compared to social festivals that, like deer hunting, affect the whole social life of a community.

In our studies, anglers contacted on Southern Wisconsin streams were more likely to give high ratings to companionship with friends and family as important to their trout angling satisfactions than their northern counterparts. As one small stream specialist put it, "I don't mind riding to and from the stream with another person, and I don't mind saying hello to one old man at noon, but other than that I don't want to see another angler." One consequence of this individualistic nature of trout fishing is the difficulty of effectively introducing new participants to the sport. The best teaching model may well reflect the coaching of a mentor, who personally takes the neophyte trout angler under their wing and insures the safety, success and satisfaction of the pupil.

Changes Through Time and Experience

Human motivations and satisfactions also change over time and through experience. Psychologist A. H. Maslow (1954) asserted human needs can be divided into: (1) basic physiological needs; (2) safety from external dangers; (3) love affection and social activity; (4) esteem and self-respect; and (5) self-realization and achievement. People tend to fulfill first order needs before being able to satisfy higher order needs. Development is then sequential and cumulative; earlier needs, motives and satisfactions do not disappear but only give way to those of a higher order while the lower needs are met. One researcher (Kirkpatrick, 1966) put motivations for fishing within the context of Maslow's Hierarchy. He suggested that fishing, hunting and other activities can satisfy any number of needs found under the last three categories denoted by Maslow.

Bryan (1982) suggests a similar conceptual approach based on a continuum where at one end of the activity or sport is a person with a general recreationist interest while at the other end is a person who devotes or limits interests to some special branch of the sport. Recreationists, he agrees, tend to go through a predictable sequence of experiences. Drawing on semi-structured interviews with trout anglers, he sorted anglers into four categories according to their frequency of fishing, the type of fishing setting they preferred, the fishing technique they used, and the level of their commitment to fishing. This classification scheme yielded four categories of trout anglers: occasional anglers, generalists, technique specialists, and technique/setting specialists. At each level of specialization they find group identification with other sportsmen with similar attitudes and interests.

One hundred years ago Dr. James Henshall, a physician and angler wrote that we go through predictable stages of development as fishermen. First, he suggested, the angler simply wants to catch fish (limiting out). Second the angler advances to where catching a trophy is paramount. Finally, he moves to a stage where how he catches fish (method) is more important than how many or how big. As I searched the literature for this paper, I couldn't find the exact quote, but at the age of 30 I can remember reading about Henshall's theory in a magazine column and feeling that this hypothesis exactly described my own behavior. It became the basis of an expanded theory (Jackson, et al 1979) that anglers, hunters, and other recreationists go through five predictable stages.

The first in the sequence is a "How does it work?" period. A fisherman wants to master the rod and reel and other basics; the hunter is a "shooter" who may test out his firearm on insulators, signs, or any nearby form of wildlife. This author agrees with Henshall on the next two stages. The angler moves then to catching fish, and later to angling for trophy trout.

Significantly, the fourth stage takes the individual from motivations focussing on products of the angling experience, to a primary interest in process. Methods (fly fishing, dry flies, nymphing, feather light equipment, etc.), become more important than catching fish. Characteristically these method specialists identify with other anglers with similar attitudes and interests, often adopting special vocabularies (Quill Gordon, hex hatch, rod blanks, etc.) or uniforms (our research suggests fly vests are the distinguishing symbol of the trout angler) which identify and associate these trouters with their sport. The author would hypothesize that much of the attrition from trout fishing occurs when anglers can't make this transition from product to process. Those who have developed to the method stage consistently cite challenge as a major motivation for trout angling; we hear this same word, challenge, again and again from bow, waterfowl, and turkey hunters who in Wisconsin all become unusually committed and dedicated to their sports.

Trout angler development seems to demand a fifth stage, the sportsman stage. The angler at this stage no longer has to catch fish to find satisfaction. Often he is strongly motivated to teach and to become a mentor. He finds satisfaction in introducing or coaching others in the sport. Anglers in this last stage characteristically have an intimate knowledge and experience with trout and trout habitat. Among individuals in this stage I sensed an awareness of what Aldo Leopold (1947) described as an ecological "oneness" (in this case of man, trout, and the natural environment). Now the individual may fish simply to be part of the setting. Finally, anglers in this last phase of development often report that trout fishing gives them an almost transcendental experience; it is something often reported in similar words by those who climb mountains. It is a "high" but one based solely on natural stimulation, and it does not discriminate by social class, sex, or angling method. One trouter stated, "When I'm belly high in the river, I forget everything else."

To evaluate this hypothesis for trout anglers, our Wisconsin studies asked subjects to "Rate how your angling attitudes and practices have changed since you started fishing for trout". The Likkert type scale used for this item ranged from 1 - decreased, through 3 - stayed the same and to 5 - increased. The means and their rankings (Table 2)

TABLE 2

MEAN RATINGS FOR TROUT ANGLER POPULATIONS

Change in angling attitudes
and practices over time

T.U.	Northern	Small Streams	Categories
4.47	3.87	3.65	Interest in catch and release
4.40	3.53	3.13	FISHING METHOD: fly fishing
4.31	4.01	3.65	Importance of how I catch trout
4.12	3.84	3.47	Interest in catching trout
3.76	3.54	3.20	Number of fishing days per season
3.69	3.52	3.51	Interest in trophy trout fishing
3.67	3.43	2.83	SELECTION OF TROUT WATERS: time spent on large streams
3.64	3.05	2.69	Off season activities (tying flies, constructing rods, etc.)
3.27	3.41	3.30	SELECTION OF TROUT WATERS: time spent on small streams
2.80	2.85	3.29	SELECTION OF TROUT WATERS: time spent on spring holes
2.45	2.74	2.92	FISHING METHOD: spinner (lure) fishing
2.40	2.55	2.67	SELECTION OF TROUT WATERS: time spent on trout trout lakes
2.05	2.78	2.77	Interest in catching trout to eat
2.00	2.53	2.61	FISHING METHOD: bait fishing (live or dead)
1.71	2.31	2.30	Interest in limiting out

*A mean of 2.5 would be NEUTRAL; a mean above 2.5 indicates an increase in the attitude or practice; a mean below 2.5 indicates a decrease.

indicate that catch and release, fly fishing (method), and the importance of how the angler catches trout have emerged as critical developmental directions. Fly fishing has the highest method ranking for small stream specialists who are acknowledged to be skilled live bait presenters. Interest over time in limiting out had the lowest mean value for all three groups; also decreasing were bait fishing (method) and interest in catching trout to eat.

Consumption vs. Non-Consumption

Human dimension specialists have concerned themselves with the means for changing recreational behaviors as well as the ethics and values associated with those experiences (Jackson, 1987). For example, involvement with the resource demonstratively increases responsibility and stewardship on the part of the recreational user.

Kellert (1976), in categorizing human attitudes towards animals, found three typologies to be prevalent among sportsmen: (1) consumptive, (2) dominionistic (or competitive), and (3) naturalistic. His studies indicated that those who are naturalistic tend to have more empathy towards animals than other sportsmen or anglers, as well as non-consumptive or anti-hunting groups. For these naturalistic individuals, hunting or fishing is the means rather than the end or objective of the activity. Typically, naturalistic individuals have been intensely involved with the with the natural world through their recreational activities. Other evidence (Jackson, 1981) suggests this involvement enhances a sense of stewardship and responsibility. Examples of this would be tree planting, stream improvement, and other activities that directly involve the individual with his natural environment.

Within this framework of evaluating values and behavior change, the consumptive and non-consumptive uses of the resource become particularly important. As cited earlier, Wisconsin anglers reported interest in catch and release as one of the strongest emerging facets of their trout angling behaviors. Many individuals reported intrinsic satisfactions from the act of releasing a trout back into the stream or pond.

Catch and release, as an angler behavior, is of critical interest to both anglers and managers today. Yet when the Sports Fishing Institute (1976) reported on a number of studies from eastern, midwest, and western states, they indicated reduced participation of anglers, apparently because of catch and release regulations. The general trend of the article was to discourage and move managers away from catch and release regulations. The implications were that angler satisfactions were inversely related to catch and release regulations.

The last decade has seen, of course, a dramatic turn in interest and in acceptance of catch and release fishing. Perhaps the angling community deserves more credit for this than professional managers. Peer pressure and social learning are powerful tools for shaping values and consequent behaviors. Developments in muskie angling in the upper midwest are illustrative of this and substantial credit must go to Muskies, Inc., a sportsman's group. In Wisconsin and Minnesota keeping a legal muskie is now tantamount to sin. While first emphasized by the clubs and organizations of these angling specialists, guides and resorts are now pushing this behavior. All seem to recognize that release is apparently increasing the overall harvest and the incidence of sizeable, trophy fish in state waters.

Bryan (1983) suggests that this emphasis is a product of increasing numbers of fishermen and concern over the preservation of fisheries resources. He credits the later development of this ethic in bass fishing as compared to trout angling due to earlier pressures on the more limited cold water resources. Research by Fedler and Ditton (1986), however, also traces low-consumptive values and behaviors to individuals with strong motives and satisfactions associated with interacting with nature, relaxation, and escaping the daily routine. Low-consumptive fishermen were generally more satisfied than were high consumptive anglers.

Studies (Hall, et al, 1989) in other areas indicate that local populations often seem unaware of the fragility of the resource, or that it could be depleted or eliminated. Currently, this is being reported for the Cajuns in Louisiana in reference to their overharvest of ducks through poaching on the bayous. Our research interviews with fish managers have suggested this same value among the northern regions of the upper midwest. The ethic among these folk towards forest, field, and fish is apparently highly consumptive. Managers report that there is little stewardship toward the extensive and significant resources of the region. It is suggested that this relates historically to the consumptive attitudes of the "big timber" days as well as a psychological characteristic of humans to place less value on those things of greatest supply or availability. For these individuals, the resource exists to be harvested.

Of course no agency can afford to raise unlimited numbers of trout simply for purposes of their being caught and eaten. Apparently they won't have to. There seems to be ample evidence that given years of angling experience, and the challenge of moving towards the more intensive participation of the method angler or technique specialist, that the recreationist will develop away from consumption through the phases towards non-consumption. These individuals release, not because the resource is not important, but rather because it has become so critically important to them and to their satisfactions and values.

Our Wisconsin studies also suggest that enhancement of the motivations and satisfactions associated with catch and release can be accomplished through any strategy that introduces the angler to the act. Many trout fisherman could recall to our interviewers just how, why, and when they had first begun to release trout. Eventually the act becomes intrinsically satisfying and an important part of the angler's value system. Case histories indicate that individual anglers and sometimes clubs become almost evangelistic in bringing catch and release to others on the stream...and perhaps their own worst enemies.

Managers sometimes create regulations or policies which convey that how the fish is taken is unimportant. Catch or kill rates (yield) are cited as the only criteria for regulations. One example of this was the permitting of anglers to snag salmon and trout in the Great Lakes and their feeder streams. There are many who do think that the ethics of how fish or game are taken are the ultimate values. For example, emphasis on the clean or one shot kill rather than the size of the animal you are hunting. Trout anglers interested in the fourth or fifth stages usually have similar feelings. Many feel that the essence of sport angling is defined in how fish are taken, not simply in body counts.

CONCLUSION

Management decisions influence recreational values and behaviors. The decision maker needs at least two types of information to put into effect a management scheme which capitolizes on angler motivations and maximizes satisfaction: (1) a resource inventory, and (2) a user inventory. Good management in part can be defined as giving people what they want to the extent that the ecosystem can support it. Experienced Wisconsin trout anglers might agree and add to this criteria the Leopold (1933) theorem, "The recreational value of a head of game is inverse to the artificiality of its origin, and hence in a broad way to the intensiveness of the system of game management which produced it." Whenever the demand greatly exceeds the supply, pressure to fill the gap often results in inferior services or products, and environmental conditions of a more artificial quality.

Wisconsin trout anglers have given convincing evidence through our surveys and through the endorsement of new regulations which reflect an inventory of both the resource and the user, that they believe in today's trout research and management programs. They wish our professionals luck in balancing the probability of increased demands on the resource with the need to perpetuate the very conditions that make trout angling so special. They feel about trout angling the way one female Trout Unlimited member put it in a group interview, "Each morning I go out from the cabin and look at the trout stream. And each morning I am filled with wonder and awe!"

LITERATURE CITED

Avery, E. 1981. Popular dynamics of wild brown trout and associated sports fisheries for Central Wisconsin streams. Wisconsin: Wisconsin DNR Technology Bulletin. #121. 26 pages.

Bryan, H. 1976. The sociology of fishing: a review and critique. Marine Recreation Fisheries. Washington, D.C.: Sport Fishing Institute. pp. 83-92.

Bryan, H. 1982. A social science perspective for managing recreational conflict. Marine Recreation Fisheries. Washington, D.C.: Sport Fishing Institute. pp. 15-22.

Bryan, H. 1983. The role of the fishery resource in the recreational angling experience. A Research Report Submitted to the Sport Fishery Research Foundation. University of Alabama. Unpublished.

Bultena, G. L. and D. R. Field. 1978. Visitors to national parks: a test of the elitism argument. Leisure Sciences. Vol. 1, No. 4.

Fedler, A. H. and R. B. Ditton. 1986. A framework for understanding the consumption orientation of recreational fishermen. Environmental Management. Vol. 10, No. 2. pp. 221-227.

Fenske, J. L. 1983. Attitudes and attributes of anglers who fish for trout in Michigan. Fisheries Research Report No. 1916. 52 pages.

Hall, D. L. 1989. The relationship of enforcement, courts and sentencing to compliance with waterfowl hunting regulations. Paper presented at the 1989 North American Wildlife and Natural Resources Conference. Washington, D.C. In print.

Hendee, J. C. 1974. A multiple-satisfaction approach to game management, Wildlife Society Bulletin, Vol. 2, No. 3.

Heywood, J. L. 1987. Experience preferences of participants in different type of river recreation groups. Journal of Leisure Research. Vol. 19, No. 1. pp. 1-12.

Hicks, C. E., L. C. Belusz, D. J. Witter, and P. S. Havelrand. 1983. Application of angler attitudes and motives to management strategies at Missouri's trout parks. Fisheries. Vol. 8, No. 5. pp. 2-7.

Hummel, R. L. 1983. Hunting and fishing, sports of millions, neglected subjects of sociology of sport. Paper presented at the 1983 Annual Meeting of the Midwest Sociological Society. Kansas City, Missouri as part of a session of "Sociology of Sport". Unpublished.

Hunt, R. L. 1988. A compendium of 45 trout stream habitat development evaluations in Wisconsin during 1953-1985. Technical Bulletin No. 162.

Jackson, R. M., R. C. Norton, and R. Anderson. 1979. Improving ethical behavior in hunters. Transaction, North American Wildlife and Natural Resources Conference. Vol. 44 p. 306-318.

Jackson, R. M. 1981. Get involved: be a better hunter. Wisconsin Natural Resources. Vol. 5, No. 6. pp. 10s-11s.

Jackson, R. M., H. E. Moe, and R. C. Norton. 1987. Effectively teaching and enhancing hunter responsibility: an innovative model. Transaction, North American Wildlife and Natural Resource Conference. pp. 132-142.

Jackson, R. M. 1988. . . .And then there were trout. Wisconsin Natural Resources. Vol. 12, No. 2. pp. 4-7.

Kellert, S. R. 1976. Perceptions of animals in American society. Transaction, North American Wildlife and Natural Resources Conference. Vol. 41, pp. 533-546.

Kirkpatrick, T. O. 1966. Social values of hunting and fishing. New Mexico Wildlife. Vol. 11, No. 3. pp. 19-20.

Knopf, R. C., B. L. Driver, and J. R. Basset. 1973. Motivations for fishing. Transaction, North American Wildlife and Natural Resources Conference. Vol. 38. pp. 196-209.

Leopold, A. 1933. Game management. Charles Scribners's Sons. New York. page 481.

Leopold, A. 1947. The ecological conscience. Wisconsin Conservation Bulletin. Vol. 12, No. 12. pp. 4-7.

Maslow, A. H. 1954. Motivation and personality. New York. Harper and Row.

Roberts, K. 1970. Leisure. Longman Group Limited, London.

SFI Bulletin. 1976. People fish mostly to catch fish. Sport Fishing Institute. No. 274. pp. 1-6.

Anglers, Common Sense, and Fishery Management[1]

Robert W. Wiley[2]

Abstract. A 1988 survey of Wyoming anglers indicates a wide range of preference with respect to the fishing experience. The 1,601 respondents reported the essence of fishing in Wyoming to be characterized by the opportunity to be outdoors, to relax, to catch and eat fish, to fish in pleasant surroundings, and to hook or catch a large fish. Of the 104,500 resident anglers in Wyoming, 22% expressed preference for wild fisheries, 40% favored harvesting fish without special restrictions, 17% desired fishing for trophy-sized fish, and 21% expressed interest in warm water species of fish. Successful management programs must address public interests as well as the biology of fish so that angler expectations are at least partly fulfilled.

INTRODUCTION

Fishing in Wyoming is Big Business. Fishermen spend an estimated $124,000,000 getting ready to fish, travelling to fishing sites, and fishing. That translates to 3.4 million recreation days at $36.00 per angler day. The Sport Fishing Institute (1989) reported that $29.9 million in wages and salaries (2,638 jobs) was generated in 1985 by sport fishing in Wyoming. Previous Wild Trout conferences have carried strong messages that wild trout are best, that trout are too valuable to be caught only once, and that keeping fewer fish ought to be emphasized. Dr. Willis King (1975) asked fishery managers to ponder how best to provide a satisfactory angling experience and said that a satisfactory experience is very personal and variable. I suggest that no single kind of trout or single kind of fishing (such as fly fishing for wild trout) will satisfy the general angling public because of the great diversity of interests and experience among fishermen. Moreover, all habitat will not support fishable stocks of wild trout.

Public meetings are held in Wyoming every two years to discuss planned regulation changes, to learn about angler preferences, and to discuss the fishery resource, generally. People in Wyoming continue to express confidence in the technical expertise of fishery managers. During the past decade anglers have become more interested in helping plan resource management programs rather than simply receiving information about what has been planned for them. To more fully understand angler preferences, a survey of resident and non-resident anglers was planned and conducted by the Wyoming Game and Fish Department and the University of Wyoming.

THE SURVEY

The survey began in May 1988 with 24 public meetings throughout the State and was followed by a mail survey of resident and non-resident anglers to determine the number and size of angler groups, fishing preferences, probable responses to changes in management, and criteria for a successful fishing experience. Phillips, Anderson, and Krehbiel (1989) sampled four groups of anglers - those attending the public meetings, residents, non-resident season-long license holders, and non-resident tourists with 5-day fishing licenses. The study culminated with a detailed report (Phillips, Anderson, and Krehbiel 1989).

The survey consisted of two parts. Participants were asked to rank, on a scale of 1 to 10, their feelings about various fishery management strategies and their perception of what constitutes a quality fishing experience. Values near 1 indicated negative interest, values near 5 indicated neutrality, and values near 10 indicated strong positive interest. They were also asked to allocate their fishing time among possible fishing opportunities designed to mimic those available in Wyoming. Anglers had been asked about management strategies and quality of experience in 1975 and 1980 surveys, but had never been asked how they might allocate their fishing time.

---

[1]Paper presented at Wild Trout-IV, Yellowstone National Park, September 18 and 19, 1989.
[2]Robert W. Wiley, Fish Research Supervisor, Wyoming Game and Fish Department, Laramie, WY 82070.

RESULTS

Kind and Size of Angler Interest Groups. All respondents were asked to rate the importance of each of 24 statements that described an aspect of fishing experience or fishing site (Phillips, Anderson, and Krehbiel, 1989). Analysis of those data defined five groups of anglers with common site and experience interests (Table 1).

Table 1. Fishing interest groups, numbers and percent distribution by drainage area.

Interest Groups	Drainage Areas * 10	20	30	40	50	Total
Wild	1,067 (25)	5,518 (28)	2,985 (18)	6,465 (34)	7,397 (16)	23,432 (22)
Family	536 (13)	4,371 (22)	2,807 (17)	3,127 (16)	9,517 (21)	20,358 (20)
Yield	979 (23)	3,896 (20)	3,472 (22)	3,798 (20)	9,337 (21)	21,482 (21)
Trophy	1,113 (27)	1,780 (9)	3,147 (19)	2,014 (10)	9,743 (22)	17,797 (17)
Warm	490 (12)	4,213 (21)	3,813 (24)	3,798 (20)	9,156 (20)	21,470 (20)

* Drainage areas are: 10--Snake River; 20--Wind-Big Horn; 30--Belle Fourche-Powder; 40--Green-Little Snake; 50--North Platte.

Each interest group represented about 20% of the angling population, an indication of the diverse interest of the fishing public.

The Wild (22%) and Trophy (17%) groups favored fishing for wild fish, trophy fish, and would not reject restricted limits. The family (20%) and yield groups (21%) do not favor restricted limits; they are in favor of stocking fish, including hatchery-reared catchable trout. The Warm Water group (21%) favors warm water fishing, but they do fish trout waters. There was high interest among all groups in catching or playing a large fish and a high general interest in trout fishing.

A comparison of the results of surveys from public meetings with resident mail surveys showed that people attending meetings were distinguished by a strong desire for managing for trophy fish, even if most fish caught must be released; managing for wild fish; reduced creel limits; and keeping fewer fish. People attending meetings in northwestern Wyoming - the Jackson-Afton area - favored these interests most strongly. Non-resident season anglers shared about the same interests.

Residents responding to the mail survey expressed a strong desire for managing waters for sustained yield, little or no reduction in creel limit, and stocking catchable sized fish. As expected, the interests of people attending meetings was different from those responding to the mail survey. Tourist-5-day licensees held similar interest.

Fishing Preferences. Fishing tackle preference tended to combine the four sample groups into two classes. The public meeting and non-resident seasonal respondents indicated almost a 50% preference for artificial flies. The resident and tourist groups indicated a preference (about 44%) for natural bait and a 25% preference for artificial flies (Table 2).

Table 2. Percent tackle preference according to survey respondent group.

Terminal tackle	Public meeting	Non-Res. season	Non-Res. tourist	Resident mail
Natural bait	25.1	24.1	44.3	44.3
Lures	25.5	25.3	30.7	30.7
Flies	49.4	50.0	25.0	25.0

Preference for terminal tackle was governed by level of angling experience. More experienced anglers chose artificial flies while anglers of lesser experience chose lures or natural bait. Most (89%) of the people attending public meetings considered themselves as experienced (64%) or expert (25%) anglers. Ninety-three percent of the anglers holding non-resident seasonal licenses could be classed as experienced (72%) or expert (21%). Residents responding to the mail survey indicated that 89% classed themselves as experienced (77%) or expert (12%). Tourist anglers were not queried about fishing experience.

Some fishing preferences have changed over the years. From 1975 through 1988 anglers reported increased desire for large fish, for fish that taste good, and an increased interest in keeping fewer fish. Increasing interest in opportunities to catch big fish, improving fishing skills, and desire for better equipment suggest that the shift away from keeping fish is accelerating. Anglers continued to indicate that they favor stocking trout, fishing close to home, and family-type fishing areas. Fishermen do not favor increased fees to fish specially managed waters.

The Essence of a Satisfactory Angling Experience. Anglers fishing in Wyoming describe a satisfactory fishing experience according to a core set of expectations: opportunities to be outside, relax, and get away from people, fish in pleasant surroundings, keep fish, and to hook or catch a large fish ranked very high - 8 or above.

The elements of a satisfactory fishing experience differ for anglers attending the meetings and for residents responding to the mail survey. People at meetings and non-resident season anglers were satisfied by meeting and talking with other anglers, honing fishing skills, and were not greatly concerned about fishing close to home or keeping fish. Resident fishermen favored keeping fish, fishing close to home, and were less interested in talking with other anglers or improving fishing skills. Fishing evidently has great therapeutic value beyond catching fish because the opportunity to be outdoors and relax scored higher (8.6 to 9.2) than any other characteristics of fishing.

Responses to Change. Anglers were presented several fishing opportunities from which to choose and were asked to allocate 10 typical fishing days among the opportunities. Each survey contained 8 sets of 3 choices from a total of 192 possible fishing opportunities. If choices in a set were not desirable, people could choose not to fish. Analysis of choices provided a measure of the importance of different management strategies and of different attributes.

Data showed that anglers would allocate their fishing time depending on interest. Angler responses were varied to the opportunity to fish a water characterized by 12 inch fish caught at the rate of 0.75 fish per hour and managed according to different strategies (Table 3).

Table 3. Percent distribution of fishing days by management program for typical fishing opportunities.

Mgmt. program	Res. survey	Public Mtg. survey	Non-Res. Seasonal survey	Non-Res. Tourist survey
Restricted limit	27.7	38.3	39.0	33.0
Sustained yield	32.7	26.5	27.6	33.5
Warm water	25.6	24.7	16.1	20.3
Non-fishing recreation	14.0	10.5	17.3	13.2

DISCUSSION

Tables 1 and 3 show that about 40% of the Wyoming anglers surveyed favored fisheries governed by general statewide regulations, 22% were interested in fishing waters where wild fish could be caught, 17% were interested in trophy fishing, and about 21% favored pursuing fish such as bass and walleye. The interest in warm water species has grown since 1970 in response to developing fisheries. Before 1970, very few such fisheries existed in Wyoming. Fishery management programs must address diverse interests to be successful.

Surveys conducted in 1975 and 1980 suggested increased interest in keeping fewer fish, although all anglers keep fish on occasion. Catching and keeping fish is a less important motivation for fishing today than in the past. No anglers chose to devote all fishing time to one kind of fishing, confirming that variety of experience and diversity of opportunity are essential parts of the fishing experience. Managers must offer varied opportunity through different fishery management strategies to meet the desires of the fishing public, continue to provide interesting angling opportunity, and maintain good fish stocks.

Varying angler interest across fishery management areas requires varied management. Anglers in northwestern Wyoming expressed greatest interest in development of new management strategies and favored more fisheries for trophy trout, stocking fewer fish, reducing limits, and emphasizing wild fish. Such interests are not surprising as the largest number of "expert" anglers were encountered at meetings in northwestern Wyoming. Commercial tourism and the economic aspects of recreation, including fishing, receive great emphasis in this corner of the State. Reduced limits, wild fish, trophy fish, and less stocking represent elements of fishing that the "expert" angler finds challenging. Anglers in northwestern Wyoming have accepted proportionately more "special" fishing conditions than their counterparts elsewhere.

Interest of Wyoming respondents indicated that continuation of current management strategies or initiation of some change would be acceptable. People at public meetings were more favorable towards change (6.1); respondents to the mail survey were neutral (5.3).

Fishermen attending public meetings represent a bellwether of future fishing preferences. For example, strong interest (score 8 of 10) in restricted limits in 1988 confirmed what had been expressed in 1975 and 1980 by similar groups of people. Monitoring the interests of people attending public meetings is a valuable and inexpensive way to follow the changing attitudes and desires of the fishing public. Surveys of the sort administered in 1988 must be conducted periodically (perhaps each five years) so that a representative cross section of ideas, including those of people who don't attend meetings, can be obtained. Fishery management strategies can then be fine-tuned from biological information about the fishery in concert with information obtained from anglers.

The fishery resource can be fairly allocated among the interest groups by understanding angler desires as well as the biological capability of the water. Although 17% of the angling public may desire trophy fishing, setting aside 17% of the waters in the State for trophy fish is not possible because many waters will not produce large fish (Nehring and Powell 1989, Wiley 1989). A strategy of allocation by percentage would not be acceptable to fishermen, generally, because of the diversity of preference. Managers must address angler interests by discussing the issues with them and obtaining general approval before a different strategy is implemented. The responsibility of anglers is to communicate desires to fishery managers and to interest other anglers in the same kind of fishing so that the "consumer" group becomes larger.

Experienced fishermen choose fishing techniques requiring more skill. The more expert angler favors keeping fewer fish, while the less experienced fisherman wishes to keep and eat fish. For example, anglers in the Jackson Hole area expressed great interest in restricted limits, trophy fishing, and wild fish. Many of these people are expert anglers who have chosen to locate in the area to indulge their fishing preference. This interest has been balanced with that of anglers not wishing restricted fishing by setting aside stream reaches governed by different management strategies. Similar trends among anglers have been recorded in Virginia (Chipman and Helfrish 1988), California (Kershner and Van Kirk 1984, Fletcher and King 1988), and Wisconsin (Jackson, Claggett, and Nelson 1988), suggesting that experienced fishermen create diversity by choosing fishing techniques that require higher levels of skill and represent greater challenges.

Conflict between interests often arises, with conservation agencies in the middle. Some important fisheries in Wyoming would not exist without the hatchery-reared product. Information from this survey does not suggest that any area in Wyoming should be completely set aside for a single kind of fishing, such as using only barbless hooks or for put and take fishing. It does suggest, though, that some different opportunities for fishing may be well received.

Fishery managers across Wyoming offer a large menu of fishing opportunity for public approval. For example, more waters in southeastern and northwestern Wyoming have been recommended for management under restrictive angling regulations to produce larger fish in response to public desire for trophy fishing. Prior to the 1988 survey, no waters in southeastern Wyoming had been specifically targeted for trophy fish management, although several supported big fish. Where regulation has been suggested for streams, specific reaches have been recommended rather than entire streams so that companion interests are not completely excluded. Public support has been gratifying.

Successful fishery management in the 1990's must be founded on healthy habitat; the biological capability of the water to produce, grow, and sustain fish; an awareness about what is best for the fish; and an understanding of the desires and interest of the public. From this basis, management strategies can be developed and discussed that will provide diversity.

Common sense suggests that conservation agencies not decide for anglers what is best for them. Fishery prescriptions invite rebellion because fishermen are not offered choice (lack of choice is precisely what ignited the American Revolution). Satisfactory angling experiences can be provided if fishery managers and the fishing public work towards resource management as partners rather than adversaries.

Fishery managers, and the conservation agencies they work for, will be judged on how well the desires of all anglers are met rather than on how well satisfied a single group of fishermen may be. It is axiomatic that no single interest will be completely satisfied and that all interests will receive some satisfaction. Thus far, allocating Wyoming fisheries for the benefit of anglers and the fish has been interesting, challenging, and rewarding.

LITERATURE CITED

Chipman, B. D. and L. A. Helfrich. 1988. Recreational specializations and motivations of Virginia river anglers. North American Journal of Fisheries Management. 8:390-398

Fletcher, J. E. and M. King. 1988. Attitudes and preferences of inland anglers in the State of California. The Survey Research Center, University Foundation, California State University, Chico, CA.

Jackson, R., L. Claggett, and E. Nelson. 1988. The Wisconsin trout angler studies. Wisconsin Department of Natural Resources, Madison, WI.

Kerschner, J. L. and R. R. Van Kirk. 1984. Characteristics and attitudes of some Klamath River anglers. California Fish and Game. 70:(4):196-209.

King, W. 1975. Keynote Statement. Proceedings of the Wild Trout Management Symposium. Trout Unlimited, 501 Church Street, Vienna, VA.

Nehring, R. B. and T. Powell. 1989. Establishing special regulations on trout waters: criteria and biological responses. Colorado Division of Wildlife, Mimeo. 8p.

Phillips, C., D. Anderson, and T. Krehbiel. 1989. Fishing in Wyoming: A Statewide Study of Angler Preferences and Fishing Patterns. University of Wyoming, Laramie, WY 82071

Sport Fishing Institute. 1989. The economic impact of sport fishing in Wyoming. Sport Fishing Institute, Washington, D.C. 20001.

Wiley, R. W. 1989. Habitat for big fish in Wyoming. Wyoming Wildlife, July, 1989. Wyoming Game and Fish Department, Cheyenne, WY 82006.

Visiting Hours Only, or: Catch and Release Revisited[1]

D. W. Chapman[2]

This paper reviews concepts of participant entry limitation in fisheries. I contend that entry control should lead to highest net annual return to society, hence maximize fishery values in competitive resource allocation. I suggest that managers could limit entry in sport fisheries by sale of weekly permits, odd or even day fishing controlled by ending license number, drawings, or check stations. I argue that entry control will prove necessary even in catch and release fisheries.

We rarely acknowledge that catch-and-release fisheries limit entry in sport fishing. I review here the concept of entry limitation and the connection to non-consumptive regulations. I discuss the role of entry limitation in natural resource allocation, and more direct means of entry limitation that would permit harvests.

Entry limitation originated in commercial fishery management. Crutchfield's (1962) landmark paper on "Economic aspects of the Pacific halibut fishery" first treated the concept of excess capital investment and fishing capacity. Crutchfield pointed out that the problem of policy in halibut management turned on the necessity of conserving the halibut resource. He noted that in pre-regulation days, halibut were treated as a completely free good, open to all comers without restriction. Overfishing resulted. The quota system for halibut, which allowed a fixed harvest each year, prevented overfishing, but promoted overcapitalization and inefficiency, encouraging investment in faster vessels that could travel to and from the fishing grounds rapidly to obtain a greater share of the quota. Engine sizes increased accordingly, for example. The regulations led to dissipation of potential net economic gain in excessive costs.

What has the halibut fishery to do with sport fishery management, especially with Wild Trout IV? The answer requires review of some basic truths in fish population responses to harvest, as well as some simple ideas from economics.

An unharvested fish population will contain a relatively large number of large, older animals and will have somewhat low survival in the early life history stages. It will also have a low population growth rate, in the sense of tissue elaboration or production, because the larger animals have a higher requirement for maintenance energy. They do not convert energy to tissue as efficiently as do young, rapidly growing animals.

As fishing mortality increases, the population for a time becomes more efficient because the large, slowly-growing population components die sooner, "releasing" younger fish to produce efficiently. Reproductive success and survival of young fish increase as competition relaxes. As a result, total weight yield in the fishery reaches a peak at moderate rates of fishing mortality (Figure 1).

Total weight (biomass) yield to the fishery does not occur without other effects. For example, the mean weight of fish in the population decreases with increased fishing mortality because the large, slowly-growing fish disappear (Figure 1). This result, anathema to many sport fishermen, must occur in consumptive fisheries.

Finally, aggregate weight of the population declines with increased fishing mortality (Figure 1). In spite of this, the

[1] Paper presented at Wild Trout IV, September 18-19, 1989, Yellowstone National Park, Wyoming.

[2] Don Chapman Consultants, Inc., Boise, Idaho

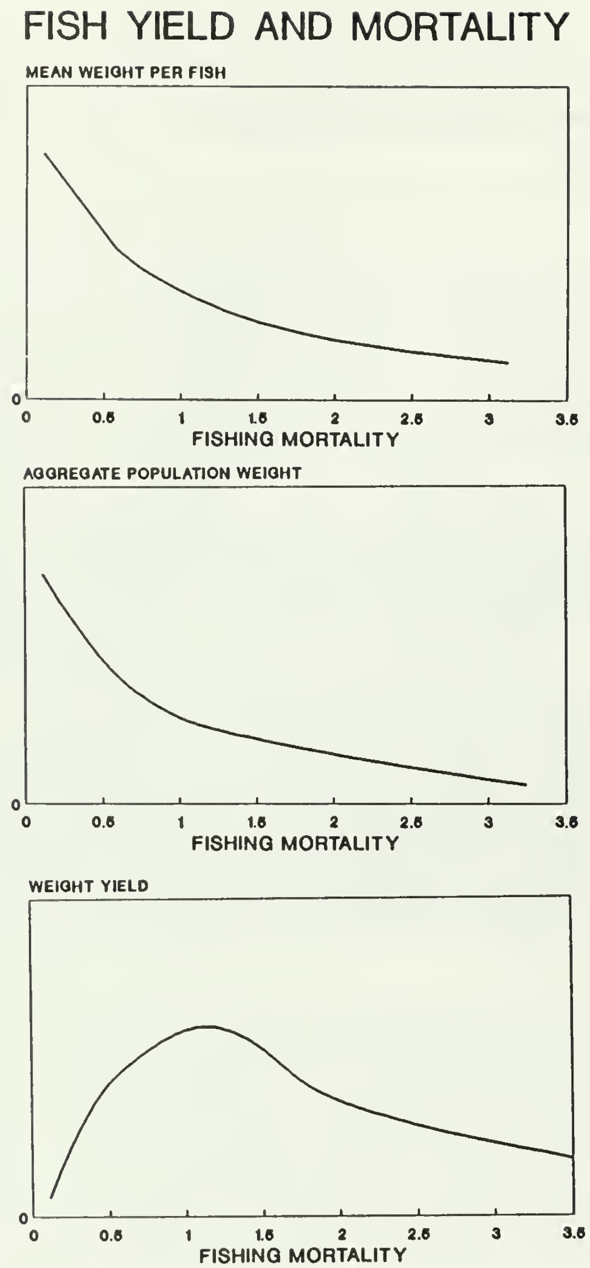


Figure 1. Generalized relationship between mean weight per fish, aggregate population weight, and population weight yield to a fishery at various levels of fishing mortality.

population actually produces the most tissue at intermediate fishing, not at zero harvest. Fishing mortality increases with fishing effort, so total weight yield from the population has a dome-shaped relationship to fishing effort (Figure 2).

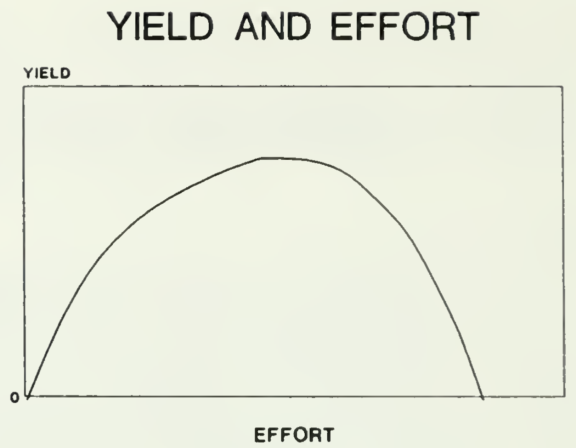


Figure 2. Yield of fish numbers or weight in relation to fishing effort.

Crutchfield (1962) connected economics to the weight yield/effort function by stating that in most fisheries, abundance of alternative foods allows us to directly convert pounds of fish to dollars, and to show that cost to the fleet increases linearly with increased effort (Figure 3). He also pointed out that in a common property fishery resource, effort will increase as long as potential entrants into the fleet perceive that they can make a net profit. This means that effort inevitably increases to point C in Figure 3; the point at which receipts

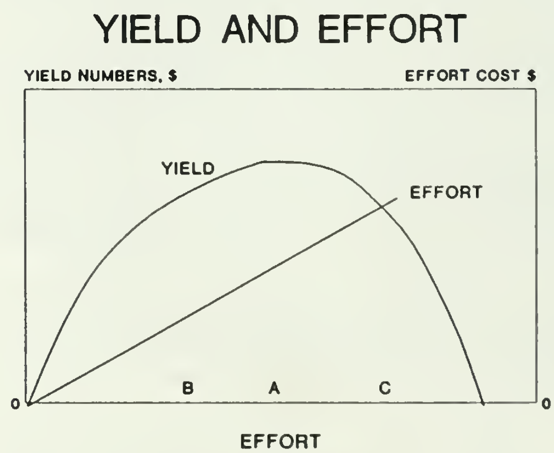


Figure 3. Yield in monetary value of numbers of fish, and cost of effort at various effort levels in a common property commercial fishery. A = effort level at maximum sustained total yield. B = effort level at maximum sustained net economic yield. C = effort level normally expected in a common property fishery.

just equal costs. Very efficient fishermen, sometimes called "highliners" continue to realize a positive net return, but many other fishermen lose money.

Commercial fishermen (to say nothing about sport anglers!) always think the next voyage will yield the bonanza catch that will turn their fortunes around. This notorious optimism, as well as a poor market for vessels and gear and "once a fisherman, always a fisherman" inertial resistance to occupational change, keeps effort at point A. Furthermore, many fishermen tend not to think in terms of opportunity cost, the return they could realize in alternative investments. They tend also to forget to include owner/skipper labor when they calculate cost of effort. A false picture of real return on investment thus emerges when these fishermen total up income and costs at the end of the year.

If a prudent monopolist owned the fishery resource, he would manage effort at the point at which the distance between the cost and return line maximized (Figure 3, point B). Point B denotes the maximum net economic yield from the fishery. All fishery management operates under three constraints: biological, technologic, and socioeconomic. Fishery conservation should provide economic benefits to man (Crutchfield 1962). Sound conservation would control effort so as to maximize net economic return. I suggest later that we should include sport fisheries in this mandate, as Jim McFadden first suggested in 1969.

In the absence of the private entrepreneurial option to limit entry, government must control fishing in a manner that assures conservation, defined as assurance that the stock can perpetuate itself. In salmonid fisheries, this means management to assure adequate escapement. This means that government must resort to short fishing periods, single nets, certain net materials, and certain areas of fishing; in short, must make fishing more inefficient to prevent overfishing. Gear and time restrictions that assure inefficiency become extremely onerous. Most of us would agree that entrepreneurs in a capitalistic system ought to have every opportunity to become efficient.

How does one limit entry in a commercial fishery on a common-property resource? Government, authorized by legislatures, may simply stop issuing new licenses, increase the cost of annual relicensing, buy licenses from willing sellers, and even buy boats and gear with license proceeds or general tax revenues. Once the fleet reaches the desired size, licenses change hands much as private land does. Some Canadian salmon fisheries, the lower Columbia River gillnet fishery for salmon, and certain Alaskan fisheries offer examples of this approach. Oyster beds in estuaries are owned, limiting entry.

Has entry limitation worked in real time? After entry limitation, the value of a Bristol Bay gillnet license increased by at least 15-fold. When last I heard, one could buy a license for perhaps $160,000 (without boat and gear). The Bristol Bay sockeye fishery now is worth more in net annual return to investment.

What connection can we find between entry limitation and stock-recruitment relationships? The latter define the relationship between progeny numbers as adults and parent escapement. These functions developed in Pacific salmon manage- ment, especially in stocks and species with predominantly fixed generation time. Coho salmon, pink salmon, sockeye salmon, and chum salmon offer examples of mostly three, two, and four-year generation times. A generalized stock-recruitment function (Figure 4) relates parent spawners on the X axis to progeny adults in the resulting return run on the Y axis. The straight line shows where returning run just equals parent spawner numbers. At any point above the replacement line, a given escapement produces a harvestable surplus.

An escapement of about 1.3 spawners produces a maximum returning run (maximum N) of about 2.9 (Figure 4). Harvestable surplus equals about 1.5 (difference between replacement line and curve). A lower escapement of about 0.8 spawners produces only about 2.6 returnees, but will sustain a harvest of 1.7. This occurs because of reduced competition at the lower escapement; competition for spawning sites and perhaps for juvenile rearing. Still, an escapement of 0.8 "fully seeds" the available environment. We term

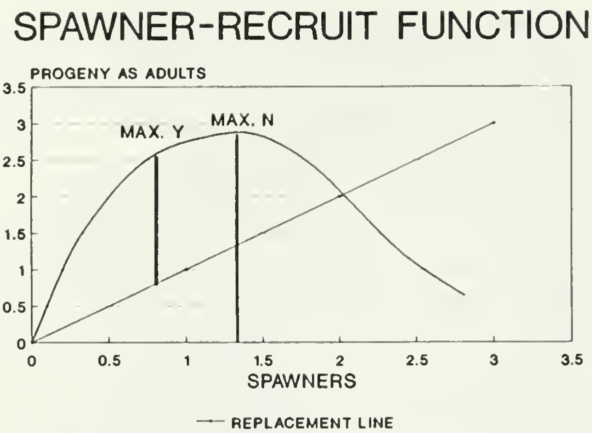


Figure 4. Progeny adults in relation to parent spawners. A spawner population of about 1.35 leads to maximum returning progeny, while a population of about 0.8 leads to maximum sustained yield (distance from replacement line to curve).

management for an escapement of 0.8 as management for maximum sustained yield (MSY). We call management at 1.3 spawners as maximum sustained numbers (MSN). A prudent monopolist would manage his fishery for MSY, where he can take about 65% of the returning run, on average, if he manages at MSY. He would harvest the surplus with limited entry so as to maximize efficiency. The connection between entry limitation and MSY in publicly owned fisheries is that both management schemes would maintain effort, hence fishing mortality, at intermediate levels that maintain the stock at highest productivity (biomass growth).

Management for MSY becomes very difficult where two or more stocks with different stock-recruitment functions mix in the fishery. The less-productive stock in Figure 5 has a harvest rate at MSY of less than 40%. Fishing at MSY at the required 70% harvest rate for the productive stock would overfish the less productive one, and may drive it to extinction, or at least to greatly underescaped levels. This has happened, and continues, on the Columbia River, where gillnet fisheries for mixed fall chinook salmon and large Idaho steelhead leads to underescaped wild steelhead. The problem would greatly decline in severity, but would not disappear, without hydro dams on the system.

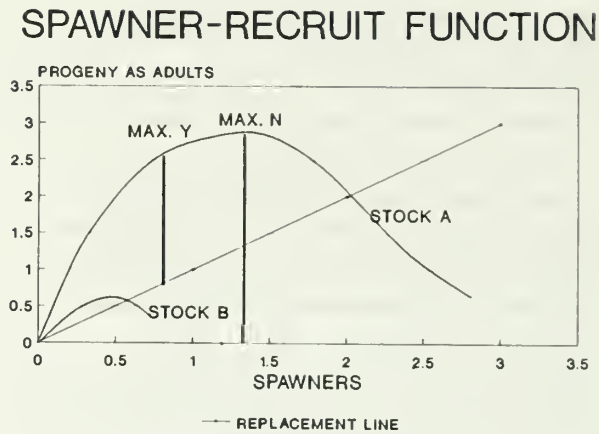


Figure 5. Spawner-recruit function for a productive population (stock A), and an unproductive population (stock B).

In sport fisheries, management may seek either MSY or MSN. Catch-and-release fisheries reduce consumptive harvest of large, slowly-growing older members of the population. Resident fish populations generally have four or more age classes, unlike most Pacific salmon stocks. Thus, the stock-recruitment function blurs. However, the relationships in Figure 1 hold. That is, multi-aged populations decline in mean size and aggregate population weight as fishing mortality increases. After the fishing mortality rate increases enough, aggregate yield declines.

Whether one manages for MSY or MSN, one must employ measures exactly like those used by the commercial fishery manager. One can limit efficient gear (no dynamite, closed areas, single lures, barbless hooks, artificial lures, etc.), or times of fishing (no night fishing, closed seasons), or size of fish kept. Or one can require that anglers release all fish. Some regulations that limit efficiency must remain in place in all fisheries. No one wants to see dynamite used to harvest fish, and snagging in spawning populations does not usually serve management well.

Biological conservation most often requires time, size, and gear restrictions to reach MSY or MSN. But what about MSYE or MSDE? These I might define as maximum sustained yield of esthetics or maximum sustained days of esthetic experiences.

Most of us would probably argue, for example, that the value per fish as meat declines with each steelhead caught. That is, we do not value the fourth steelhead caught as highly as the first. We must, for it usually ends up a year later with locker burn. I also argue that the first steelhead caught has high esthetic value, but that additional fish add less per fish to the esthetic experience (Figure 6). I hurriedly note that the total value of the esthetic experience increases for each added fish caught. The marginal value decreases. I have, a few times, reached the point of zero marginal benefit, where the next fish was not worth the effort required to catch it. Some would call that nirvana; nonetheless it fits with economic theory.

I can combine the discussion so far by depicting a yield function for recreational fishing where meat and esthetics values exist (Figure 7). I take the liberty here of assuming that a day of fishing has a dollar value, as many economists have shown indirectly (Mathews and Wendler 1968, Brown et al. 1964). Suppose we eliminate meat yield, at whatever cost in the spectrum of participants and nutrition. Certainly those who remain or come to fish in a catch-and-release fishery differ in characteristics from those who participate in a harvest-oriented fishery. And certainly most stocks could contribute to human nutrition to some degree; a value lost in catch and release fisheries. Ignoring those factors, I suggest that catch

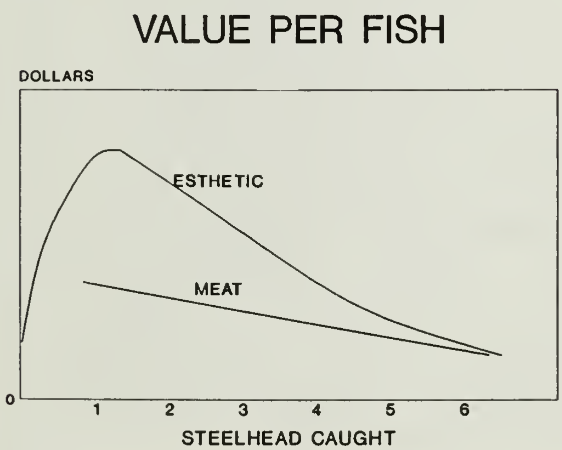


Figure 6. Value per fish for esthetics and meat as related to number of steelhead caught.

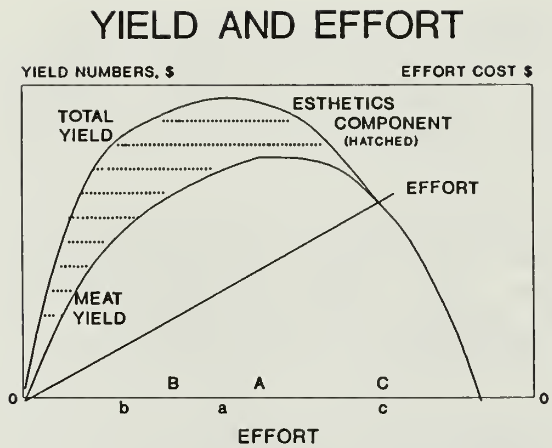


Figure 7. Yield value in a sport fishery at various effort levels. Hatched area shows esthetics component, additive to the meat yield value. Effort cost increases linearly with increased effort. A, B, C defined as in Figure 3. a = effort that maximizes total economic yield of esthetics and meat. b = effort that maximizes net economic return to society from combined esthetics and meat. c = effort reached eventually in a common property sport fishery.

and release fishing for esthetics will take a functional shape (Figure 7) much like that for commercial fishing. This implies, in a publicly-owned resource, that effort will increase until the net return of esthetics declines to zero. This means that entry will tend to point C in Figure 7.

Why does net return decline? First, it does so because catch-and-release regulations,ironically, attract too many "elitists." Many of these anglers prefer to see no other angler, and want unrestricted access to each favored casting spot. They develop a certain resistance to crowding. Participation of more and more fishermen eventually must decrease the "return" per angler. Secondly, even catch-and-release angling causes some mortality, which may, in heavily used fisheries, lead to a reduced fishable population that offers less catch opportunity even where the fishery objective is to maintain a large population of big fish. For example, a study of steelhead catch and release in British Columbia showed a mortality rate of 3.4% for 3,715 fish caught with bait and barbed hooks; (Barnhart and Roelofs 1987). Where anglers may capture steelhead more than once, the rate may rise, especially where fish take the lure, even a barbless one, deeply. I think this describes Idaho's catch and release program for wild fish on the Salmon River.

The point of MSY for esthetics lies at effort level b in Figure 7. A prudent monopolist who charged for access to his fishery resource would limit entry at b so that his net return maximizes. Can society do the same? If so, why?

On some public shooting grounds, a limited number of blinds are available to duck hunters who must apply in advance and receive a blind for a given day, or who must line up at the entrance to the shooting ground well before dawn on a first-come, first-served basis. Why must one use only the established blinds? The answer is that decoy shooting for ducks offers a classic case of decreased net benefits with increased effort. Too many hunters too close to each other completely spoil hunting for everyone as ducks never have a chance to work to the decoys.

Golf offers a fine example of limited entry. In fact, I golf more than I fish, in part because of golf's entry limitation. Tee times every 8 minutes or so guarantee spacing on the course. Certain rules permit fast golfers to move through slow ones. The amazing feature of the system is that conflicts between good and poor golfers are so few. The system usually offers a pleasant and rewarding experience to all entrants (although some would argue that golf's very virtue is that it offers pain and suffering to willing masochists!).

On the popular Middle Fork Salmon River, one can only begin a float (of 5 days or so) if in possession of a permit that was applied-for in January and issued on a random selection basis as part of a numerical quota (or one can float with commercial outfitters who automatically get about half of all permits; a problem outside the thrust of my paper). Over 8,000 floaters use the river each summer. A catch and release regulation for the stream, together with the float quota, guarantees a quality experience. If too many floaters used the stream, solitude would disappear, campgrounds on the few available areas in the deep canyon would not offer sufficient space, and the cutthroat trout fishing would suffer.

How can some of these resource partitioning programs apply to fisheries, even to catch and release? All angling licenses end with a digit. Regulations might allow anglers with odd-ending license digits to fish only on 26 of the available 52 weeks; even digits would fish on the alternate weeks. One might obtain a special permit to fish two weeks (actually three) in a row. A block of these permits could be made available to anglers in a drawing. Alternatively, regulations on popular catch and release streams would require a fishing permit obtained from a drawing each winter, with unused permits available on a second drawing. We already manage many big game harvests in this manner. In some cases governments collect significant revenue from limited-entry drawings. Less desirably, entry checkpoints might allow a quota of anglers into given stream reaches, with no more entrants until someone departs.

This all sounds rather Draconian. Why should we go to such lengths? I think that our objective should be to maximize net return, at least for many salmonid fisheries. This maximization increases the annual "rent" from the resource, whether society actually collects that rent or gives it away to anglers. I would maximize rent from harvest as well as catch and release fisheries. Once the obligation of full and adequate seeding by adults is assured, society should then maximize net benefits from fishing harvest and/or opportunity. My reasoning is that net benefit maximization provides a high-quality experience for participants and assures the most competitive role possible in resource allocation. Not all allocation decisions (kayaking v. fishing, timber production v. fish habitat, grazing v. riparian zones) will or should be made on economic criteria. However, fisheries will get the most consideration possible from resource owners or managers by having the greatest economic "clout" possible. Sport fisheries will have least clout if managers dissipate rent by excessive entry.

In a paper called "Economic criteria for division of catch between sport and commercial fisheries with special reference to Columbia River chinook salmon," Mathews and Wendler (1968) examined net rent from sport and commercial fisheries. They concluded that the coefficient of catchability in the sport fishery on the Columbia River is 5 times as high on the spring chinook run as on the fall run. Since net value of sport fishing depends on the average level of angling success, the spring fish are potentially more valuable for sport fishing. The authors showed that only if the commercial fleet were reduced to increase net economic value could a continued commercial fishery be justified. On the basis of the economic criteria examined, the authors stated that resource managers should consider managing the spring chinook stocks with more favor toward the sport fishery unless the commercial fleet were reduced in size (made more economically efficient). They suggested no change in the fall season fishery, although entry limitation would substantially increase economic rent in that fishery.

I suggest that as fuel costs rise, making ocean trolling even less economic, and as more salmon reared in net pens reach the market at low prices, management of salmon for sport fisheries becomes much more appropriate. Furthermore, even if terminal commercial fisheries continue to harvest important quantities of salmon, regional economic returns from salmon would increase substantially. More biomass would reach the mouths of parent streams. Ocean harvesters (sport and commercial) take salmon that are growing new tissue faster than natural mortality consumes it. Furthermore, hooking mortality is very high, wasting more biomass. About 117,000 coho salmon were wasted in hooking mortality during a chinook-only fishery off Oregon last year, or about 17% of the legal harvest of coho salmon in all-species seasons. An additional hooking mortality is associated with the latter fishery. I estimate that every hundred coho in the legal harvest off Oregon represents 30 more fish killed and lost. Coho salmon could be taken in terminal or sport fisheries with great increases in net rent.

Will the angling public support limited entry? To answer this question, I examined a 1988 angler opinion survey of Idaho fishermen (Idaho Fish and Game News, March-April 1989). In 8,599 usable returns, 56% of respondents would be willing to restrict number and size of harvest to maintain fishable wild populations; 54% would manage streams and lakes to provide larger than average trout at increased catch rates, even where methods, numbers and size would need restriction; and 48% would continue to fish a favorite trout stream if the water were managed for trophy trout with catch and release. When asked whether they considered it important to avoid angler crowding, 89% of the respondents said it was important (22.4%), very important (34.2%), or crucial (26.2%). From these data, I conclude that anglers want to maintain wild trout and would accept catch restrictions, including catch-and-release regulations, to do so. The respondents do not want crowding, so limited entry appears acceptable in some form.

Limited entry certainly would control crowding. It would also lead to increases in fish size, if coupled with such measures as catch and release. For the respondents who would not support large fish management through catch and release, the latter would likely limit <u>their</u> entry. The May 15, 1989 Idaho Statesman shows one response in an article titled: "Sportsmen may sue over Big Wood fishing rules." The Idaho Fish and Game commissioners had voted 3 to 2 to restrict 17 miles of the Big Wood River above Deer Creek to catch and release fishing with artificial lures. Protestors called for a "fish-in" on opening day, with one ring-leader stating: "I've already told the Fish and Game where I'll be opening day, and I told them to bring their handcuffs." Presumably, this individual would form part of the approximately half of questionnaire respondents who would not support catch and release as a measure to increase fish size or protect wild trout! On the other hand, I think that respondents who support such protective measures in general, sometimes or often would not support them if applied to their favorite stream.

The time may not yet have arrived for wide support of limited entry, whether accomplished by catch-and-release or other measures. But it will. One need only visit trout streams close to metropolitan areas, or the growth of tourism in the mountains of the western United States, to see the developing pattern. I have watched the West change for 35 years as a professional biologist and fisherman. I know that 25 years ago very few fly anglers fished for steelhead on the Clearwater River in Idaho. One could fish all day without seeing another rod. Today one often cannot find a known holding spot for steelhead that does not contain a fly fisherman. Where the lower Deschutes was little used, it now is super-saturated with steelheaders. I think it is time to initiate entry limitation on certain popular waters to increased net benefits.

Apart from direct benefits to anglers, high net rents from resident fisheries, whether oriented to harvest or catch-and-release, provide ammunition to allow Forest Service and BLM administrators to more easily justify livestock reductions on public riparian zones. They give the manager justifications to improve stream habitat, better land husbandry, and to compare social benefits of roading and timber harvest to those from fisheries and other resources not traditionally considered as commodities. Should the fishery manager fear economic comparisons? I do not think so. From the ranks of contented anglers come informed and participating publics.

Literature cited

Barnhart, R., and T. Roelofs. 1987. Catch and release ten years later. Humboldt State College, California Cooperative Fishery Unit, Proceedings of a symposium on catch and release fishing a decade later.

Brown, W. G., A. Singh, and E.N. Castle 1964. An economic evaluation of the Oregon salmon and steelhead sport fishery. Oregon State University Technical Bulletin 78. 47 p.

Crutchfield, J., and A. Zellner. 1962. Economic aspects of the Pacific halibut fishery. United States Department of the Interior, Fishery Industrial Research 1 (1).

Mathews, S. B., and H. O. Wendler. 1968. Economic criteria for division of catch between sport and commercial fisheries with special reference to Columbia River chinook salmon. Washington Department of Fisheries, Fisheries Research Papers 3(1):93-104.

McFadden, J. T. 1969. Trends in freshwater sport fisheries of North America. Transactions of the American Fisheries Society 98 (1):136-150.

British Columbia Wild Trout Management: More Than Dollars and Sense[1]

John W. Cartwright[2]

Abstract.--A brief overview is presented of the fishery resources and wild trout management program in the Province of British Columbia. Also discussed are changing client expectations, economic values of the resource, and the necessity to build and to receive support from a strong tourism industry based on quality fishing opportunities. The planned changes to British Columbia's angling guide policy, including the concept of limited entry fishing, to be implemented in the 1990 angling season on the Dean and Babine rivers, and efforts to maintain quality angling for wild trout are discussed.

INTRODUCTION

Wild trout management in inland waters of British Columbia is more than a matter of dollars and sense, it is a matter of policy.

In a recently adopted "Statement of Ethics", the Ministry of Environment takes the position that emphasis will be on environmental quality rather than on increasing exploitation.

The prime mission of the Ministry is the maintenance of healthy ecosystems. The emphasis of recreational fisheries management is directed toward the quality of experience, in a variety of natural environments, rather than on harvest.

The goal of our Recreational Fisheries Program is to provide social and economic benefits to the Province through conservation and management of freshwater fish and associated habitats.
In support of this goal are three primary objectives dealing with habitat, recreational opportunities, and social and economic benefits.

In this Paper, British Columbia wild trout resources, management philosophy, client expectations, benefits and costs, and the reality of rapidly changing angler philosophies are discussed.

---

[1]Paper presented at the Wild Trout IV Symposium. [Mammoth, Wyoming, September 19, 1989].
[2]John W. Cartwright is Section Head, Fisheries, British Columbia Ministry of Environment, Fish and Wildlife Branch, Kamloops, B.C.

THE RESOURCE

British Columbia is a province of contrasts, not only geographically, but also in terms of its fishing opportunities. We have low elevation lakes with high productivity in semi-desert surroundings as well as alpine and coastal lakes of extreme low productivity. We have, as portrayed in tourism promotions, some of the best, accessible, rainbow trout fishing in small lakes and world-class steelhead fishing of anywhere in North America. Our coastal anadromous rivers are generally of low productivity, while southern interior rivers are capable of supporting strong populations of salmonids.

We also have lakes and streams that are crowded, overfished, and subject to all of the social problems that go along with too many people and unrealistic expectations. These are some of the characteristics of British Columbia freshwater fish resources which put our management concerns and emphasis in perspective.

British Columbia is considered by many anglers and unfortunately, by politicians as well, to be a province of seemingly endless lakes, streams and wilderness fishing opportunities. This is the stuff that tourism promotion is made of! Reality is that of the ten Canadian provinces only two, Ontario and Quebec, have a greater land area than does B.C., and yet B.C. ranks only fifth in area of freshwater systems. For example, in the prairie province of Manitoba, lakes and waterways occupy 15% of the surface area, while in B.C. they occupy only 2%. In total we have only about 20,000 lakes with fisheries potential as compared with over

250,000 in Ontario. Our rivers and streams, although seemingly abundant, are frequently steep in gradient and relatively unproductive in terms of sustaining large populations of resident salmonids.

The number of legally defined game fish is limited to 18 of which 10 are salmonids. Steelhead and cutthroat trout dominate in coastal drainages, along with chinook and coho salmon. Inland, in the southern half of the Province, the rainbow trout is king, while in the northern half of the Province lake trout assume progressively greater prominence. Dolly Varden are found in rivers and most large lake systems throughout the Province. Westslope cutthroat are native to lakes and streams in the southeast corner of the Province, while kokanee are native to most large lake systems Province-wide. Arctic grayling are popular throughout the far north, while mountain whitefish are common throughout the mainland of the Province. Brook trout and brown trout have been successfully introduced in various waters earlier in the century.

MANAGEMENT PHILOSOPHY

Like the world around us, freshwater fisheries management in British Columbia is changing rapidly. Twenty years ago, the focus of management was on production of fish for a public that wanted maximum quotas when they went fishing. Fortunately today, most anglers expect a quality experience rather than a full freezer.

Our long-standing management philosophy, to maintain a wide range of angling opportunities, is basically supported by our Fisheries Program goal and objectives. We are faced with managing multiple species in a province with over 366,000 square miles of area. This is over twice the size of California, or larger than the combined areas of Washington, Oregon, Idaho and Wyoming. With eight widely scattered administrative centres, a relatively small staff of professionals and modest operating budgets, clear policy and objectives are essential to a cohesive program.

Much of British Columbia's management effort is directed toward maintenance of wild, native stocks by habitat protection and improvement and by conservative regulation. We actively manage, by stocking and other enhancement strategies, only about 1,200 (6%) of the 20,000 lakes with identified fisheries potential.

As a relatively young agency originating in 1949, staffed primarily with professional biologists and technicians, we have had the luxury of learning from the mistakes of others. We have witnessed some of the pitfalls of major stocking programs elsewhere and have resolved to try to avoid those traps. We believe that our "wild trout only" policy serves the resource well in this regard.

The British Columbia fish culture system is unique and the envy of almost every fisheries agency in North America in its 99% dependence on eggs from wild fish. We have over 30 trout, char and kokanee stocks available for egg collections. In fact, the only brood stocks maintained are to supply small urban fisheries with catchable domestic fish, some special late maturing stocks, and piscivorous stream rainbows. This wild trout policy includes our steelhead program where only wild, unmarked adults are collected (by angling!) for brood stock.

British Columbia steelhead rivers are classified into three management categories. Wild rivers are those where no stocking is done (the majority of systems). Augmented rivers are those managed to include both a wild and a hatchery component often separated in space (47 streams). Hatchery rivers are those with little or no remaining productive capability and are heavily stocked (3 streams). Virtually all steelhead used for brood stock are caught by angling (±1400 individuals). The origin of each fish is maintained and all progeny are returned to the parent river.

Stocking is done with either smolts (all must be marked by removal of the adipose fin for identification in the fisheries) or with fry of the year which may or may not be marked. Fry are normally stocked into inaccessible headwater areas, or into identified rearing habitat that is lacking adequate seeding of juveniles. Natural rearing for two years before smolting is the normal expectation from fry stocking.

The majority of steelhead stocking is done in heavily fished streams in the southern part of the Province, or on Vancouver Island. On these streams the release of all wild steelhead (intact adipose fin) is required by regulation. However, a limited retention by anglers of marked hatchery fish is permitted.

With the exception of four or five large lake systems which have been impacted by major hydro developments, our lake stocking program is directed almost entirely toward small lakes (i.e.) those under 1000 hectares (2470 acres). The majority of these have limited or no natural spawning habitat and would produce few fish without stocking. Even these lakes receive only progeny derived directly from wild trout.

We do not normally stock streams with the intent of maintaining trout fisheries. Our stream management programs focus on habitat management and protection and on angler regulation. However, occasionally we may stock a special race of wild trout into a stream on a pilot basis to establish a population.

Management for wild fish in natural surroundings may cost more initially, but it is critical to maintaining resource diversity and future angling opportunity.

ANGLER EXPECTATIONS

British Columbia has been long perceived as a last frontier. If a favourite lake were fished out there was another over the next hill. Not so any more. The change in public attitude, as a result, has been dramatic.

Only ten years ago the majority of anglers were preoccupied with limits. Today, quality of angling experience, reduced kill, and endorsement of catch and release are becoming the norm.

For example, in a 1985 survey of British Columbia freshwater anglers, it was learned that the success of a day's fishing was primarily measured by the quality of environment encountered. Major factors desired were natural beauty, quality of the water, access to wilderness areas, weather conditions, and lack of crowding. In fact, fish were not even mentioned until the seventh factor. Species, size and wild fish were more important than the number of fish caught or catching fish for food, which ranked only 10th and 11th respectively.

THE COSTS--AND THE BENEFITS

Managing for wild trout by protection of habitat, management of angler demand and dependence on wild trout spawning runs for our Provincial Fish Culture Program is costly. However, benefits in terms of quality experiences and angler satisfaction outweigh any disadvantages. Look at the record. Sport fishing throughout North America is a major recreational activity with exceptional economic impact. It is, in fact, one of the fastest growing participation sports.

Looking at Canada, in 1985 nearly 7 million anglers spent 2.5 billion dollars to fish 84 million days. In addition, the 1985 market value of sportfishing equipment used solely for angling was 8.6 billion dollars. One of every four Canadians fished at least once in 1985, and in total caught 350 million fish of which 100 million were released.

In the fresh waters of British Columbia, in 1985, 420,000 anglers spent 303 million dollars fishing 4.7 million days for a catch of 9.4 million fish of which 1.5 million were released. The average catch per day was 2 fish. This expenditure supported over 5200 person years of employment, 110 million dollars of household income and 174 million dollars of Provincial gross domestic product.

This is a brief indication of the growing Canadian demand for and value of sport fishing. As all of you know, the same growth in demand and impressive value exists in the United States. In British Columbia this demand is growing at a rate of 4% to 6% per year. Sport fishing across North America is a major social activity and is clearly big business.

Many anglers will think that various comparisons of sport fishing with Provincial or State economics is a bore and of little real value. They must think again! It is critical to the future of quality angling.

There is no question that credible documentation of fisheries values will often make or break resource conflicts. In society today, without reducing angling to economic values, we all too often have no argument at all to protect wild fish, fish habitat, or the associated angling environment.

There is no doubt that development and maintenance of a strong tourist industry based on quality angling for wild trout in an uncrowded, natural environment can produce large, long-term benefits. I often hear complaints from B.C. anglers about nonresident fishermen crowding lakes, streams or campsites. I'm sure this is not unique to B.C. However, we must move away from the we and they attitude. Development and maintenance of a strong tourist industry based on quality angling for wild fish can benefit everyone. Without strong economic arguments from a strengthened tourist-oriented angling program, government will to maintain the resources critical to quality angling will remain weak, not only in B.C., but I'm sure in your states or provinces as well.

REALITY

One reality which Fisheries Managers in British Columbia have recognized for a number of years is that in many of the more popular small lake and river systems in the southern one-half of the Province, we are running out of fish. What we see is a repeat of the "tragedy of the commons". Too many people are killing too many fish. A familiar story, but it is a scenario which we must address in order to maintain many of our quality wild trout fishing experiences.

Another reality is that too many resource decisions are still made in favour of immediate gain from resource extraction rather than adopting a sustainable development philosophy to provide for the longer-term values of quality angling opportunity in wild settings. Once timber or mineral is developed and roads are in place, future values of quality fisheries are compromised, often permanently. A recently renewed attempt to implement true integrated resource management planning is now a hope in British Columbia.

A third reality is that we, as managers, are merely caretakers of our public fishery resources for future generations. We have recognized in policy the angling public's desire for wild fish and quality of angling experience. As biologists, we understand what anglers tell us about superior fighting qualities and appearance of wild fish.

How can we maintain our wild fish policy? Our Ministry takes the position that poor development policies are at the root of environmental degradation. Further, to effect meaningful changes, patterns of resource extraction, technology, life style and education must change significantly, and the Ministry must take a leadership role in promoting such change. We believe that anglers across North America are prepared to pay more, to contribute more by personal involvement, and to kill fewer fish in exchange for maintenance of quality angling opportunities.

In British Columbia we have taken a number of steps toward restoring quality angling in nearly a hundred "overfished" small lakes and most streams in southern parts of the Province. Winter fishing has been eliminated on these waters; gear restrictions and ban on use of bait have been introduced to allow more successful release of fish; and catch limits have been reduced to one or two fish per day. In fact, we have one lake in which no kill is permitted. Ten years ago such restrictions would have been unthinkable.

The proof is that fishing quality and the experience improved so dramatically on the restricted waters that now organizations and individuals are requesting more of this type of "intensive" management in all areas of the Province.

The fisheries resources of British Columbia are common property natural resources, owned and controlled by government for the benefit of anyone who chooses to enjoy them. As a result, the "tragedy of the commons" is probably more evident to Fisheries Managers than to most other resource managers. Perhaps nowhere is overcrowding a more serious threat than on some of our world famous summer steelhead rivers such as the Dean and Babine rivers. We are now developing policy to address this problem.

Fisheries Managers will classify our major steelhead and trout rivers into categories. New legislation enables Managers to restrict the number of guide operations and require each guide to prepare a management plan on Class I and II rivers.

On Class I waters the total number of anglers permitted on a river in any season or time period and the length of stay on a river in any year will be regulated. Anglers will have to apply in advance for permits for desired fishing times. Nonguided, nonresident anglers will be the first group to be restricted by limited entry and ultimately it may be necessary to control resident angler numbers the same way. Few rivers are ever expected to be designated Class I; at present only the Dean and Babine rivers are so classed.

The basic intent is to develop and implement controls not only on the kill of fish but also on the numbers of people allowed the PRIVILEGE of using the resource at any given time.

BACK TO THE FUTURE

What is the future for wild trout, for their habitat, and for a quality fishing experience in British Columbia?

There is no question that wild trout and wild places to fish are under intense pressures as never before, from industry, from access developments, from subdivisions and from people. All of these pressures will tax our ability to maintain that uncrowded, quality angling experience.

In British Columbia you can expect to see expanded emphasis on catch and release programs and more intensive regulation of our fisheries. This will include more lakes and streams with bait bans, gear restrictions, and reduced limits.

You can also expect to see increasingly aggressive efforts by British Columbia Fisheries Managers to bring "the tragedy of the commons" under control on many more of our best river and lake systems.

You can expect to purchase additional licenses, as well as pay additional fees to fish "special" or "restricted" waters. In exchange, you can expect to enjoy better, less crowded fishing experiences for wild trout in wild settings.

Anglers and professional biologists must work more closely together. We must focus on the real issues of the world we live in and accept that economics drive our societies and inspire our governments to act. We must be willing to commit more of our time and resources to education of government, bureaucrats, and the public. Active, knowledgeable anglers on corporate boards and elected to government can be powerful allies.

We must convince our elected representatives that the short-term gains from ill-conceived developments are just that--short term. And we must be willing and able to show that to forego some immediate profits can produce long-term gains far in excess of imagined losses.

Without question, management for wild trout and quality fishing opportunities in wild places can make big dollars and certainly makes good sense.

The Economic Effect of No-Kill Regulations on Communities[1]

Richard W. Talleur[2]

The purpose of this paper is to document and assess the effect that quality trout fishing, resulting from the implementation of no-kill regulations, has on the economy of the localities in which said regulations are applied.

In addressing the topic of this paper, which is the economic effects of no-kill trout fishing on a locality, a few introductory paragraphs will be of considerable value.

No-kill regulations on a particular fishery means just what it sounds like; no trout may be killed in the waters where such regulations apply. All trout must be returned to the water unharmed.

It must be appreciated that in order for no-kill (also known as catch-and-release) regulations to produce economic benefit in a community, the desired biological result must be obtained; that is, "quality" trout fishing. It's not the no-kill, per se, that lures anglers to a river, it's the quality fishing that no-kill produces. For purposes of this paper, a quality fishing resource is defined as one where the population and typical size of the trout in residence somewhat approximates the potential of the given body of water, and the trout, if not truly wild, at least manifest wild behaviorisms. In other words, not a put-and-take fishery.

It is recognized that no-kill is not always necessary in managing for optimal fishing in certain situations; the Big Horn is an example. However, it is becoming increasingly imperative as angling pressure escalates. Advocates of limited-kill would do well to consider the Beaverkill in New York State. During prime time, approximately 500 anglers per day fish the two no-kill sections. Suppose each angler kept just one fish daily, this in a river which has limited capacity for reproduction?

No-kill is also much easier to enforce than limited-kill. This has to do with certain sociological phenomena. No-kill areas are generally heavily fished, and peer group pressure makes it extremely difficult for persons to violate the regulations. Quite obviously, it also makes the warden's job much simpler.

In order for no-kill to be effective, it must be accompanied by certain restrictions of angling method, specifically, the prohibition of the use of organic baits. Trout tend to swallow real food without realizing that it contains a hook which is attached to a line, and those who fish bait tend to encourage this, as the objective is to infallibly catch and possess the trout. Safe release is not an issue.

There has been much debate about the relative merits of fly-fishing-only vs. artificials-only, which includes spinning lures, rubber worms, et cetera. The latter, being more liberal, tends to somewhat reduce resistance to no-kill; however, it may also compromise the effectiveness of no-kill, because of the inherently-lethal effect of the treble and multiple hooks most lures employ.

Certain studies tend to indicate that treble hooks are no more damaging than single hooks. I suggest that such studies were probably conducted under controlled conditions. Even a cursory examination of the cutthroat trout at Buffalo Ford on the Yellowstone in the Park refutes any contention that treble hooks are not excessively damaging, as many of these trout are severely muti-

---

1 Paper presented at Wild Trout IV, September 18-19, 1989, Yellowstone National Park, Wyoming.

2 Angling author, lecturer, and teacher, Clifton Park, New York.

lated.

In some no-kill areas, such as the Railroad Ranch section of the Henry's Fork of the Snake, single barbless or de-barbed hooks are specified. This greatly reduces wear and tear on the trout and the amount of time involved in releasing them. The absence of visible damage to the fish tends to defuse contentions by certain non-angling factions as to the "cruelty" of no-kill. It would seem that such regulations regarding hooks would be universally beneficial in no-kill management.

The preceding sets the stage for the thrust of this paper.

There is not much available in the way of "hard" numbers regarding the economic effect of no-kill. In the several areas researched, I could find no instances of studies which would produce such numbers. However, much empirical data exists. Locals who have resided and conducted businesses in these areas before and after no-kill were unanimous in their acclamation of it as a source of economic benefit.

The Beaverkill is probably the best case study of any. This no-kill is now in its 25th. year. It has been expanded roughly fourfold since its inception, and has also been extended to included a major portion of the Beaverkill's main tributary, the Willowemoc Creek.

This author has fished the "Bea-Moc" since the mid-1950's. Quality, as defined earlier, declined to the extent that by 1962 I had almost totally given up going there. Fishing was almost exclusively for freshly stocked yearling trout from the state hatchery. Bait fishing, usually by spinning, was considerably more prevalent than fly fishing.

The Beaverkill and Willowemoc join at Roscoe, NY, a rural village with a population so small it doesn't appear in the Rand-McNally Atlas; something less than 1,000. There is no industry in the Roscoe area, and virtually no agriculture. At one time, lumbering and related operations brought some businesses and jobs into the region, but that had petered out by the turn of the century. So had the native brook trout, thanks to habitat degradation and over-fishing. This all but terminated a fairly lucrative tourist trade.

The introduction of the brown trout in the late 1800's recreated and enhanced that trade. The Beaverkill soon became the most famous trout river in the world, and anglers came from all over the country to fish there. This influx of outside money supported Roscoe and its environs for over half a century. During the depression years, locals were able to make a living tying flies, working in hotels and restaurants and otherwise catering to visiting anglers.

As indicated earlier, this fishery degenerated after World War II because of lethal angling technology and overharvesting. In an effort to restore it, the New York State Department Of Environmental Conservation elected to try no-kill as a management tool. The chronology is as follows:

<u>1965:</u> First no-kill established on the Beaverkill proper, approximately 2 miles. Bait fishing allowed.

<u>1969:</u> First no-kill established on the Willowemoc, initially 3 miles, later reduced by 1/2 mile because of problems with an uncooperative landowner.

<u>1972:</u> Beaverkill no-kill expanded by 1/2 mile. Bait fishing banned.

<u>1975:</u> Second Beaverkill no-kill section implemented, 1.6 miles.

<u>1986:</u> Second section expanded by .7 miles.

<u>1988:</u> Willowemoc no-kill expanded by approximately 1 mile.

In all cases, the sections of river covered by special regulations represent prime habitat. This is not fly-fishing-only; artificial lures are allowed, but rarely used. Outside of the no-kill sections, regulations permit killing five trout per day, and bait fishing is allowed.

This brings up an important point, specifically that the siting of no-kill sections has everything to do with their success. While absolutely-perfect habitat isn't a prequisite (which is fortunate because there's very little of that), the water chosen must be capable of carrying over trout for the regulations to be effective, and indeed, make sense.

It should be noted that the initial no-kill proposal brought screams of protest from many residents of the area. They felt they were being deprived of traditional "rights". Mostly, this was an emotional reaction, based on resentment of what was considered outside interference.

Based on glowing reports, I began to fish the area again in 1968. It was immediately apparent that a profound transition had taken place. There were at least as many anglers as before, perhaps more, but almost all were fly-fishers. This is significant in light of the fact that spin and even bait fishing were allowed at that time.

I had occasion to speak with the proprietor of the Antrim Lodge, a restaurant and hotel that has long been frequented by anglers. He had been strongly opposed to the no-kill at first, and argued against it. Now, his perception had changed dramatically, because of the beneficial effect on his business.

He told me that the new crop of anglers were mostly out-of-towners, and often stayed overnight, thus requiring food and lodging. They also tended not to be just weekenders, and were spending vacation time in the area. He expressed hope that the no-kill would be expanded, which it eventually was.

Subsequently, circa 1984, this individual was able to sell the Antrim to new owners for a most interesting sum. Business has continued to increase, especially the hotel part. Rooms that rented for as little as $2.00-$3.00 circa 1960 now rent for $50.00, and reservations far in advance are usually required.

Within the last few years, two new eating places have opened in Roscoe; a breakfast/lunch restaurant and a lunch/dinner restaurant. Both do very well during the six or seven months of good trout-fishing, and the respective proprietors speak in glowing terms of the no-kill.

Another hotel/restaurant proprietor, a former New Jersey law enforcement officer, built a small establishment circa 1970, to cater to fishermen and deer hunters, who invade the area for a few weeks in the fall. Vociferously anti-no-kill at first, he strongly opposed the implementation of the second, or "lower" no-kill, which affected his section of the river.

It was established anyway, and his attitude changed dramatically when business boomed. He built a new house and a large addition to the restaurant and motel. He was instrumental in getting reluctant landowners to go along with the 1986 expansion of the lower no-kill.

At the time of the initiation of the no-kill there was only one fly tackle shop in the area. It was a small family operation, run by a husband and wife in their home. Unfortunately, they have both passed away; certainly, they would have been able to provide interesting data on the effect of no-kill on their business. Meanwhile, two other shops have opened, and are apparently thriving. Also, the general store in Roscoe has put in a sizeable inventory of fly tackle.

I am aware that it sounds as though I am trying to build a case for fly fishing, per se, rather than no-kill. This is because, almost without exception, the flyfishers are the only ones who care about, demand, and economically and politically support quality angling, i.e., no-kill. Thus it seems that the case builds itself.

The no-kill has attracted new residents, and thus, outside money into the region. Some are weekenders who have purchased "second" homes, others have taken up permanent residence. One man of my acquaintance retired and moved to the area. He bought land and built a house, using local craftspeople. He also bought a second car from a local dealer, so as to have a fishing vehicle while his wife uses the family car.

Another gentleman who resides in Manhattan bought a waterfront cottage on the Beaverkill in 1973, for the sum of $12,000. Two years later, the second no-kill was established, and it included his water. He has spent about $40,000 renovating the cottage. Three years ago, I was witness to his declining an offer of $100,000 for the property.

Real Estate booms, such as that currently taking place in Roscoe, are a double-edged sword. Without stringent controls and constraints in the form of zoning, waste disposal laws and wild and scenic protection for the rivers themselves, that which created the bonanza can quickly and irreparably be destroyed. That may be happening in Roscoe at this time; we shall see.

I consulted with Mr. Robert Lambrigger, long-time Roscoe resident, business man, real estate agent and Chairman of the Chamber of Commerce. He emphasized the allure of the no-kill thusly; "Just count the anglers on any weekend within the no-kill and outside of it. No comparison". He went on to say that the community had realized significant benefits tax-wise. The new and remodeled houses owned by non-residents has expanded the tax base while placing little additional burden on such services as police and schools, as most of the owners are weekend and vacation residents only.

Thus it is clear that the great popularity of no-kill in this area has produced a "chain-effect" of economic benefits. The tackle stores are barely the tip of the iceberg. A listing of those businesses that realize major benefit includes gas stations and garages, restaurants, hotels and motels, local tradespeople, stores of various types, gift shops, places of entertainment, campgrounds, and as mentioned previously, property owners, real estate agents and the municipality itself.

So much for Roscoe and the Bea-Moc region. We now turn our attention to the midwest, and Michigan's famous Ausable. Perhaps the term "infamous" would be more appropriate, as the proposal of no-kill regulations for approximately 8 miles of the river's blue-ribbon center branch precipitated a brou-ha-ha which ended up in court. The end result is that the no-kill is now fact, as of the beginning of the 1989 trout season.

I have consulted with Mr. Rusty Gates, the proprietor of a lodge and restaurant that is situated on the river, in the heart of the special-regs section. He was one of the most active proponents of the no-kill, and put forth a great deal of effort in its behalf.

He reports the same highly emotional resistance among local residents as was encountered in Roscoe a quarter of a century ago; obviously, one area does not become enlightened through the experiences of another. He feels it will take a while for this to subside; at this point, people are still throwing dead suckers onto his lawn at night.

Mr. Gates reports that already a noticeable difference can be seen in fishing quality, which serves to disprove the opposition's claim that, "We all throw back our fish as it is". There was an early-season decline in fishing pressure, but that corrected itself as the season moved into May-June prime time. He observes that boat pressure, meaning guide boats, is down a bit. However, fly fishing guides who cater to quality-oriented anglers are reporting a brisk business. He reports that his lodge business is down slightly-about 5%-but the volume in his fly shop is up.

Mr. Gates observed that there has already been an increase in property values. The majority of the property owners along the river are non-residents. They are in favor of the no-kill, but not heavily so; the margin is about 55% for, 45% against. It will be interesting to see how this changes as owners enjoy the windfall benefits of property value enhancements.

An unfortunate side effect of the implementation of no-kill on the Ausable's center branch is the resultant inundation of the smaller, more fragile north branch by kill-oriented fishermen. The south branch of the Ausable, another top-quality resource, is partially protected by virtue of no-kill, flies-only regulations which were the conditions set by George Mason, former Chairman of the Board of American Motors, in his bequest of a large section of the river, which he owned, to the State of Michigan. It is hoped that the success of the no-kill on the center branch will create a strong case for following suit on the north branch in the near future.

It would be of great value if a tracking system could be put into operation immediately for the purpose of gathering "hard" data on the economic effects of this new no-kill from the very beginning. Given the superior quality of the resource, biological success should be spectacular. If quantifiable economic benefits accrue, this can become a landmark case for the establishment of no-kill elsewhere.

Now let's look at one of the Rocky Mountain's premier rivers, the Madison. This author has personal history to relate to there, also.

I first fished the Madison in 1968, spending a considerable amount of time in what is now the no-kill section. Even during Labor Day weekend, there was little fishing pressure; I and my partner had it pretty much to ourselves. However, the fishing was disappointing as to both size and numbers of trout. We also spent a couple of days in the Ennis area, and that was even less productive.

At just about that time, a study was done on the Madison to determine the effects of dumping hatchery trout into a river which had a population of naturally-propagated trout. This study, now considered landmark, demonstrated that this practice interfered with the welfare of the natural trout population and adversely affected the fishing quality of the river. Thus if became apparent that stocking, along with overkill, had contributed to the decline of the Madison.

A number of changes in regulations were eventually adopted, eventuating in the establishment of the no-kill, artificials-only section which is presently in effect from the Hebgen Dam downstream to Lyons Bridge, or about 10 miles of river. One need only show up on any reasonably-clement day from mid-June to mid-October to see the results. The place is getting fished very heavily. It is not unusual to see license plates from seven or eight states and Canada. At prime time, one can keep forty or fifty anglers in sight from the Wade Lake bridge alone. This is not always pleasant, but it is what's happening.

Incidentally, ample proof that the entrepreneurial spirit is not dead in America exists in the fact that the owner of the land adjacent to the Wade Lake bridge charges anglers $3.00 per day for parking, and $5.00 for prime spots on the old ranch property further downstream.

Three major campgrounds presently operate in this section of the Madison, and it is virtually impossible to obtain accommodations in any of them without reservations well in advance. Those who prefer to commute take rooms in West Yellowstone and use rental cars. Almost without exception, these anglers come from outside the immediate area, many from the east and west coasts. They must eat, sleep, have transportation, be entertained in the evening and be licensed and outfitted, which includes fishing supplies and often, guide services. The more perceptive ones also are aware that it would be most unpolitic to show up at home without suitable gifts from the wilds of the Rockies.

Records indicate a decline in angling utilization of about 40% in the first year of the no-kill. Obviously, some anglers only wanted to fish where the taking of trout was allowed. Subsequenty, this decline has been made up several-fold, and by anglers who are willing to spend on quality fishing.

A 1987 study conducted by American Sports Data indicates that about 11 million persons in the United States fly-fished at least once the previous year. There it is again-that method thing! Of these, 1.84 million fly-fished at least 25 times, and of those, 1.25 million said it was their favorite activity.

The 1.84 million "serious" anglers spent an average of $330.00 per year on tackle and $748.00 per year on trips and travel, averaging four overnights per season. These numbers are represented as being very conservative.

And I can attest to that. In 1988, I spent about $6000.00 on fly fishing trips, $1600.00 on tackle and $800.00 on angling-related photography, which included the purchase of a new camera. These are also conservative figures. This, on an income of about $30,000. The major reason I had to spend so much was to get to places where there was good fishing. Most of these places had a great deal of no-kill, all the way from the Beaverkill to Alaska. On my 1988 and 1989 visits to Montana, I spent about $300.00 just on rod fees for limited-access creeks, all of which are no-kill.

Am I that unusual? Not today; there are many thousands like me who spend that much and more. The interesting fact is that most anglers, while not exactly paupers, aren't overly affluent; it is not necessary to appeal to rich people to derive economic benefits from quality fishing. However, it is a fact that people with higher incomes and equal fervor spend proportionately on quality trout fishing. It would shock all of you if I told you what some of my more well-to-do companions spend on this sport, which I will refrain from doing, as their wives might accidentally get their hands on this paper.

While it was mentioned earlier that no-kill is not the only means for producing quality angling, I must state that I know of no resource where no-kill wasn't a success, given proper siting, introduction, enforcement and sufficient time. Still, local resistance to no-kill is encountered with each proposal. Why is this, and how can it be overcome?

The welfare of the fish is generally not much of an argument. For some reason, people who reside in prime fishing country seem to have little regard for their scaly neighbors.

The Canadian Atlantic salmon fishery is perhaps the foremost example of this. Everyone beat up on the salmon; commercial netters, poachers and anglers alike. By the early 1980's, the runs had been depleted to the point that it wasn't worth going to Canada to fish, and the American "sports" were staying away in droves. This important-in fact, essential source of external revenues all but dried up.

The upshot was a new and strict set of regulations governing Atlantic salmon. Most of the rivers were designated no-kill, except that a limited number of grilse could be kept by sport anglers. Commercial fishing in the bays was quickly phased out; the government bought up the nets. For the first time, poachers were aggressively apprehended and prosecuted, rather than heroized and laughed about.

The results have been spectacular; the salmon are back, and so are the anglers. The Atlantic Salmon Federation provides the following statistics; in 1985, only the third year of the new regulations, 54,000 anglers fished for salmon in the five Atlantic seaboard provinces. These anglers spent and invested $84 millions in their pursuits. Sport fishing accounted for 93% of the revenues while taking only 29% of the catch. The recreational fishery created 2090 person years of employment compared to 190 by the commercial fishery.

Yet the netters are pressuring the Canadian government to be allowed to resume their activities, even though they cannot compete price-wise with aquaculture-produced salmon from Norway, the United States and their own country. The battle never ends.

In closing, I offer one more point for consideration. Virtually all professionals in trout management are aware that artificial stocking operations involving hatcheries, delivery and so forth are costly. New York State ENCON reports that it costs them $2.20 to raise a pound of yearling brown trout. These fish are about 8 inches long and run four to the pound, or $.55 per fish. At a capture rate of 60%, that nets out at about $1.00 per trout.

These fish are stocked in very large numbers, with some rivers getting as many as sixty and seventy thousand per year. If no-kill regulations could affect the survival of significant numbers of these trout, stocking could be greatly reduced, with commensurate savings. The effect would be much more beneficial where natural propagation contributes significantly to the population.

In summary, it appears self-evident that no-kill is a most valuable, and in many cases, essential tool in managing for quality angling, and that the value far outweighs the temporary sociopolitical discomfort encountered at the local level. A strong case can be made for the establishment of no-kill sections across the United States by virtue of the economic windfalls experienced in the affected communities.

Apache Trout: Restoration with a Twist[1]

James N. Hanson and Robert E. David[2]

Cooperative efforts among the U.S. Fish and Wildlife Service, White Mountain Apache Tribe, and the Arizona Game and Fish Department have caused effective implementation of a unique program designed to delist the threatened Apache trout and allow cessation of all rainbow trout stockings within a major portion of the historic range of this species.

Apache trout, Oncorhynchus apache, (formerly Salmo apache) (Figure 1) occur only in the White Mountains and related drainages of east-central Arizona. These drainages include the Little Colorado, San Francisco, and Salt rivers (Figure 2). Although it was known that a native trout persisted in the White Mountains of Arizona as early as 1873 , it was not until 1972 that they were described (Harper, 1978). Apache trout have been variously classified as Colorado River cutthroat, Salmo pleuriticus, by Cope and Yarrow (1875), Salmo mykiss pleuriticus by Jordan and Everman (1891), Gila trout, Salmo gilae, by Miller (1950), and finally Arizona trout, Salmo apache, by Miller (1972) (USFWS, 1983). The common name Arizona trout was changed to Apache trout in 1980 and the scientific name Salmo apache, is proposed for change to Oncorhynchus apache in accordance with the American Fisheries Society (Robins et. al. 1980; Smith and Stearley 1989).

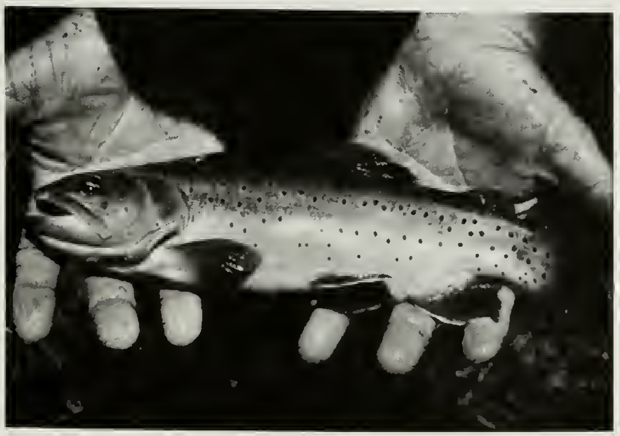


Figure 1.--Wild Apache trout, Oncorhychus apache, from East Fork of the Whiteriver, Fort Apache Indian Reservation, Apache County, Arizona.

The causes of decline of Apache trout are similar to those of many southwestern native fish species. Introduction of exotic fishes to increase recreational opportunities has resulted in extirpation or reduction in their population sizes and distribution through hybridization, competition for food and space, and depredation. Habitat destruction an alternation caused by agriculture, timber harvest, mining, recreation, livestock usage, and housing has changed former native fish habitats significantly. Many of these aquatic systems can no longer support salmonid species.

The plight of the Apache trout was known to the White Mountain Apache Tribe, the Arizona Game and Fish Department, and the Department of the Interior (USFWS and BIA) long before the fish was officially recognized as a distinct species. The White Mountain Apache Tribe was the first to act and in 1964, they adopted a management plan for the species (USFWS, 1983). The Tribal plan called for the reclamation of streams and for the construction of fish barriers and lakes for the introduction and protection of Apache trout. This led to the construction of Christmas Tree Lake; the first impoundment built expressly for Apache trout. The result of this early recovery work earned the Tribe the U.S. Department of the Interior Conservation Service Award in 1969.

Apache trout were listed as endangered under the Endangered Species Conservation Act of 1969 and this status was strengthened with the passage of the Endangered Species Act of 1973 (P.L. 93-205).

---

[1]Paper presented at the Wild Trout IV Symposium [Yellowstone National Park, Wyoming, September 18-20, 1989]

[2]James N. Hanson, Fishery Management Biologist, U.S. Fish & Wildlife Service, Pinetop Fishery Assistance Office, Pinetop, Arizona; Robert E. David, Assistant Project Leader, U.S. Fish & Wildlife Service, Alchesay-Williams Creek National Fish Hatchery, Whiteriver, Arizona.

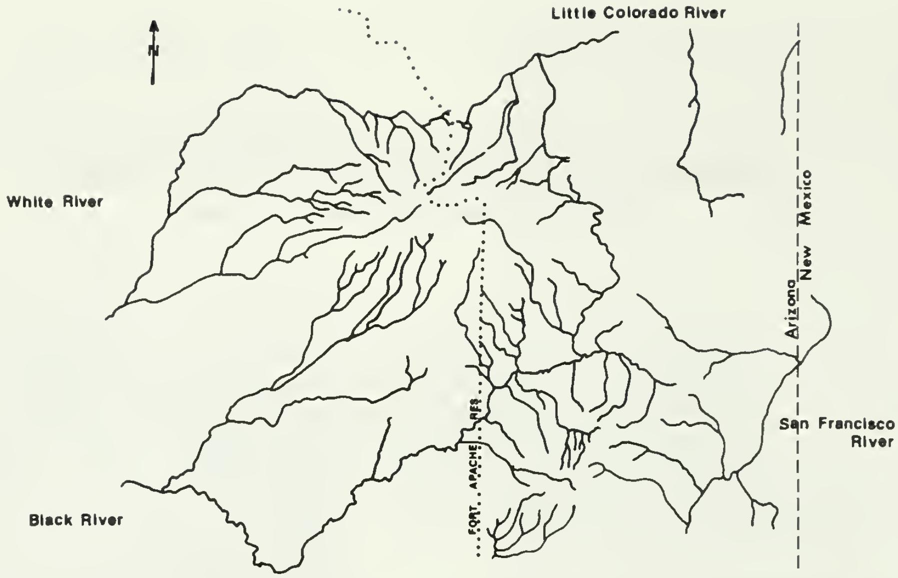


Figure 2.--Drainage Map of the White Mountains, Arizona (reprinted from Apache (Arizona) Trout Recovery Plan, 1983).

All waters in Arizona were closed to fishing for Apache trout in 1974. The Arizona (Apache) Trout recovery team was formed in 1975 and at this time the species was downlisted to threatened where it remains today. Some waters were then opened to the angling public on a restricted take basis.

The listing of Apache trout as a threatened species began the modern era for recovery of this native fish. Cooperative efforts among the White Mountain Apache Tribe, U.S. Fish and Wildlife Service, U.S. Forest Service, and the Arizona Game and Fish Department allowed effective implementation of the newly approved Apache (Arizona) Trout Recovery Plan (1979). The goal of this plan was to have, minimally, thirty pure, self-sustaining populations of Apache trout prior to delisting. To date there have been sixteen fish barriers established to exclude nonnative fish from Apache trout streams and three impoundments dedicated to Apache trout restoration. Plans to add ten more streams with barrier protection have been made. These areas, along with seven streams known to have natural barriers, will total thirty three sites that will provide Apache trout protection from nonnative salmonids.

The problem of recovery is now twofold. Although barriers have been established, some streams have been previously invaded by brown and/or brook trout. These species must be eliminated before a stream can be added to the pure, self-sustaining list. A second problem is that the genetic purity of present populations of Apache trout has never been determined. In 1988 and 1989, the U.S. Fish and Wildlife Service, Pinetop Fishery Assistance Office, collected specimens of fish from all streams thought to contain Apache trout. These specimens have been sent to Genean Laboratory in Smithville, Texas for electrophoretic analysis. To better understand what constitutes a "pure" Apache trout, rainbow and cutthroat trout genetics will be considered, as well as baseline data from rainbow x Apache hybrids that were spawned at Williams Creek National Fish Hatchery. Once the genetic status of each population is determined, it can decide whether a population must be eliminated and replaced with "pure" fish or can be saved and considered as one of the thirty populations needed for delisting.

In 1989, the Pinetop Fishery Assistance Office (FWS) completed the Apache Trout Implementation Plan. This Plan is meant to compliment the Apache (Arizona) Trout Recovery Plan by listing current status of "critical" waters (ie: those necessary for species recovery) and the steps necessary for recovery prior to delisting. The Implementation Plan also outlines a sport fishing program designed for "enhancement" populations of Apache trout. Enhancement populations are those populations created by stocking hatchery produced and reared Apache trout into streams and impoundments to provide a sport fishery.

In keeping with their long term concern and commitment for this native salmonid, the White Mountain Apache Tribe has agreed to let the U.S. Fish and Wildlife Service use Apache trout reared at the Alchesay-Williams Creek National Fish Hatchery to replace all rainbow trout stocking within the native range of the species on the Reservation. This is an unprecedented effort to allow a depleted native species every opportunity to recover.

Apache trout management has been directed toward providing the angling public with a unique fishing experience. On the Fort Apache Indian Reservation the angler pays $15.00 per day to visit Christmas

Tree or Hurricane Lakes to both fish for the Apache trout and to enjoy the solitude and beauty of these remote areas. Each lake is limited to 20 anglers per day. Take is limited to two (2) Apache trout 14 inches or longer using artificial flies or lures. It is not uncommon for anglers to catch and release 30-50 trout per day. This program is popular with a wide range of fishermen; permits are frequently sold out. Increased fishing pressure on Arizona's limited aquatic habitat will undoubtably result in more Apache trout waters of the Reservation being converted to quality status.

With increased hatchery production, both catchable and subcatchable programs will be expanded to replace rainbow trout in the stocking schedule. This will allow the everyday angler the opportunity to catch an Apache trout at a variety of locations and at normal Reservation fishing fees.

The U.S. Fish and Wildlife Service will continue to raise and stock both brook and brown trout on the Fort Apache Indian Reservation to provide a variety of angling experiences; however, none will be stocked in critical waters reserved for the Apache trout.

The concept of substituting hatchery reared, native Apache trout for previously stocked rainbow trout is simple in theory and seems a perfect solution to avoid future contamination of historical and restored populations. The idea, however, is not a new one. The original intent of Williams Creek National Fish Hatchery in 1942, almost 50 years ago, was to produce Apache trout for distribution in Reservation and State waters. The difficulties in culturing a wild species quickly gave way to the ease in obtaining eyed eggs from domestic species such as the rainbow, brown, brook, and cutthroat trouts. The program was abandoned almost before it was started. The concept was resurrected in the 1960's by the State of Arizona through efforts by personnel at Sterling Springs State Fish Hatchery. Again, difficulty arising from poor survival caused the program to be discontinued.

In response to a request from the Apache (Arizona) Trout Recovery Team, the U.S. Fish & Wildlife Service agreed to initiate research involving artificial propagation of Apache trout at their Williams Creek National Fish Hatchery. During June, 1983, wild Apache trout were spawned, on site, from the East Fork of the White River, the type locality used by Miller (1972) in describing the species. Out of 2,715 eggs collected, only 240 survived as 2-inch fingerlings. During May, 1984, wild Apache trout were again spawned from the same location. Out of 1,869 eggs collected, 1,346 survived to eye-up and 1,204 fry were hatched. These fry were used to conduct feed and equipment trials using fresh brine shrimp, frozen krill, semi-moist feed, and other larval diets introduced by pumps and vibrating feeders controlled by programmable timers. These trials resulted in the production of 704 two-inch fingerlings.

From the 240 fingerlings produced with eggs collected in 1983, 88 fish survived to sexual maturity at age three. These trout had been held inside at a constant water temperature, the effects of which apparently altered spawning times from that observed in wild populations. Wild spawning dates of May and June were preceeded by a spawning period extending from mid-February through April. Progeny resulting from this initial spawning of captive-reared Apache trout established the 1986 year-class, consisting of 1,200 trout to be used as future broodstock. Improved survival of fingerlings produced from wild eggs collected in 1984 resulted in the availability of 600 broodstock from this year class.

With larger numbers of broodstock on hand, the program was shifting from initial research to production. Problems with initial feeding had been substantially reduced through the use of highly palatable, semi-moist diets introduced by automatic feeders.

Another problem involved the loss of postspawn male broodstock due to Saprolegnia fungus infections. Initial plans included the use of both sexes of trout for spawning at age three. Fighting among three-year-old males coupled with an apparent lowering of disease resistance during spawning resulted in losses exceeding 50 percent. Chemical treatment using malachite green under permit was effective, but costly measures were necessary to treat the resulting hatchery effluent. In addition, treated fish could not be released later for sportfishing. The problem was solved by the use of two-year-old males. Under hatchery conditions, approximately 70 percent of broodstock males reach maturity at age two; however, milt production is low. Milt collection by aspiration combined with quality checks to verify motility has enabled the use of younger, less aggressive males that are not subject to fungus infections. Annual spawning programs now involve the use of age two males with age three and four females. Males are spawned once and then stocked at a length of approximately 12 to 14 inches. Females are retained through age four and then released into Reservation waters at a length of 16 to 24 inches and a weight from 2 to 5 pounds. Stocking of broodstock represents an important component in the development of a trophy fishery designed to gain sportsman acceptance of the native trout program.

The 1987 spawning season produced the first hatchery reared Apache trout for restoration efforts. Of the nearly 23,000 advanced fingerlings produced, over 17,000 were stocked into lakes and streams on Reservation and Forest Service lands. Six thousand trout were retained as broodstock.

Completion of a new tankhouse in 1987 at the Williams Creek National Fish Hatchery provided a facility designed solely for the hatching and rearing of Apache trout. The building isolates Apache trout production from other hatchery programs, assuring purity of those stocks reserved for restoration work. In addition, laboratory facilities offer opportunities for continued research directed towards refining captive rearing techniques.

Program expansion in 1988 led to the collection of over 180,000 eggs from Apache trout broodstock. An eye-up of 39 percent experienced in 1987 was increased to 65 percent. Eyed eggs totaling 117,000 produced over 90,000 three-inch fingerlings for a survival rate of nearly 77 percent. Fingerlings and subcatchable Apache trout were stocked in both restoration and enhancement programs on Reservation and Forest Service lands. For the first time, Apache trout were stocked into waters containing populations of rainbow trout in initiation of a program designed to replace this species by attrition.

Planning continued and agreements were reached to increase production of Apache trout with an overall goal of complete replacement of rainbow trout within the boundaries of the Fort Apache Indian Reservation. Previous stocking on the 1.7 million acre reservation involved four stream systems totaling 45 miles and 22 impoundments totaling over 2000 surface acres. Rainbow trout programs required the production and distribution of 219,000 subcatchable (6-inch) and 257,000 catchable (8-inch) fish. By 1991 all rainbow schedules will be replaced with a program involving 478,000 Apache trout stocked at three, eight, twelve, and sixteen inches in length. In addition, fingerling Apache trout will also be made available to support other recovery team restoration efforts to delist the species.

Concern for the insured integrity of the gene pool in the East Fork of the White River and consequent hatchery broodstock led to the establishment of programs to monitor genetic drift in successive year-classes of hatchery-reared trout. Initial characterization of the wild East Fork population utilizing starch-gel electrophoresis revealed a very homozygous genotype. This was to be expected from a relatively small, isolated population. Continued efforts by the Pinetop Fishery Assistance Office to monitor the purity of other natural populations of Apache trout using electrophoresis will also assist in hatchery production. Historical populations characterized as "pure" Apache trout, yet displaying polymorphism not exhibited by the East Fork population will be considered for future infusion of genetic material into hatchery stock. Considering the lack of diversity in the East Fork strain, it is hoped that this may help to increase the adaptability of this species to various aquatic habitats and environmental conditions inherent among waters on the Reservation.

Production goals of 266,000 Apache trout in 1989 required nearly four times the fish produced in 1988. Over 500,000 eggs were spawned with a resulting eye-up of 62 percent. A normal hatch was followed by the beginning of what may be interpreted as a resistance of a wild population to mass culture. Two distinct disease syndromes were experienced that produced mortalities from 25 percent to 52 percent in all rearing units. Although work is in progress to identify suspected pathogens and evaluate treatments, no exact cause has been determined.

To date, approximately 190,000 fingerlings remain. Additional losses prior to stocking are likely to account for a shortage of nearly 80,000 fingerlings required to meet this years production goal.

Although mortalities experienced during the 1989 rearing season have not significantly altered future rearing plans, there is some concern over the uncontrolled "selection" that hatchery rearing imposes on species such as the Apache trout. To ensure the continued success of the program, a balance will have to be reached between development of broodstock resistant to diseases caused by unnatural conditions and maintenance of the genetic integrity of the species.

LITERATURE CITED

Harper, K. C. 1978. Biology of a southwestern salmonid, Salmo apache (Miller 1972). Proc. Wild Trout-Catchable Trout Symp. 99-111. Oregon Dept. Fish and Game, Eugene.

Miller R. R. 1972. Classification of the native trouts of Arizona with the description of a new species, Salmo apache. Copeia, 1972: 401-422.

Robins, C. R., Bailey, R. M., Bond, C. F., Brooker, J. R., Lachner, E. A., Lea, R. N., and Scott, N. E., 1980. A list of common and scientific names from the United States and Canada, Fouth Edition Am. Fish. Soc. Spec. Publ., No. 12, p. 174.

Smith, J. E. and Stearley, R. F. 1989. Classification and scientific names of Rainbow and Cutthroat Trout, Fisheries, Vol. 14, No. 1, pp. 4-10.

U.S. Fish & Wildlife Service 1983. Arizona Trout Recovery Team, Albuquerque, NM.

Flowing Water, Stream Form, and Trout: Interactions and Implications for Research and Management[1]

Burchard H. Heede[2] and John N. Rinne[3]

Abstract.--The disciplines of hydrology, fluvial morphology, and fisheries have developed separately. Functionally, they have largely remained that way. There is a need for land managers and researchers to bridge the gaps between these disciplines in order to improve our understanding of their (1) complex interactions, and (2) implications for management of our valuable salmonid fishery resource.

INTRODUCTION

Fishery biologists have focused their research and management activities not only on the effects of deterioration of habitat, but also on how to improve these habitats (Duff and Banks 1988, Rinne and Turner, in press). Platts and Rinne (1985) suggested that, despite much stream improvement activity in the Rocky Mountain region, there has not been sufficient research to verify the benefits of these projects. Inconsistent results in fisheries response to stream habitat improvement projects substantiate the need to increase our knowledge in this area.

The purpose of this paper is to attempt to help fishery biologists better understand and use the sciences of hydrology and fluvial morphology: how flowing water and the physical attributes of the stream constraining it affect trout. It is our intention to help both researchers and land managers involved in smaller, headwater projects assess both natural (drought, fire) and man-induced (grazing, timber harvest, recreation) influences on salmonid habitats. This knowledge may then help prevent research approaches or management activities that are not hydrodynamically or morphologically sound. To do this, we will show how some physical parameters interact to influence stream habitat and, in turn, salmonid populations.

SALMONID HABITAT EVALUATION AND IMPROVEMENT

The literature on salmonid habitat evaluation and improvement has substantially increased since the 1970s, reflecting increased concern for this valuable resource. Limited space does not allow us to deal with it in detail here. Hence, only a few important aspects will be discussed.

Researchers and land managers should be aware that stream processes, aside from catastrophic events (e.g., floods, landslides, wildfires) are most often slow and subtle. Therefore, valid, reliable evaluation of improvement work must be continued for many (10-20+) years (Rinne 1985, Heede 1986). Modern awareness of environmental quality has precipitated many lawsuits over stream improvement projects. Legal activities may result in replanning accompanied by fish and wildlife inputs (Coffey 1982). Further, engineers also have began to show interest in the design of habitat improvement structures (Shields 1983). Emerging is the much needed team approach for stream habitat improvement projects as was suggested by Rinne (1981a). Platts (1976) also presents an excellent discussion of the need for an interdisciplinary approach to solving streamflow problems.

DYNAMIC ENVIRONMENTS: RESEARCH IMPLICATIONS

At the outset, it must be stressed that flowing streams are dynamic systems; change is the rule. Once typically slow and subtle processes reach a threshold, rapid developments lead to dramatic changes, changes that to the casual observer have no obvious reason because of

---

[1]Paper presented at the Wild Trout IV Symposium. [Yellowstone National Park, Wyo., September 18-19, 1989].
[2]Burchard H. Heede is Research Hydrologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Arizona State University Campus, Tempe, Ariz.
[3]John N. Rinne is Fisheries Research Biologist, Rocky Mountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Arizona State University Campus, Tempe, Ariz.

the lack of an outstanding disturbance event. For example, consistent undercutting of a streambank by low or moderate flows ultimately leads to a scour depth that cannot support the upper bank; sudden collapse results. Unfortunately, we in the fields of geomorphology and fisheries are yet a long way from delineating when these threshold values occur.

In a longer term (5+ years) research (or management) activity it is important to recognize the stability of a stream system. Some systems may have attained a condition of dynamic equilibrium that signifies fast adjustments toward a new equilibrium, if one or more variables change. Others are in disequilibrium (Heede 1981), and finally for others, the equilibrium concept is not meaningful, such as a stream flowing through an environment of inherent instability.

Bovee (1982) stressed the importance of first evaluating and delineating equilibrium of a stream channel before imposing improvements on it. Dynamic disequilibrium could render futile proposed improvements such as instream and streambank structures. Because each stream may be unique, Bovee (1982) did not suggest any cookbook guidelines to stream improvement relative to stream equilibrium.

Dynamic equilibrium does not imply steady state! Study of a stream over some span of time may reveal that although initially classified in dynamic equilibrium, it may not be the same at completion of the study. This aspect of change makes some investigations relying on long-term calibration difficult because of possible datum line loss. In contrast, process studies because they do not rely on comparative (empirical) investigations, do not have this weakness.

HYDRODYNAMIC INFLUENCES

Water Viscosity

Hydrodynamic variables can help to quantitatively define waterflow characteristics. In turn, waterflow variables reveal the detailed processes so important to suspended sediment transport, bedload movement, and scour--all of which may positively or negatively affect the quality of salmonid habitat. Water viscosity has its strongest effect on salmonid habitat through its influence on sediment transport. Viscosity can be envisioned as friction within the water. It is inversely related to temperature and tables exist relating temperature and viscosity (King 1954). The higher the absolute viscosity, the greater the sediment transporting capacity of the waters.

In a laboratory experiment, Colby (1964) decreased the water temperature in a flume from 26.7 C to 4.4 C. Because of the resulting increase in viscosity, sediment discharge (sand characteristic of rivers, 0.125 to 0.250 mm) increased 254%. Although the experimental temperature change may be unrealistic in natural systems, it illustrates the relationship between water temperature and viscosity and sediment transport. Perhaps it is more than coincidence that salmonids normally spawn during periods of cooler water temperatures. It may be advantageous for salmonids to spawn during increased sediment transport which may occur during seasonal (vernal and autumnal) periods of increased runoff. Cooler waters would facilitate greater sediment transport than deposition, and reduce fine sediment loading of gravels cleaned by spawning salmonids.

Another type of viscosity is the kinematic viscosity, obtained by dividing the absolute viscosity by the water density. Because density is also related to temperature, tables give kinematic viscosity values. Knowledge of this type of viscosity is required for the delineation of flow regime, as will be shown later. Thus, if flow regime must be quantified, kinematic viscosity could be important to habitat evaluation for salmonids.

A third type is apparent viscosity, which depends on the grain sizes in the suspended sediment load. If this load consists mainly of fines (silts and clays, < 0.0625 mm; Hynes 1972), often called the wash load, the internal shear of the flow is increased and much larger particles can be transported than in flows without wash load. High concentrations of fine sediments may lead to overloading of substrate materials. That is, the sediment transporting capacity becomes insufficient to move the material through the reach (Rinne, in press), and streambed aggradations may result and impact a salmonid fishery (Rinne and Medina, in press; Rinne, in press).

Flow Velocity

Flow velocity is another important factor for creating and sustaining fish habitat. Binns and Eisermann (1979) reported this variable as important in delimiting biomass of salmonids in Wyoming streams. When making measurements, it must be recognized that flow velocity is a vector force; it has direction. Because most natural streams are characterized by turbulent flow, the directions of individual flow lines change almost constantly. These changes may influence not only velocity measurements, but also the size and location of low pressure areas, such as downstream from boulders or other flow obstructions. Low pressure areas not only induce sediment depositions of grain sizes smaller than the average load (fig. 1), but also create resting and breeding sites for fishes.

The main importance of velocity to fisheries is undoubtedly the work performed in creating or destroying habitat. Well known are "shooting

Figure 1.--Looking upstream onto the bed of Woods Canyon Creek, Coconino Plateau, Arizona. Streamflow is ephemeral and may reach peaks of 140 cubic meters per second during spring snowmelt. Note deposition of fines downstream from rock with camera lens case and rock with arrow. The fines ranged between small gravel and silt.

flows" that, because of their high velocities, can attain great erosive power. Such power may create uplift forces greater than instream habitat improvement structures could resist. Accordingly, structures should not be planned or installed for reaches of stream with shooting flows.

Velocity also affects the abundance and diversity of aquatic fauna in total. Such information could provide an important predictive tool for assessing the impact of flow modifications to streams.

Flow Regime

Flow is seldom laminar in streams, because of bottom roughness and bends. In laminar flow, the stream lines appear to divide the entire region of flow into an orderly series of fluid laminae.

In contrast, turbulent flow creates a complicated pattern of eddies, and energy dissipation is high due to continuous interchange of finite masses of fluid.

A dimensionless parameter describing flow characteristics is the Froude number (Fr), which relates the inertial to the gravitational forces. If $Fr < 1$, flow is subcritical, while at $Fr > 1$, the flow is supercritical. Critical flow, at $Fr = 1$, seldom exists in natural channels and if so, only briefly. Subcritical flow is the dominant flow regime of natural streams. Thus, in most cases, the fishery biologist will encounter turbulent subcritical flow as the dominant flow characteristic of fish habitat.

Although less frequent, supercritical (shooting) flow may play a special role for maintaining good fish habitat. Its great erosive power potentially has beneficial effects, such as cleaning gravel deposits of fine sediment on riffles that provide spawning beds and downstream movement of young-of-year fish. On the other hand, shooting flows may be destructive to channel improvements or could sweep away young fish.

Space selection by fish relative to the current is also based on space-food relationships (Chapman 1966). Amount of invertebrate drift or food supply can affect salmonid territory size as has been shown for juvenile coho salmon (Oncorhynchus kisutch) (Dill et al. 1981). Less current velocity and food effectively enlarges territory sizes, and if sustained could thereby reduce standing stocks of salmonids.

Flow Resistance

Gravel-bed streams are of special importance to salmonid fisheries because they are often used for spawning, and provide habitat for aquatic organisms. In gravel-bed and boulder-strewn streams, Darcy-Weisbach's friction factor (f) or Manning's roughness coefficient (n) are not meaningful parameters to express channel roughness. These parameters, developed in sand-bed streams, measure the resistance to flow exerted by channel bed and banks. The friction factor (f) is related to flow depth, slope, and velocity, Manning's (n) to the hydraulic radius (cross section of flow divided by the wetted perimeter), slope, and velocity. These factors are averages for a given stream reach and cross section and most likely are not meaningful for a specific habitat preference of a fish.

At the current stage of the science of hydraulics, no useful parameter for roughness of flow has been defined for gravel and boulder streams. The ultimate goal of future investigations should be to find a workable flow resistance coefficient that considers the variability of flow characteristics in the cross section. Such a coefficient could possibly be used to delineate between locations of preference or rejection of stream habitat preferred by fishes.

Sediment Transport

Because sediment is generally a constituent of water flow, analyses of salmonid habitat can not neglect sediment processes. Sediment not only influences habitat quality for the existing fish population, but also future generations, because spawning activities and egg development are directly dependent on bed material characteristics. Changes induced by sedimentation may also interfere with food production.

Stream habitat in the South Fork of the Salmon River, Idaho deteriorated following a 15-year period of intensive logging and road building and a 10-year period of extensive flooding. Platts and Megahan (1975) and Megahan et al. (1980) described the natural improvement of the South Fork after a moratorium on logging and road building was instituted. Sand content of the streambed decreased dramatically, gravel-cobble substrate increased, and bed elevation decreased, all indicating the natural cleansing process in absence of excessive inputs of sands resulting from the management activities on the watershed.

The design of any habitat improvement should recognize the ongoing physical processes in a river or stream and, ideally, should work with the processes, not against them. Generally, this approach is less costly and leads to more frequent and more rapid success. An example would be the placement of logs or other gradient control structures into an aggrading stream to enhance aggradation upstream from the installations and cause pool development below them. The flow would be stepped down over the structures.

This stepping-down of flows by logs was studied by Heede (1972). He found that streamside forests, if not managed to remove timber (Bilby and Wasserman 1989), provide a constant supply of dead and dying trees to first- and second-order streams. The fallen trees will be incorporated into the stream hydraulics, forming log steps that supplement existing transverse gravel bars (fig. 2). Transverse bars are built by bedload movement. Thus, bedload transport is decreased by log steps. The spacing between the log steps was related to the channel gradient--spacing decreased with increasing gradient. Bilby (1984) demonstrated that removal of naturally occurring woody debris affected stream stability.

Artificial instream improvement structures are an attempt to create what nature normally provides if adequate riparian woody material is available (fig. 3). But Rinne (1982) cautioned against general application of log stream improvement structures in streams in the Southwest. The endangered Gila trout, Oncorhynchus gilae, was restricted in upstream movement by structures greater than 1 m in height. In one stream, Main Diamond Creek, overpopulation and stunting of this endangered trout has been attributed to excessive structure placement in the 1930s by the Civilian Conservation Corp (Nankervis 1988).

Bed Forms

The previous section illustrated that bedload movement led to the formation of bed forms. High transport rates may lead to sediment overloads and obliterate important habitat for salmonids such as pools (Bilby 1984). However, high transport may also add to habitat quality by cleaning spawning gravels and increasing riffle areas. In another montane stream, bedload transport decreased the formation of transverse gravel bars. The examples showed that bed forms are not only sediment structures, but are also actively participating in the stream's hydraulic functioning as will be discussed below.

Bed forms of gravel-bed streams, such as bars, are very little understood, and we have only recently begun to study them. Unfortunately, this stream type is of greatest importance to salmonid fisheries.

Coarse sediment supply to the channel appears to be, at least in part, responsible for the establishment of certain bar forms. The occurrence of these forms in a more or less orderly sequence, such as the pool-riffle sequence, expresses stability in many gravel-bed streams. This reasoning is based on the fact that bars develop on stable riffles.

Figure 2.--Rucker Canyon Creek is a typical high mountain stream with boulder bed. Note the formation of two gravel-boulder transverse bars at arrows. Often, as in this case, large boulders at the banks anchor the bar.

Figure 3.--Log stream improve structures such as this shown on McKnight Creek, New Mexico were first installed in the West in the 1930s by Civilian Conservation Corps workers.

At high flows, the coarsest particles that can be moved will be readily transported through the pools and deposited at the riffles, keeping the pools scoured. At low flows, sand may accumulate in the pools, but will be scoured out at higher flows, and the riffles remain stable.

FLUVIAL MORPHOLOGY: UNDERSTANDING STREAM FORM

An understanding of morphologic processes is important to anticipate future channel developments. When considering stream morphologic variables, it must be recognized that interdependency is stronger than independency, and that morphologic interactions, leading to channel adjustments, may be caused by changes that started far from where the adjustment occurs. It is also important to realize that different processes may cause the identical results. Nevertheless, anticipated changes should be the framework on which to base fishery management practices.

Local Base Level

The concept of local base level is critical for stream habitat inventories. Indicators based on the concept, easily recognizable in the field, denote type of stream equilibrium. Equilibrium condition, in turn, indicates future erosion rates and channel developments.

Although water flows downhill, some interactions caused by local base level changes are stronger in the upstream direction. Geomorphologists call the elevation of a given point the local base level. The ultimate base level is represented by the oceans, and a local base level is a selected location to which other locations are related. For example, the mouth of a river is the local base level for the upstream mainstream reaches and their tributaries, or the mouth of a tributary may be selected as the base level for all other points in the tributary.

If the mouth of a stream is cut down, the rest of the stream and its tributaries will adjust to this change by degradation of the bed. Degradation advances upstream by headward progression of knickpoints. A knickpoint is a break in bed slope gradient, and has the appearance of a gully headcut, located at the upstream end of a discontinuous gully. Knickpoints indicate channel instability, and a stream is in dynamic disequilibrium if numerous knickpoints exist. The scour hole that forms below the knickpoint is usually beneficial for fish, but in extreme cases knickpoints may be barriers to fish movement.

Slope adjustment by the chain reaction of degradation from reach to reach and into tributaries will stop once a new equilibrium slope has been established. Equilibrium slope is attained when the actual sediment load equals the equilibrium sediment load, or in other words, when the incoming sediment equals the sediment load leaving the stream or a reach.

Downcutting of a channel due to loss of the original local base level can be effectively stopped by installation of gradient control structures (dams for example). Literature on design, spacing, and other construction criteria is available. (USDI Bureau of Reclamation 1974, Heede 1965, 1966, 1976). The basic design approach should be to replace the stepped longitudinal profile of the stream, caused by knickpoints, with one caused by artificial structures.

Aggradation of a stream due to a raise of the local base level is not an infrequent event. If a tributary carries very high sediment loads into a master stream that is already carrying its equilibrium load, the tributary sediment will be deposited at the stream junction. The formation of an alluvial fan or cone signifies such a situation. But there is a limit, because the deposition gradient is always less than the original channel gradient; thus, in contrast to degradation, aggradation will not proceed throughout the system.

Banks

Banks can be an abundant source of sediment. Because there are many causes for bank instability, intricate processes may be at work whose original causes are often far removed from the damaged locations.

Degradation and aggradation are only some of the adjustment processes in streams. Even more common is channel meandering, the cutting of alternating opposite banks. Like degradation, it leads to decreased channel gradients, because stream length is increased. Meanders commonly lead to formation of pools and cover in the form of undercut banks. Both of these habitat features are generally beneficial to fishes and especially to salmon and trouts.

Unfortunately, there have been only a few studies on quantitative relationships between bank characteristics and erosion potentials. However, fishery biologists do know that streamside trees and large brush (fig. 4) are beneficial to salmonid populations (Boussu 1954, Brown and Krygier 1970, Rinne 1988). Hence management of streamside vegetation could have a beneficial dual effects: enhancement of fish habitat by providing shade and reduced water temperatures (Burton and Likens 1973), as well as resting places, increased inputs of terrestrial food (Meehan et al. 1977), decreased sediment loads, increased cover, and increased bank stability (Patterson 1976; Rinne 1988). Rinne (1978) suggested a "meander factor," which reflects stream cover, volume of water and simple linear distance, may be a more sensitive indicator of trout populations in streams than pool-riffle ratios.

Figure 4.--Presence of streamside vegetation (alder-willow) on the Rio de las Vacas, New Mexico provides cover, regulation of stream water temperature, bank stability, and entrapment structure for woody debris.

Pools and Riffles

Both pools and riffles are part of the hydraulic geometry of the stream, and tend to occur at intervals of five to seven times the channel width. Pools have been demonstrated to be very important for the survival of one endangered southwestern trout in headwater streams in New Mexico (Rinne 1978, 1981b). Riffles form in the transition zone between bends, while pools are located at the concave (outside) bank in the bend. Pools and riffles are not restricted to meandering channels, but are also found in straight reaches. This is because alternating bars, typical for many straight stream sections, force the thalweg into a meander course (Heede 1980). Pools and pool-riffle ratios have long been considered by fisheries biologists to be important to salmonid habitat quality (Bisson et al. 1981, Binns 1982, Osgood and Barber 1982, Platts et al. 1983, 1987). However, Rinne (1978) suggested it is more the structure (or quality) of the pool than the linear distance as reflected in pool-riffle ratios that delimited Gila trout populations in headwater streams in New Mexico.

Flow over riffles is supercritical; in pools it is subcritical. At high stage, pools located at the concave bank of meanders may be scoured and the material deposited at the next downstream convex bank. At low stage, however, the riffles experience scour and the pools deposition. Normally, bed particle sizes in riffles are larger than those in pools. At or close to flood stage (bankfull stage), however, because of greatly increased transport capability, larger material may be deposited in the pools. At low stage, due to turbulent water over riffles, more transport occurs from riffles than pools, resulting in a coarse material cover on the riffles and fines in the pools.

In addition to spawning habitat, the larger-sized material in riffles provides the primary food producing areas for salmonids. These dynamics suggest that all descriptions of pool and riffles should be made at some base level flow, such as summer low flow. Otherwise stage can become an uncontrollable variable.

The interaction between flow regime, sediment transport, and bedform demonstrates how intricately interwoven the individual hydrologic processes are and how damaging human interference can be. If a stream is in dynamic equilibrium, don't interfere! For disequilibrium conditions, interference should be considered only if the causes for the present state of the stream are clear, and future developments can be projected.

CONCLUSIONS AND RECOMMENDATIONS

The disciplines of hydrology, fluvial morphology, and fisheries have, for the most part, developed separately. However, the functioning and interactions of the former two dictate the habitat and its quality for the latter. Some parameters appear to be more relevant in determining salmonid habitat than others, in part, perhaps because of our current level of understanding of them. Nevertheless, all factors interact to produce conditions either beneficial or detrimental to salmon and trouts. We have discussed some selected variables of streamflow, sediment transport, and channel morphology as examples of important factors that influence salmonid habitat. Also, some examples of habitat improvement were discussed. Our objective was to alert both the researcher and land manager to the intricate relationships between all variables, and to the fact that disturbance of dynamic equilibrium will cause changes of one, some, or all variables.

Immediately or ultimately, the results of both naturally occurring and human-induced changes in stream habitat may be detrimental or beneficial to fishes. Characteristics of salmonid fish habitat must be modified with great care, and then only if (1) the causes for an undesirable condition are known, and (2) the measures will be compatible with future stream development. In such an evaluation of salmonid habitats, the inclusion of hydrodynamic and fluvial morphologic (stream form) variables should prove useful and, conceivably, enable more precise quantification of habitat characteristics in the future. Fishery research based on such variables will not only benefit the field of fish management, but also that of the fluvial geomorphologist.

LITERATURE CITED

Bilby, R. E. 1984. Removal of woody debris may affect stream channel stability. Journal of Forestry 82:609-613.

Bilby, Robert E., and Lawrence J. Wasserman. 1989. Forest practices and riparian management in Washington State: data based regulation development. p. 87-94. In Robert E. Gresswell, Bruce A. Barton, and Jeffrey L. Kershner, eds. Practical approaches to riparian resource management: An education workshop. [Billings, Mont., May 8-11, 1989] USDI Bureau of Land Management, Billings, Mont.

Binns, N. A. 1982. Habitat quality index procedures manual. Wyoming Game and Fish Department, Cheyenne. 209 p.

Binns, N. A., and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108:215-228.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1981. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. p. 62-73. In Neil B. Armantrout, ed. Acquisition and utilization of aquatic habitat inventory information: Proceedings of a symposium. [Portland, Oreg., Oct. 28-30, 1981] Western Division, American Fisheries Society, Besthesda, Md.

Boussu, M. F. 1954. Relationship between trout populations and cover in a small stream. Journal of Wildlife Management 18:229-239.

Bovee, K. D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper 12. Western Energy and Land Use Team, USDI Office of Biologic Service, Fish and Wildlife Service, Washington, D.C.

Brown, G. W., and J. T. Krygier. 1970. Effects of clearcutting on stream temperature. Water Resources Research 6: 1133-1139.

Burton, T. M., and G. E. Likens. 1973. The effect of strip-cutting on stream temperatures in Hubbard Brook Experimental Forest, New Hampshire. BioScience 23(7):433-435.

Chapman, D. W. 1966. Food and space as regulators of Salmonid populations in streams. American Naturalist 100:345-357.

Coffey, Albert. 1982. Stream improvement: the Chicod Creek episode. Journal of Soil and Water Conservation 37(2):80-82.

Colby, Bruce, R. 1964. Discharge of sands and mean velocity relationships in sand-bed streams. USDI Geological Survey Professional Paper 462-A, 47 p. Washington, D.C.

Dill, L. M., R. C. Ydenberg, and A. H. G. Fraser. 1981. Food abundance and territory size in juvenile coho salmon (Onchorhynchus kisutch). Canadian Journal of Zoology 59(9):1801-1809.

Duff, D. A., and N. Banks. 1988. Indexed bibliography on stream habitat improvement. 119 p. USDA Forest Service, Intermountain Region, Ogden, Utah.

Heede, B. H. 1965. Multipurpose prefabricated concrete check dam. USDA Forest Service Research Paper RM-12, 16 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Heede, B. H. 1966. Design, construction, and cost of rock check dams. USDA Forest Service Research Paper RM-20, 24 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Heede, B. H. 1972. Flow and channel characteristics of two high mountain streams. USDA Forest Service Research Paper RM-96. 12 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Heede, B. H. 1976. Gully development and control: The status of our knowledge. USDA Forest Service Research Paper RM-169, 42 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Heede, B. H. 1980. Stream dynamics: An overview for land managers. USDA Forest Service General Technical Report RM-72, 26 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Heede, Burchard H. 1981. Dynamics of selected mountain streams in the western United States of America. Zeitschrift für Geomorphologie 25(1):17-32.

Heede, Burchard H. 1986. Designing for dynamic equilibrium in streams. Water Resources Bulletin 22(3): 351-357.

Hynes, H. B. N. 1972. The ecology of running waters. University Toronto Press. 202 p. Toronto, Canada.

King, H. W. 1954. Handbook of hydraulics. 10 Chapters. McGraw-Hill Book Co., Inc., New York.

Meehan, W. R., F. J. Swanson, and J. R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. p. 137-145. In R. R. Johnson and D. A. Jones, tech. coord. Importance, preservation and management of riparian habitat: Proceedings of the symposium. USDA Forest Service General Technical Report RM-43. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Megahan, W. F., W. S. Platts, and B. Kulesza. 1980. Riverbed improves over time: South Fork Salmon. p. 386-395. In Symposium watershed management, Volume II. American Society of Civil Engineers, New York.

Nankervis, J. M. 1988. Age, growth and reproduction of Gila trout in a small headwater stream in the Gila National Forest. M.S. thesis. 58 p. New Mexico State University, Las Cruces.

Osgood, M. E., and W. E. Barber. 1982. Assessment of fish habitat in streams: goals, constraints, and a new technique. Fisheries 7(3):8-11.

Patterson D. W. 1976. Evaluation of habitats resulting from stream bank protection projects in Siskiyou and Mendocino Counties, California. California-Nevada Wildlife 1976:53-59.

Platts, W. S. 1976. The place of the aquatic specialist in the interdisciplinary approach to solving streamflow problems. p. 636-647. In: J. F. Orsborn and C. H. Allman, eds. Instream Flow Needs: Proceedings of the symposium and special conference, Volume II. American Fisheries Society, Bethesda, Maryland.

Platts, W. S., and W. F. Megahan. 1975. Time trends in riverbed sediment composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. Transactions of the North American Wildlife and Natural Resources Conference 40: 229-239.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream and biotic conditions. USDA Forest Service General Technical Report INT-138, 70 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Platts, W. S., and J. N. Rinne. 1985. Riparian and stream enhancement management and research in the Rocky Mountains. North American Journal of Fisheries Management. 5: 115-125.

Platts, William S., Carl Armour, Bordon D. Booth, et. al. 1987. Methods for evaluating riparian habitats with applications to management. USDA Forest Service General Technical Report INT-221, 177 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Rinne, J. N. 1978. Development of methods of population estimation and habitat evaluation for management of the Arizona and Gila trouts. p. 113-125. In John R. Moring, ed. Proceedings of the Wild Trout--Catchable Trout Symposium. [Eugene, Oregon, February 15-17, 1978] Oregon Department of Fish and Wildlife, Research and Development Section.

Rinne, J. N. 1981a. Stream habitat improvement and native southwestern trouts. USDA Forest Service Research Note RM-409, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Rinne, J. N. 1981b. Problems associated with habitat evaluation of an endangered fish in headwater environments. p. 202-209. In Neil B. Armantrout, ed. Acquisition and utilities aquatic habitat inventory information: Proceedings of a symposium. Western Division, American Fisheries Society, Bethesda, Md.

Rinne, J. N. 1982. Movement, home range, and growth of a rare southwestern trout in improved and unimproved habitats. North American Journal of Fisheries Management 2:150-157.

Rinne, J. N. 1985. Livestock grazing effects on southwestern streams: a complex research problem. p. 296-299. In R. R. Johnson, C. D. Ziebell, D R. Patton, P. F. Ffolliott, R. H. Hamre, tech. coords. Riparian ecosystems and their management: reconciling conflicting uses. First North American Riparian Conference. USDA Forest Service General Technical Report RM-120. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Rinne, J. N. 1988. Grazing effects on stream habitat and fishes: research design considerations. North American Journal of Fisheries Management 8(2):240-247.

Rinne, J. N. In press. The utility of stream habitat and biota for identifying potential conflicting forest land uses: montane riparian areas. Forest Ecology Management.

Rinne, J. N., and A. L. Medina. In press. Factors influencing salmonid populations in six headwater streams, central Arizona, USA. Polskie Archiwum Hydrobiologii 34(4-5).

Rinne, J. N., and P. R. Turner. In press. Reclamation and alteration as management techniques, and a review of methodology in stream renovation. In W. L. Minckley and J. E. Deacon, eds. Battle against extinction: native fish management in the American West. University of Ariz. Press, Tucson.

Shields, Fletcher Douglas, Jr. 1983. Design of habitat structures for open channels. Journal of Water Resources Planning and Management 109(4):331-344.

USDI Bureau of Reclamation. 1974. Design of small dams. Water Resources Technical Publication. 816 p. U.S. Government Printing Office, Washington, D.C.

Acidic Deposition and the Status of Virginia's Wild Trout Resource[1]

J. R. Webb,[2] P. E. Bugas,[3] B. J. Cosby,[4] J. N. Galloway,[5] G. M. Hornberger,[6] J. W. Kauffman,[7] L. O. Mohn,[8] P. F. Ryan,[9] and P. P. Smith[10]

Abstract.--Virginia's wild trout resource is endangered by the present level of acidic deposition. This assessment is based on the magnitude of the acidic deposition load, on the low alkalinity concentrations of the streams, on the predicted increase in stream water sulfate concentrations, and on observations of acidification-related trends in both stream chemistry and biota.

INTRODUCTION

Virginia has about 450 small mountain headwater streams that support reproducing populations of <u>Salvelinus</u> <u>fontinalis</u>, the native brook trout of the southern Appalachian region (Mohn and Bugas 1981). The spatial distribution of these wild trout streams is indicated in figure 1. Most of these streams drain relatively pristine forest-covered watersheds that are managed as National Forest or National Park land. Despite the protection provided by this management status a large percentage of these streams may be subject to ecological deterioration as a consequence of acidic deposition. This paper provides a brief review of the evidence that leads to this concern.

[1]Contributed paper, Wild Trout IV Symposium at Yellowstone National Park, Mammoth, Wyo. (September 18-19, 1989).

[2]J.R. Webb, Research Scientist, Dept. of Environmental Sciences, University of Virginia, Charlottesville, Va.

[3]P.M. Bugas, Fisheries Biologist, Va. Dept. of Game and Inland Fisheries, Staunton, Va.

[4]B.J. Cosby, Associate Professor, School of Forestry and Environmental Studies, Duke University, Durham, N.C.

[5]J.N. Galloway, Associate Professor, Dept. of Environmental Sciences, University of Virginia, Charlottesville, Va.

[6]G.M. Hornberger, Associate Professor, Dept. of Environmental Sciences, University of Virginia, Charlottesville, Va.

[7]J.W. Kauffman, Regional Fisheries Manager, Va. Dept. of Game and Inland Fisheries, Charlottesville, Va.

[8]L.O. Mohn, Supervising Fisheries Biologist, Va. Dept. of Game and Inland Fisheries, Staunton, Va.

[9]P.F. Ryan, Scientific Programer, Science Applications International, Inc., Oak Ridge, Tenn.

[10]P.P. Smith, Fisheries Biologist, Va. Dept. of Game and Inland Fisheries, Charlottesville, Va.

ELEVATED ACIDIC DEPOSITION

The mountains of western Virginia are located downwind of the major sulfur and nitrogen emission regions of the nation (National Academy of Sciences 1986; Michaels et al. 1988). As a result, the acidity of precipitation in Virginia, which has a mean pH value of about 4.2 (Buikema et al. 1985), is on the order of ten times greater than in uncontaminated precipitation, which has pH values of $\geq$ 5.0 (Galloway et al. 1984). About two-thirds of the acidity in this precipitation is sulfuric (NAPAP 1984). This is reflected in the elevated sulfate load of Virginia precipitation versus that in less-impacted areas. In figure 2, the deposition of sulfate in precipitation at Virginia's Shenandoah National Park is compared with deposition at other U.S. National Parks.

SENSITIVITY OF THE STREAMS

Most of Virginia's wild trout streams have physical characteristics consistent with low ionic strength water and high potential for acidification. Most of these poorly buffered streams drain watersheds with steep slopes, shallow soils, and weathering-resistant bedrock. Stream water concentrations of alkalinity, or acid neutralization capacity, are notably low relative to concentrations that have been cited as criteria, or index values, for surface water sensitivity assessment.

Information concerning alkalinity and other chemical characteristics of Virginia's wild trout streams has been obtained through the Virginia Trout Stream Sensitivity Study (VTSSS). About 80% of the state's wild trout streams were sampled for analysis of alkalinity and major ions in the Spring of 1987. The methods and results of this synoptic sampling survey have been reported by Webb et al. (1989a, 1989b). Figure 3 indicates the percentage of the sampled streams in relative sensitivity classes based on alkalinity criteria. Alkalinity concentrations for 93% of the sampled streams were < 200 μeq L^{-1}, a value that is perhaps the most

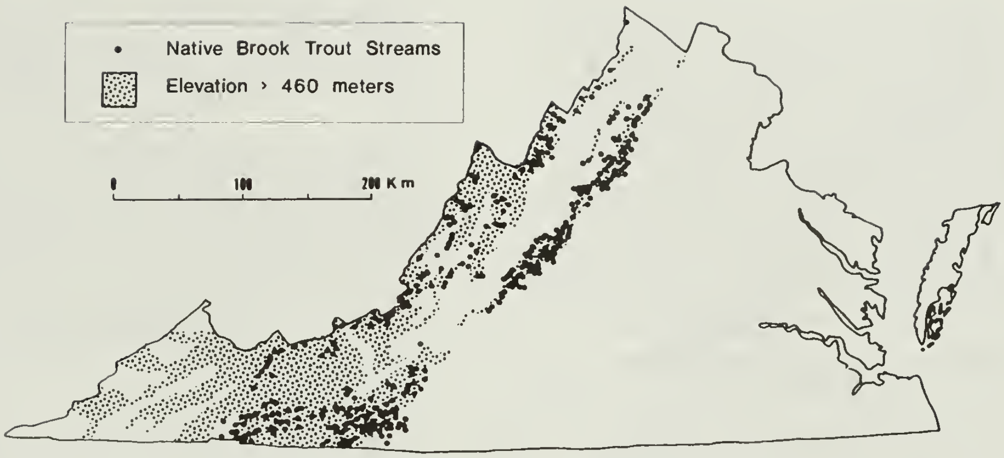


Figure 1.--Distribution of native brook trout streams in Virginia shown in relation to mountain areas with elevation greater than 460 m.

commonly cited criterion for identification of sensitive surface waters (Altshuller and Linthurst 1983; Winger et al. 1987; Knapp et al. 1988). Alkalinity concentrations for 78% of the sampled streams were ≤ 100 μeq L^{-1}, another value that has been cited for identification of sensitive surface waters (Lynch and Dise 1985). The alkalinity concentrations for 49% of the streams were ≤ 50 μeq L^{-1}, a value that has been cited for identification of extremely sensitive surface waters (Gibson et al. 1983; Schindler 1988). About 10% of the sampled streams were, by definition, acidic (alkalinity ≤ 0 μeq L^{-1}).

ESTIMATES OF ACIDIFICATION

A simple linear model of surface water acidification has been used to estimate the past and potential future acidification of the wild trout streams sampled in the VTSSS survey (Webb et al. 1989a, 1989b). As represented by this model, stream water acidification, or loss of alkalinity, is driven by increasing concentrations of sulfate in stream water. For application of this model with the VTSSS data the past increase in stream water sulfate concentrations was determined as the difference between present-day measured concentrations and an estimated concentration (22 μeq L^{-1}) for stream waters in equilibrium with preindustrial atmospheric deposition levels. The future increase in sulfate was determined as the difference between current concentrations and an estimated minimum concentration (220 μeq L^{-1}) for stream waters in equilibrium with present-day deposition. While present-day stream water sulfate concentrations (with a median of 71 μeq L^{-1}) are low relative to the present-day equilibrium value, they are expected to rise as the sulfate retention capacity of watershed soils is exhausted.

Based on trends observed for two intensively monitored streams in Shenandoah National Park (White Oak Run and Deep Run) alkalinity loss in the sampled native trout streams is estimated to equal about 40% of the increase in sulfate concentrations. Figure 4 indicates the distribution of measured alkalinity for these streams relative to distributions of past and future alkalinity predicted with the model. The present-day median alkalinity of 52 μeq L^{-1} compares with a preindustrial median of 70 μeq L^{-1} and a potential future median of -9 μeq L^{-1}.

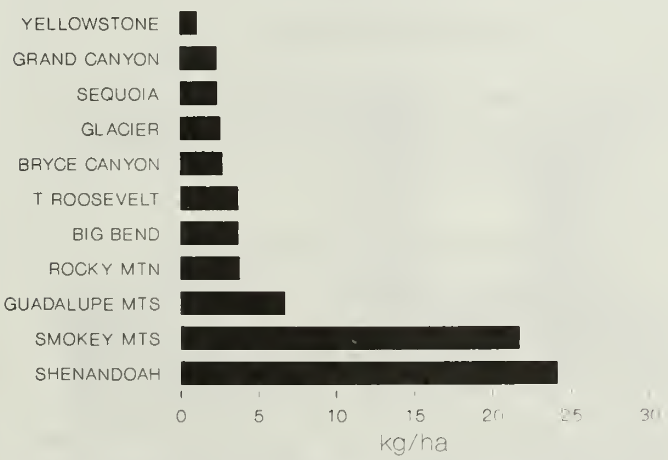


Figure 2.--Deposition of sulfate in precipitation of U.S. National Parks in 1985. Data source: NADP/NTN (1989).

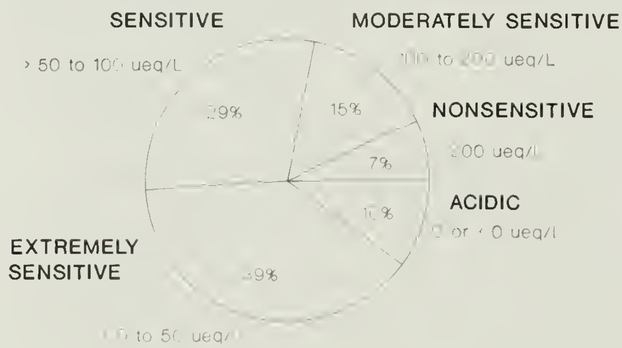


Figure 3.--Sensitivity classification of the wild trout streams sampled in the Spring 1987 survey. (n=341)

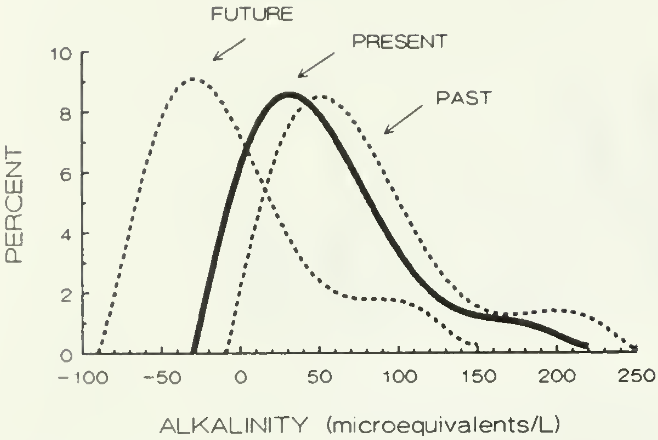


Figure 4.--Distributions of estimated original, measured current, and potential future alkalinity concentrations for the wild trout streams sampled in the Spring 1987 survey. (n=341)

The ecological significance of the predicted future change in alkalinity is best understood by reference to biologically critical pH levels, which range from about 6.0 to 4.7 for a number of fish species commonly present in native brook trout waters (Cooper and Wagner 1973; Haines and Baker 1986; Schofield and Driscoll 1987). At present, the median pH for the sampled streams (6.7) is still well above the range of critical values. Given the predicted loss of alkalinity, the median pH for these streams will be about 5.0. About 40% of the streams will have a pH of < 4.7, compared with none at present. A substantial change in the fisheries status of these streams can be expected.

OBSERVED CHANGE IN STREAM CHEMISTRY

Chronic stream water acidification has been documented for Deep Run and White Oak Run, two Shenandoah National Park streams that have been sampled weekly since 1979 by the Shenandoah Watershed Study (Ryan et al. 1989). Although only White Oak Run sustains a wild trout population, both streams share geologic and other physiographic characteristics in common with many of the wild trout streams throughout western Virginia. Consistent with the hypothesis of acidification due to acidic deposition, alkalinity has decreased in these two streams while sulfate and hydrogen ion have increased.

Changes in the annual volume-weighted mean concentrations of sulfate, alkalinity, and hydrogen ion for White Oak Run and Deep Run are indicated in figure 5. Over the eight-year period, sulfate concentrations in both streams have risen about 2 $\mu eq\ L^{-1}$ per year and alkalinity has declined 0.5 to 0.75 $\mu eq\ L^{-1}$ per year. Hydrogen ion concentration in Deep Run has increased about 0.4 $\mu eq\ L^{-1}$ per year. In pH units, Deep Run has declined from about 5.6 to 5.3 over the eight-year period. White Oak Run, which has more buffering capacity, has shown less increase in hydrogen ion. In pH units, White Oak Run declined from about 6.1 to 6.0. For both of these streams, the observed acidification indicates a state of ecological deterioration. The acidity level of White Oak Run has approached the biologically critical range, while the acidity level of Deep Run is already well within the critical range.

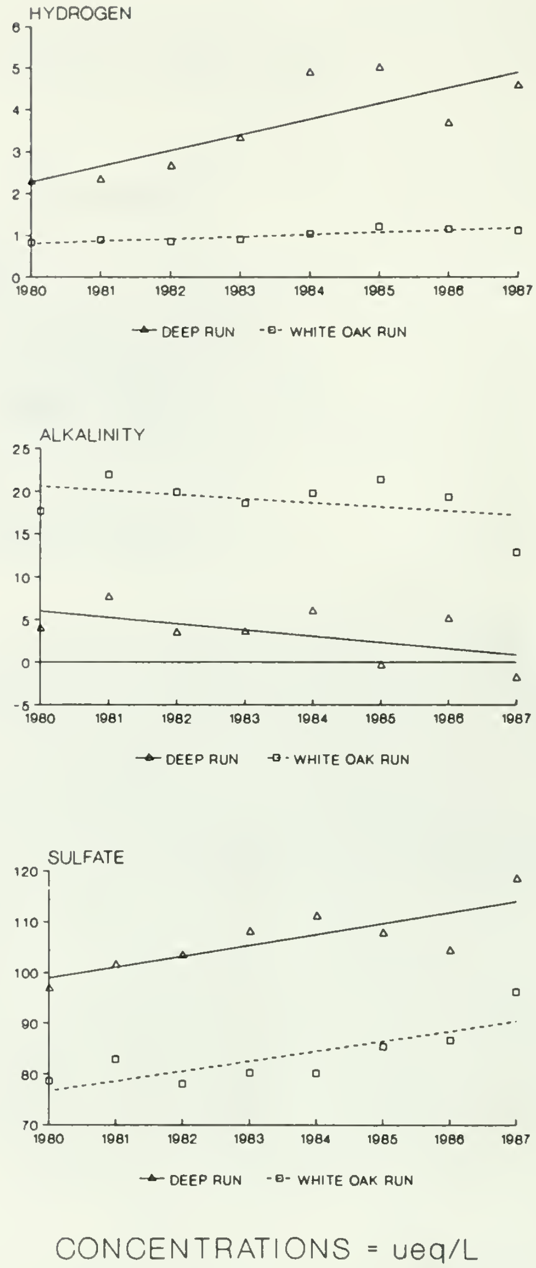


Figure 5.--Trends in sulfate, alkalinity, and hydrogen ion concentrations (volume-weighted annual means) for two streams in Shenandoah National Park.

OBSERVED CHANGE IN STREAM BIOTA

Saint Marys River is one of Virginia's higher quality trout streams. This quality is recognized in its management as a special regulation trout stream, in its designation by the U.S. Forest Service as a featured-species brook trout stream, and by Federal designation of its watershed as a wilderness area. Saint Marys has been identified as one of Virginia's most acid sensitive wild trout streams (Webb et al. 1989a). Extensive invertebrate surveys were conducted as early as 1936, providing good comparisons with data collected by the Virginia Dept. of Game and Inland

Fisheries (VDGIF) in 1976, 1986, and 1988. Fish population data were also collected by the VDGIF in 1976, 1986, and 1988. These data provide a unique opportunity to compare reliable biological data on a poorly-buffered stream in an undisturbed watershed over a 50-year period.

Procedures and techniques for collection of invertebrate data are described by Surber (1951) and by Mohn and Bugas (1980). Changes in the invertebrate community over the 50-year period are consistent with stream water acidification. Genera such as Ephemerella sp. have disappeared (fig. 6a).

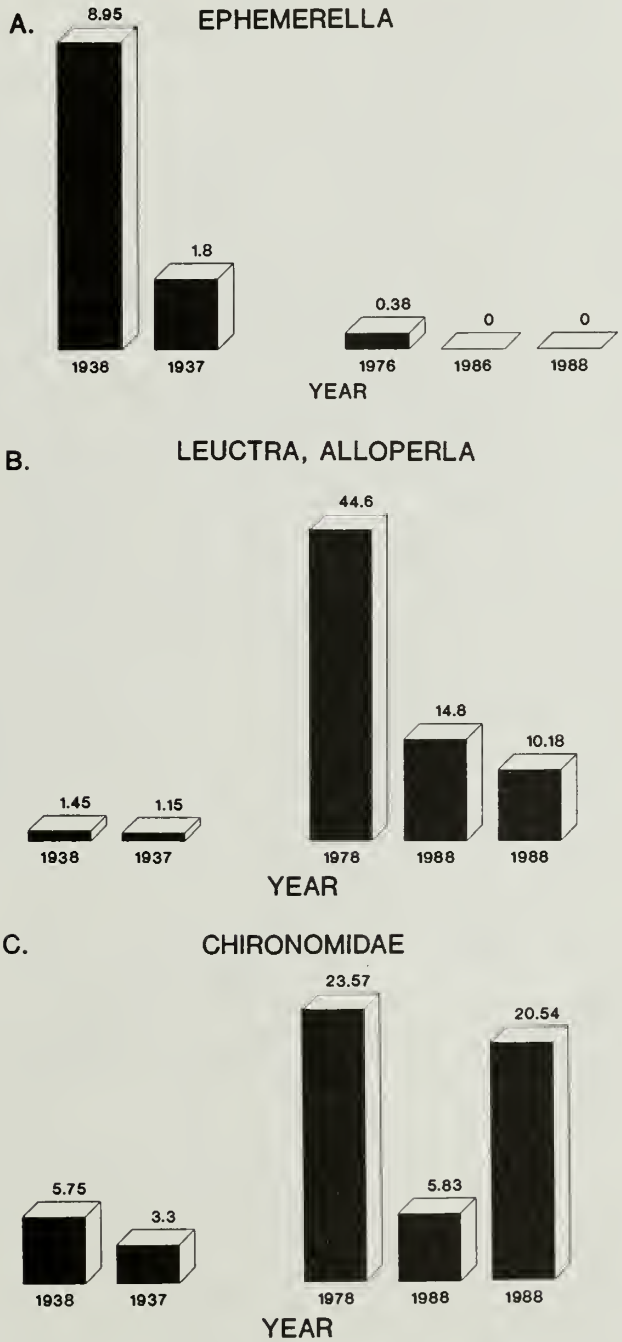


Figure 6.--Change over time in stream invertebrates of Saint Marys River, indicated as number of individuals collected per square foot.

Some of the other common genera which have disappeared are Dolophilodes, Epeorus, and Baetis. These genera can be considered "acid sensitive" with declines expected in acidified waters (Hall and Idle 1987; Lasier 1986; Feldman 1986). The taxa Leuctra sp. (fig. 6b) and Chironomidae (fig. 6c) have increased in abundance over time. Hall and Idle (1987), Lasier (1986), and Kimmel (1985) report that these groups are acid tolerant and usually increase in abundance when waters are acidified. Indices of abundance, including number of taxa collected (fig. 7), Shannon Weaver Diversity Index, and EPT (number of Ephemeroptera, Plecoptera, and Trichoptera taxa) have all declined.

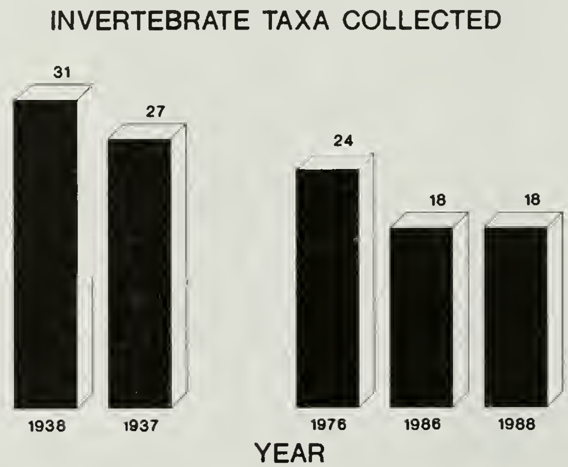


Figure 7.--Change over time in stream invertebrates of Saint Marys River, indicated as number of taxa collected.

Procedures for collection of fish data are described by Mohn and Bugas (1980). Changes in the fish community over a 12-year period are consistent with stream water acidification. Brook trout (Salvelinus fontinalis) and naturalized rainbow trout (Oncorhynchus mykiss) are both present in Saint Marys River. Since 1976 brook trout numbers have remained stable (fig. 8a) while rainbow trout numbers have declined drastically (fig. 8b). Rainbow trout are reported to be more acid sensitive than brook trout (Altshuller and Linthurst 1983). Blacknose dace (Rhynichthys atratulis) are reported to decline in numbers when the pH is less than 6.0 (Schofield and Driscoll 1987). Numbers of blacknose dace collected in the upper (lower pH) sections of the stream show a sharp decline between samplings (fig. 9), while numbers remained high in the lower (higher pH) sections of the stream.

CONCLUSION

Our review of evidence indicates that acidification of Virginia's wild trout streams is an ongoing phenomenon. The mountains of Virginia receive a high level of acidic deposition and the watersheds associated with the wild trout streams provide minimal buffering capacity. The magnitude of estimated past and future increases in stream water sulfate concentrations indicate that stream water acidification has occurred in the past and that substantially more stream water acidification may be anticipated in the future. While trend data are limited to a few streams, observed changes in both chemical and biological composition are consistent with acidification.

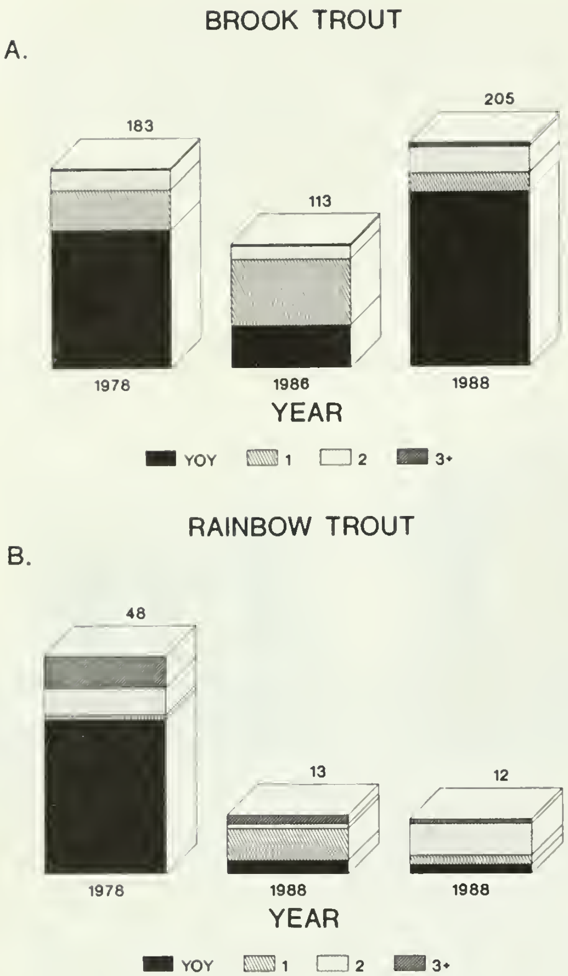


Figure 8.--Change over time in abundance of brook trout and rainbow trout collected from Saint Marys River, indicated as the number of individuals by age group (young of the year and 1st, 2nd, and 3rd year) collected from designated sampling reaches.

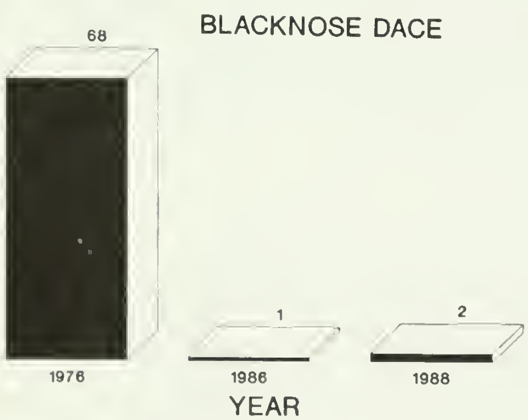


Figure 9.--Change over time in numbers of blacknose dace collected from the upper sections of the Saint Marys River, indicated as the number of individuals collected in designated sampling reaches.

ACKNOWLEDGEMENTS

Funding and support for the research described in this review have been provided by a number of sources. The Virginia Trout Stream Sensitivity Study is jointly funded by the Va. Dept. of Game and Inland Fisheries and the U.S. Fish and Wildlife Service through the Federal Aid in Sport Fish Restoration Program (Va. F-72). Additional funding and support has been provided by the U.S. Forest Service and the Va. Council of Trout Unlimited. Funding and support for the Shenandoah Watershed Study is provided by the National Park Service (NPSCA4000-6-8012). The recent collections of Saint Marys River fish and invertebrate data were conducted by the Fish Division of the Va. Dept. of Game and Inland Fisheries.

LITERATURE CITED

Altshuller, A.P., and R.A. Linthurst (eds). 1983. The Acidic Deposition Phenomenon and Its Effects: Critical Assessment Review Papers. Vol.II. U.S. EPA Report EPA-600/8-83-016A.

Buikema, A.L., B.I. Chevone, F.M. Hawkridge, E.L. Kropp, E.E. Mason, J.M. McManus, W.W. Parks, G.L. Pellet, D.D. Salkovitz, and P. Toczydlowski. 1985. Virginia Acid Precipitation Network Summary Report: 1982 - 1984. Report to State Air Pollution Control Board, Richmond, Va.

Cooper, E.L., and C.C. Wagner. 1973. The effects of acid mine drainage on fish populations. In: Fish and food organisms in acid mine waters of Pennsylvania. U.S. Environmental Protection Agency, EPA-R-3-73-032.

Feldman, R. S. 1986. The influence of alkalinity on stream macroinvertebrates in the Shenandoah National Park: implications of acid deposition. M. S. Thesis, University of Va., Charlottesville, Va.

Galloway, J.N., G.E. Likens, and M.E. Hawley. 1984. Acid precipitation: natural versus anthropogenic components. Science, 226: 829-831.

Gibson, J.H., J.N. Galloway, C. Schofield, W. McFee, R. Johnson, S. McCarley, N. Dise, and D. Herzog. 1983. Rocky Mountain Acidification Study. U.S. Fish and Wildlife Service, Division of Biological Services, Eastern Energy and Land Use Team, FWS/OBS-80/40.17.

Haines, T.A., and J.P. Baker. 1986. Evidence of fish population responses to acidification in the eastern United States. Water, Air, and Soil Poll., 31: 605-629.

Hall, R. J., and F. P. Idle. 1987. Evidence of acidification effects on stream insect communities in central Ontario between 1937 and 1985. Can. J. Fish. Aquat. Sci. 44:1652-1657.

Kimmel, W. G., D. J. Murphy, W. E. Sharpe, and D. R. Walle. 1985. Macroinvertebrate community structure and detritus processing rates in two Pennsylvania streams acidified by atmospheric deposition. Hydrobiologia. 124:97-102.

Knapp, C.M., D.G. Heimbuch, H.S. Greening, and G.J. Filbin. 1988. Maryland Synoptic Stream Chemistry Survey. Prepared by International Science and Technology, Inc. for Maryland Dept. of Natural Resources, Power Plant Research Program. Annapolis, Md. AD-88-2.

Lasier, P. J. 1986. The use of benthic macroinvertebrates as indicators of acid sensitivity in headwater streams of the southern Blue Ridge province. MS Thesis. University of Georgia, Athens, Ga.

✩U.S. GOVERNMENT PRINTING OFFICE: 1990 774-173/25037

Lynch, D.D., and N.B. Dise. 1985. Sensitivity of Stream Basins in Shenandoah National Park to Acid Deposition. U.S. Geological Survey, Water-Resources Investigations Report 85-4115, 1985.

Michaels, P.J., P.J. Stenger, D.E. Sappington, and P.C. Knappenberger. 1988. Origin and Destination of Pollutant-Bearing Airstreams Impacting and Exiting the Commonwealth of Virginia. State Climatology Office, Dept. of Environmental Sciences, University of Va., Charlottesville, Va.

Mohn, L.O., and P.E. Bugas, Jr. 1980. Virginia Trout Stream and Environmental Inventory. Final report F-32. Va. Dept. of Game and Inland Fisheries. Richmond, Va.

NADP/NTN 1989. National Atmospheric Deposition Program (IR-7)/National Trends Network. March 8, 1989. NADP/NTN Coordination Office, Natural Resources Ecology Laboratory, Colorado State University, Fort Collins, Co. 80523

NAPAP 1984. Annual Report to the President and Congress. National Acid Precipitation Assessment Program, Washington, 1984.

NAS 1986. Acid Deposition Long-Term Trends. National Academy of Sciences, National Academy Press, Washington, D.C.

Ryan, P.F., J.N. Galloway, B.J. Cosby, G.M. Hornberger, and J.R. Webb. In press. Changes in the chemical composition of stream waters in the Shenandoah National Park, Va, in response to atmospheric deposition of sulfur. Water Resour. Res.

Schindler, D.W. 1988. Effects of Acid Rain on Freshwater Ecosystems. Science 239: 149-157.

Schofield, C.L., and C.T. Driscoll 1987. Fish species distribution in relation to water quality gradients in the North Branch of the Moose River Basin. Biogeochemistry. 3: 63-85.

Surber, E. 1951. Bottom fauna and temperature conditions in relation to trout management in St. Mary's river, Augusta County, Va. Va. Journal of Science. Vol 2, No. 3, 190-202.

Webb, J.R., Cosby, B.J., Galloway, J.N. and G.M. Hornberger. 1989a. Acidification of Native Brook Trout Streams in Virginia. Report (Project F-32) to the Va. Dept. of Game and Inland Fisheries, Richmond, Va.

Webb, J.R., Cosby, B.J., Galloway, J.N. and G.M. Hornberger. 1989b. Acidification of Native Brook Trout Streams in Virginia. Water Resour. Res. 25(6): 1367-1377.

Winger, P., P.J. Lasier, M. Hurdy, D. Fowler, and M.J. Van Den Avyle. 1987. Sensitivity of high-elevation streams in the Southern Blue Ridge Province to acidic deposition, Water Resour. Bull., 23, 379-386.