Management Implications of Co-occurring Native and Introduced Fishes

Proceedings of the Workshop
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Hosted by:

Fish Division

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&

Sustainable Fisheries Division

National Marine Fisheries Service

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These Proceedings contain unedited, non-peer reviewed papers (unless otherwise specified) of oral presentations given at the workshop “Management Implications of Co-occurring Native and Introduced Fishes” held in Portland, Oregon, on October 27-28, 1998. Although care was taken to present the information in an accurate, standardized manner, errors may exist. Please contact the authors before interpreting or quoting any information presented.

Preface

On October 27 and 28, 1998, the Oregon Department of Fish and Wildlife and the National Marine Fisheries Service brought together scientists, fishery managers, fishing and conservation organizations, and other stakeholders for a snapshot of the issues and facts surrounding the management of introduced and native fishes. This volume contains the papers that were presented by those speakers; a record of the presentations for anyone with a stake in these issues no matter their perspectives.

This symposium was occasioned by increased concern for native fish species, as evidenced by the numerous listings under the Endangered Species Act in the past several years, and the assumed role of introduced, non-indigenous species in many of those listings. *The Oregon Plan for Salmon and Watersheds* identifies the need to examine these issues associated with steelhead and coho salmon, and to take management actions where they are warranted. In order to present a region-wide view of both anadromous and resident fish issues, as well as the associated issues of managing important recreational fisheries on introduced fisheries, this symposium was extended to include states well beyond the scope of the *Oregon Plan*. Speakers from throughout the West presented views and findings.

Both the Oregon Department of Fish and Wildlife and the National Marine Fisheries Service will consider the papers presented here as they develop and implement policy direction for responding to the issues which occasioned this meeting. At issue is recovery of native fish species and the future of many fisheries on introduced species. The issues are complex, and the risks and remedies are often uncertain. We urge that stakeholders review the material presented here and participate in the public hearings of the Oregon Fish and Wildlife Commission and review of NMFS documents on these vital questions.

Ray Temple, Oregon Department of Fish and Wildlife

Lance Kruzic, National Marine Fisheries Service

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History, Distribution, and Recent Management of Introduced Fishes

Session Chair:

Herb Pollard
National Marine Fisheries Service

"The Coming of the Pond Fishes"

An Account of the Introduction of Certain Spiny-Rayed Fishes, and Other Exotic Species, into the Waters of the Lower Columbia River Region and the Pacific Coast States

Herb Pollard
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"The Coming of the Pond Fishes" by Ben Hur Lampman, published in Portland in 1946, summarizes the early history of exotic fish in the northwest. The book is written with the enthusiasm of an avid angler and friend of warm-water fish. It also points out some of the controversy and concern about introducing potential predators and competitors to waters that support native species that existed even in the 1800's.

Two of the most important dates in the history of non-native fish to the western U.S. are 1869 and 1884. In 1869, the Union Pacific and Central Pacific railways met at Promontory Point, Utah in the famous "Golden Spike" ceremony. The first non-native fish, shad, arrived by rail and were released in the Sacramento River in 1871, courtesy of Seth Greene, one of the earliest American fish culturists (Table 1).

The Oregon Short Line was completed in 1884, connecting the UP mainline at Granger, Wyoming to the Pacific Northwest via the Oregon-Washington Railroad and Navigation Company. By 1887, largemouth bass were established in the Snake River Drainage and other species were on the way.

Although most of the new introductions were met with much enthusiasm, there was some opposition. As early as 1893 the Oregonian carried an editorial debate on the merits of bass introductions-at least five years after the introductions had occurred. And some of the introductions by state game wardens and early fishery biologists were clearly done without sanction of their commissions or real consideration of the impacts.

Many of the very early introductions were made by private individuals, often with a profit motive. Some of the early enthusiasm for carp reads a lot like the recent publicity for ostrich and emu ranching. The only people to make any money were those that sold the brood stock and soon both the markets and natural waters were flooded.

The U. S. Fish Commission was soon involved. Livingston Stone, first deputy to Spencer Baird, the first U.S. Fish Commissioner, developed and freely utilized the "Aquarium Car". From the 1870's through the 1920's the Fish Commission operated a salvage station on the Illinois River. As spring floods receded, salvage crews seined the oxbow lakes and sloughs for bass, catfish and sunfish. The assorted fish were loaded on the aquarium cars and shipped westward. Some of the fish were delivered to state game wardens for distribution, others were consigned to individuals or sportsman's club. Others were apparently dipped out and dumped at water stops or released where the train broke down. There must have been some sorting of fish, or the western waters would have received even more species, but the use of salvaged fish probably explains some of the unusual species and distribution that occurs today.

Introductions of non-native fishes seems to have gone through three stages. From the 1870s through the 1920s there were numerous introductions without much thought or evaluation of impacts. By the 1920s, most of the species currently managed in the West were well established. From the 20s through the 60s, the state agencies proceeded to transplant from established stocks to suitable waters--often with the unauthorized assistance of fishermen. There was a more scientific approach, especially as new reservoir habitat was created and managers attempted to match species with habitat. However, bass and panfish remained low priorities for most anglers and most fishery managers. In the 1970s tournament bass fishing and interest in warm-water fishing increased rapidly, leading to more intense management.

Table 1. Brief chronology of the coming of the pond fishes.

Common Name	Earliest introductions to western waters
Shad	1871 Sacramento River; Seth Greene and California Fish Commission 1885 Columbia, Snake and Willamette; U.S.Fish Commission (Diverted from Puget Sound, due to blocked railroad)
Striped Bass	1879 San Francisco Bay, Livingston Stone and California Fish Comm. (This introduction also included eels and lobsters)
Tench	1895 Spokane Co., Washington and Kootenai County, Idaho, USFC
Carp	1872 Sonoma County, California, private citizen, from Germany via ship and rail 1880 Troutdale, Oregon, private citizen from California 1882 USFC, California, Washington, Idaho and Oregon
Catfish	1874 White catfish, brown bullhead, San Joaquin and Sacramento; USFC 1880 Bullheads, Willamette River, private citizens 1877 Channel catfish, Sacramento, USFC 1893 Channel Catfish, Boise River, USFC (also Willamette, but not reported in Willamette and Lower Columbia until 1940's) 1943 Blue Catfish (probably flatheads) Snake River, USFWS and IDFG (There are several species including black and yellow bullheads, flathead catfish, tadpole madtom and white catfish that were introduced with no clear records, probably in mixed loads of salvaged fish.)
Largemouth Bass	1887 Boise River, private citizen 1888 Willamette River, private citizen 1892 USFC Boise, Willamette with mixed sunfish
Smallmouth Bass	1874 California, USFC 1920 Blakely Island Washington, Private timber Company 1924 Willamette River, ODFW from Blakely Island 1925 Yakima River, Benton County Game Commissioners
Crappie	1892 Boise River, USFC 1893 Willamette River, USFC mixed with other bass and sunfish. 1905 Willamette/Columbia, Releases from Lewis and Clark Centennial Exposition aquaria, included both crappies, both bass, yellow perch and assorted sunfish
Sunfish	1891-1893 Various species in mixed salvage, USFC
	1874 California, USFC 1890 Loon Lake, Washington, USFC
Northern Pike	1950s Pend Orielle Lake, Idaho from Clark Fork River 1970s Couer 'd Alene Lake, Idaho, Illegal private transplants from Montana
Walleye	1950s Lake Roosevelt, USFWS or possibly private citizen 1975 Salmon Falls Creek Reservoir, IDFG

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Distribution and Recent Management of Introduced Fishes in Washington

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Abstract- *Nineteen introduced warmwater fish species are currently found in Washington. Of these, seven are common and occur statewide, four have limited general distribution, and eight have very limited regional distribution. In addition, eight species of introduced salmonids are present in Washington waters. Of these, two, hatchery rainbow trout and brook trout, are found abundantly throughout the state, two have limited general distribution, and four have very limited regional distribution. Introduced common carp, grass carp, tench and American shad are also found in Washington waters. Most of these species were intentionally introduced into Washington around the turn of the century. The distribution and abundance of most of these species have remained relatively stable for nearly a century.*

Management emphasis for introduced game fish species is on maximizing long-term recreational benefits while minimizing adverse impacts to native fish and wildlife populations and their habitats. Major management challenges include: 1) Balancing increasing public demand for more and improved fishing opportunity with the increasing need to protect and restore co-occurring native fish and wildlife, 2) determining the nature and extent of interactions between specific introduced and native fish species, and 3) successfully implementing a legislatively mandated, $1.25 million/year, Warmwater Fish Enhancement Program.

Introduction

Washington's freshwater fisheries are heavily dependant on introduced species, introduced strains of native species, and the expanded distribution of native and introduced species into waters where they did not naturally occur. The majority of these introductions occurred around the turn of the century, and where the direct result of government actions designed to increase the diversity and quality of recreational angling in the state.

Distribution of Introduced Fish

Warmwater Fish Introductions

A total of nineteen warmwater game fish species are currently found in Washington waters. These species fall into three general categories of distribution and abundance; common and statewide distribution (C), limited general distribution (L), and very limited regional distribution (R). See Table 1 for a list of these species and a description of their distribution and relative abundance in Washington.

Introduced Salmonids

There are six introduced salmonid species and several introduced domesticated hatchery strains of two other native salmonid species found in Washington. See Table 2 for a list of these species.

Other Introduced Fishes

Table 3 lists four additional introduced fish species that are commonly found in Washington. Several other introduced species that have been identified in Washington, including fathead minnow, lake whitefish and striped bass, are not listed because of their limited occurrence in the state.

Table 1. Introduced Warmwater Fish in Washington

Species	First Water	Year Introduced	Distribution
Sunfish Family			
Largemouth Bass	Sprague/Loon Lakes	1890	C
Smallmouth Bass	Blakley Island	1924	C
Bluegill Sunfish	Loon/Deer/Colville Lakes	1891	C
Pumpkinseed Sunfish	Lower Columbia River	1893	C
Black Crappie	Lower Columbia River	1893	C
White Crappie	Lake Washington	1890	L
Green Sunfish	Loon/Deer/Colville Lakes	1890	R
Warmouth Bass	Loon Lake	1892	R
Rock Bass	Lower Columbia River	1893	R
Perch Family			
Walleye	Banks Lake	1962?	L
Yellow Perch	Loon/Colville Lakes	1893	C
Catfish Family			
Channel Catfish	Clear Lake (Skagit Co.)	1892	L
Flathead Catfish	Snake River	1970?	R
Blue Catfish	Snake River	1905?	R
Brown Bullhead	Silver Lake (Cowlitz Co.)	1883	C
Yellow Bullhead	Columbia River	1905	L
Black Bullhead	Columbia River	1905	R
Pike Family			
Northern Pike	Long Lake (Spokane Co.)	1970?	R
Tiger Musky	Mayfield Reservoir	1988	R

Table 2. Introduced Resident Salmonids in Washington.

Species	Source	Year Introduced
Brown Trout	Europe	1923
Brook Trout	Pennsylvania	1894
Lake Trout	Wisconsin	1900
Golden Trout	Wyoming	1959
Arctic Grayling	Montana	1921
Atlantic Salmon	New York	1973
Lahonten Cutthroat Trout	Nevada	1970
Rainbow Trout (hatchery stocks)	Utah, New England, California	1920

Table 3. Other Introduced Freshwater Fish Species in Washington.

Species	Source	Year Introduced
Common Carp	Europe	1882
Grass Carp	Europe	1990
Tench	Europe	1885
American Shad	Atlantic Coast	1876

Management of Introduced Fishes

The overall objective for the management of introduced fishes in Washington is to **balance increasing public demand for more angling opportunity for these species with the increasing need to protect and restore co-occurring native fish and wildlife species.** This objective implies that:

1. Maintenance of healthy harvestable populations of native fish and wildlife have a higher priority than introduced species.

2. Introduction or range expansion of introduced species should occur only after a comprehensive assessment of both direct and indirect species interactions.
3. Many introduced species play important roles in altered environments and provide important recreational, economic and cultural benefits to Washington citizens.

Warmwater Fish Management Principles

Management principles applied to warmwater fish in Washington are identified in Table 4.

Table 4. Management Principles - Warmwater Fish

Management emphasis for these species is on maximizing long-term recreational benefits while minimizing impacts to native fish and wildlife populations.

The greatest recreational benefit and least impact is achieved when a balance between predator species (bass, walleye, tiger musky, channel catfish) and prey species (perch, crappie, sunfish) is maintained.

Prey species which have high natural reproductive potential and a tendency to become over-abundant, are normally managed without catch, possession or size limits to encourage harvest.

Predator species, which tend to be less abundant and more susceptible to over-fishing, are generally managed with catch, possession and size limits to minimize harvest and maintain predation pressure. This prevents over-population and stunting of prey species.

Many other variables (including weather, water levels fluctuations, other fish species, etc.) can play a major role in maintaining a balance between warmwater predator and prey species.

Hatchery production has much more limited application in warmwater fisheries management because of high reproductive capacity.

Management Guidelines for Introduced Fishes

Current **draft** guidelines for the management of existing introduced fish species in Washington are listed in Table 5.

Table 5. Washington Guidelines for the Management of Existing Introduced Fish Populations.

- Where introduced fish populations currently exist, provide significant recreational benefits, and do not significantly impact native fish and wildlife populations, they should be managed in accordance with the goals and objectives established through integrated ecosystem planning.
- Where the preponderance of scientific evidence indicates that existing introduced fish populations significantly impact listed fish and wildlife species, populations should be managed in accordance with recovery plans for the listed species.
- Where introduced fish populations have been illegally or unintentionally introduced into state waters designated, as a result of integrated ecosystem planning, for the management of other species, causing harm to these species, they should be managed for removal, consistent with economic, social and environmental considerations.
- The enhancement of existing introduced fisheries, including the use of artificial production, habitat manipulation and/or the introduction of additional fish species, should be encouraged when it is consistent with the goals and objectives of integrated ecosystem plans, provides cost effective recreational benefits, and does not significantly impact native fish and wildlife.

Current **draft** guidelines for the introduction of new species in Washington are described in Table 6.

Table 6. Washington Guidelines for the Importation of Introduced Fish Species.

Prior to any range expansion or first time introduction of a non-indigenous fish species to Washington, the following sequential steps shall be taken:

- A formal proposal shall be developed and approved by the Director. This proposal should indicate the management need, assess the expected biological impact, identify all potential risks to native and established introduced fish and wildlife species, and identify the proposed source and destination of introduced species.
- All affected governments and agencies shall be consulted prior to making any such proposal public. Issues raised by these entities must be resolved to the satisfaction of the Director prior to proceeding to the next step.
- Public meetings on the proposed introduction should be held in the communities most directly affected. Sport fishing and environmental groups should be notified of proposal directly and advised of any scheduled public meetings.
- An environmental review shall be completed in accordance with the State Environmental Policy Act (SEPA).
- The proposed introduction must be compatible with the goals and objectives of integrated ecosystem plans already established for the involved basin, or , if no plan exists, one must be developed prior to any new species introduction.

Aquatic Nuisance Species Management

Washington Department of Fish and Wildlife has taken an active and lead role in establishing a program to prevent the introduction of aquatic nuisance species (ANS) in Washington and in the Pacific Northwest. We believe that the relatively new threat from species such as zebra mussel, green crab, mitten crab and New Zealand mud snail must be addressed very aggressively and in regional way. Washington has recently completed a State Aquatic Nuisance Species Plan and submitted the plan to the national ANS Task Force for implementation funding. The Washington State Legislature has directed the Department of Fish and Wildlife to establish a State ANS Task Force to develop recommendations during the 1999 legislative session for actions that need to be taken to protect Washington from the introduction of ANS. Copies of the State ANS Plan and Report to the Legislature can be obtained by contacting Scott Smith, Aquatic Nuisance Species Coordinator, Washington Department of Fish and Wildlife, Olympia, Washington 98501.

Warmwater Fish Enhancement Program

The 1996 session of the Washington State Legislature established a Warmwater Enhancement Program within the Department of Fish and Wildlife. Funding for this program comes from a $5.00 surcharge on freshwater fishing licenses required to fish for bass, walleye, channel catfish, crappie and tiger musky. The surcharge generates $1.25 million dollars a year that is spent on projects that directly contribute to increasing opportunities to fish for and catch warmwater fish species in Washington.

Key elements of the program are listed in Table 7. The fiscal year 1998 spending plan for the Warmwater Enhancement program is outlined on Table 8.

Table 7. Key Elements of the Warmwater Bill.

- # Increase opportunities to fish for and catch warmwater game fish
- # Fund “new” activities only.
- # Emphasize in-the-field work activities.
- # Utilize co-op groups and volunteers.
- # Minimize adverse impacts on native fish and wildlife.
- # No increase in deleterious exotic species.
- # No construction or O & M funding for Ringold.

Table 8. Summary of Warmwater Enhancement Activities/Spending FY98.

Activity		Spending Level
Fish Production		
Ringold Construction		$350,000
Fish Stocking (plus $30K carryover)		90,000
Fish Management		
Stock Assessment Teams		210,000
Start-up Equipment		90,000
Access/Habitat Projects		100,000
Research		65,000
Rehabilitation		34,000
Aquatic Nuisance Species		36,000
Office/Computer Support		20,000
	Total	$995,000

Distribution and Recent Management of Introduced Fishes in Oregon

Kin Daily
Warmwater Fish Biologist, Oregon Department of Fish and Wildlife

Current Distribution of Introduced Fishes

At least 23 species of introduced game fish are found in freshwater habitats in Oregon. These include four species of salmonids, American shad, striped bass, and 17 spiny-rayed fishes classed as warmwater or coolwater game fish. The salmonids include brook, brown and lake trout, and Atlantic salmon. The spiny rayed group includes large and smallmouth black basses, walleye, catfishes, and several species of “panfish”. Some non-game species are also introduced, most notably common carp and grass carp. The current distribution within the state is the result of deliberate stocking for fisheries, the natural spread into new habitats (such as walleyes in the Columbia, which are believed to have originated in Washington) and by illegal transfers of fish. The black basses and panfishes are the most widely distributed, with at least six species occurring in each of the state's 18 river basins. Brook trout are the most widely distributed non-native salmonid, occurring in all but the coastal basins. Distribution of the other non-native game fish species is much more limited.

History of Introductions

All of these fishes came to Oregon through the efforts of persons or agencies that saw benefits to their introduction. Most initial introductions into the state occurred before the turn of the century when there were few restrictions. Ben Hur Lampman in his book "The Coming of the Pond Fishes" (Binfords & Mort, *Publishers*, Portland, Oregon, 1949) did a thorough job of documenting early introductions, starting with the escape of carp from a pond at Troutdale in 1881.

Early settlers were eager to establish the good eating, white-meated fish they had been accustomed to "back home". Since those early years, little has changed in the mainstream public attitude and education regarding the introduction of new species. In the early days fish introductions by private citizens were unregulated. Even today many people are unaware of or disregard state restrictions on the transport and release of fish. Therefore each year new species show up in new places.

Warmwater fish species were brought to Oregon late in the nineteenth century and were stocked into many of the coastal lakes in the 1930's. ODFW records show that Tahkenitch Lake was stocked with 20,000 warmwater fish of "unknown" species in 1935, followed by catfish, largemouth bass, crappie and bullfrog in 1937-38. Yellow perch must have been included with the "unknowns". It probably didn't take long for these species to be carried the few miles to Siltcoos and other Florence area lakes.

ODFW stocking records for warmwater fish show that Devils Lake received 90,000 "catfish" in 1928 and thousands of "unknowns" in 1933, 1934 and 1935, followed by catfish, largemouth bass, crappie and bluegill in 1936.

The Tenmile Basin Fish Management Plan states that bullhead catfish were stocked in Tenmile Lakes in 1920. The district reports that yellow perch were present before the 1950's. Apparently other warmwater species were slower to arrive, as bluegill were not found there until 1964. The lake system was treated with rotenone in 1968 to eliminate bluegill, bullheads and perch for the benefit of coho. However bluegill soon reappeared and largemouth bass were stocked in 1971 to prey on them. Crappie and yellow perch have also shown up in recent years.

Table I. First Introductions of Non-Native Fish Species into Oregon Waters (from The Coming of the Pond Fishes by Ben Hur Lampman, 1949).

Species	Year	Location
American Shad	1876	Columbia River; migrated from 1871 plant in Sacramento River
Carp	1880	Willamette Valley in Lane County; Columbia River in 1881
Brown Bullhead	1880	Willamette Valley in Lane and Yamhill Counties
Largemouth Bass	1888	Willamette River near Salem and Oregon City
Green Sunfish	1890's	Thought to have immigrated from Washington plantings
Black Crappie	1893	Willamette River near Salem
White Crappie	1893	Willamette River near Salem
Bluegill	1893	Willamette River near Salem
Pumpkinseed	1893	Willamette River near Salem
Warmouth	1893	Willamette River near Salem
Channel Catfish	1893	Willamette River near Salem
Yellow Perch	1904	Columbia River; from 1894 plant in Silver Lake, WA
Yellow Bullhead	1905	Willamette River at Portland
Striped Bass	1914	Coos Bay; migrated from 1879 introduction in San Francisco Bay
Smallmouth Bass	1923	Lake Oswego
White Catfish	1930	Willamette Valley

Rules and Policies Governing New Introductions

ODFW has regulated the introduction, transport, and stocking of fishes through its administrative rule authority for many years. In addition, ODFW is bound by rules which regulate its decisions regarding the movement of fishes to new areas. The framework of protective rules is intended to restrict unauthorized establishment of any fishes, whether native, non-native, hatchery, or wild. Transport permits are the primary basis for regulation of the movement of live fish and avoidance of stocking in areas where they may be detrimental. Permits are required to transport, hold, or release live fish. The basis for approval or disapproval of transport permits is in other rules which prescribe management safeguards for native fishes (such as the Wild Fish Management Policy).

Rules that apply to the introduction of new species include the following:

Fish Management Goals (OAR 635-07-510)

(1) The overriding goal of fish management is to prevent the serious depletion of any indigenous fish species through the protection of native ecological communities, the conservation of genetic resources, and control of consumptive uses such that fish production is sustainable over the long term.

Operating Principles for Natural Production Management (OAR-07-523)

(2) Competition, predation and disease: Introductions of fishes of the same or different species as those already present may seriously reduce natural production through competition for food and space or through predation. Introduction of disease may also reduce natural production. The Department shall oppose any actions that allow competition, predation, or disease to prevent meeting natural production objectives of management plans.

Wild Fish Management Policy (OAR's 635-07-525 through 635-07-529)

(3) Gives the highest consideration to the protection and enhancement of wild fish stocks.

Management Plans (OAR 635-07-515)

(1) Resources of the state shall be managed according to plans which set forth goals, objectives and operating principles for management of species, waters, or areas. Such

> plans are a primary means of implementing Department policies regarding fish management.
>
> (2) The Warmwater Fish Plan adopted in 1987 under authority of OAR 635-07-515 which gives first priority to the protection of endemic salmonids.

The internal ODFW policy pertaining to new introductions is contained in "Guidelines for Fish Introductions or Transfers". This requires that proposals for new introductions go through the established fish introduction proposal review process and receive approval by the Chief of Fisheries. Those rules require that proposals be written and the first test to be met is to protect endemic species. Proposals must be reviewed for avoidance of biological harm and for creation of substantial new recreational opportunity. It also contains a number of conditions and safeguards that must be met before an introduction can proceed. Recently-updated stocking guidelines for warmwater fish limit new introductions to basins where the species already occurs or where there is no chance of escape into flowing waters.

The Department has been conservative in introducing new species into Oregon waters. Few new legal introductions have occurred since the 1970's. The agency does not approve introductions that will place native species at ecological, genetic, or disease risk. In the last 25 years only two new introductions of species capable of reproducing have been made in coastal drainages. One was the introduction of largemouth bass into Tenmile Lake in 1971 to prey on the growing bluegill population. The other was of black crappie into Town Lake, a small sand dune lake near Pacific City that already contained largemouth bass. The two other recent introductions of exotic fish into the coastal systems were of sterile or functionally sterile fish. One was of white-striped hybrid bass into North Tenmile Lake from 1982-88. This program was canceled due to concerns over fish straying into other waters. The other was of triploid grass carp into Devils Lake by the Devils Lake Water Improvement District in 1986, 1987 and 1993 to control aquatic vegetation.

Illegal introductions are a continuing problem with far-reaching ecological and management consequences which are often extraordinarily hard to reverse. At least 17 instances have been documented since 1987. Legal constraints are ineffective when the probability of being apprehended is very low. Whenever possible, the media and employee contacts with individuals and groups are used to educate the public about the damage to resources and fisheries that result from these irresponsible acts.

By rule, illegally introduced fishes have no standing in ODFW's fish management unless they are included in the objectives of fish management plans adopted by the State Fish and Wildlife Commission. In the past ODFW has often attempted to make the best of a circumstance beyond its control by managing to maximize the public benefits from the illegal introductions. This response could be interpreted as rewarding the perpetrators for their illegal act. Recently when largemouth bass appeared in Davis Lake the Department made the decision to actively manage against the species by excluding them from the statewide bag and size limits for bass. The decision was also made not to transplant bass removed from the lake to other waters where bass anglers could benefit from them (an exception was made to allow them to be stocked in a juvenile-only fishing pond).

The following table describes changes in fish distribution in the last decade due to illegal and legal introductions as well as natural expansion of distribution since adoption of the Warmwater Fish Management Plan in 1987.

Table II. Fish Introductions Since 1987.

Status	Location	Introduced Species
Illegal	Eel Lake	black crappie
Illegal	Prineville Res.	black crappie
Illegal	Saunders Lake	yellow perch
Illegal	Tenmile Lakes	smallmouth bass and black crappie
Illegal	Henry Hagg Reservoir	black crappie and bluegill sunfish
Illegal	Phillips Res. [1/]	yellow perch and walleye
Illegal	Town Lake	yellow perch
Illegal	St Louis Warm-Water Fishing Ponds	carp
Illegal	Diamond Lake	Tui chub
Illegal	Willamette River	golden shiners
Illegal	Cape Meares Lake	bluegill sunfish
Illegal	Crane Prairie Res. [2/]	largemouth bass, crappie, bluegill
Illegal	Rogue River [3/]	Umpqua squawfish
Illegal	Emigrant Res.	channel catfish
Illegal	Davis Lake 1/ [4/]	largemouth bass
Illegal	Langdon Lake	brook trout (subsequently chemically treated)
Illegal	Mid Fork Willamette River [1/,5/]	walleye
Legal	Town Lake	black crappie
Legal	Four Mile Lake [6/]	lake trout
Legal	Thompson Valley Reservoir	hybrid bass
Legal	Owyhee R. below reservoir	brown trout
Legal	Lake Lytle	black crappie
Legal	Devils Lake	triploid grass carp
Natural	Willamette River below falls	walleye
Natural ?	Willamette River above falls [1/]	walleye
Natural ?	Willamette River above falls	smallmouth bass
Natural ?	Brown trout [7/]	lower Deschutes R.

Footnotes:

[1/] Not protected by angling regulations.

[2/] The basin fish management plan contains specific management objectives for largemouth bass.

[3/] Umpqua squawfish is native to the Umpqua River, but is introduced to the Rogue basin.

[4/] Largemouth bass in Davis Lake are not protected by angling regulations.

[5/] Walleye in the Middle Fork are separated by a long distance from any other walleye known from the Willamette, suggesting that they were introduced rather than spreading naturally, not protected by angling regulations.

[6/] The OFWC adopted as an objective of the Klamath Basin Plan to review this proposed introduction which is still pending.

[7/] Brown trout in this reach originated from fish stocked in Lake Simtustus; the lake is no longer stocked with brown trout and the population in the Deschutes below the lake is not expected to persist.

Recent Management

The Oregon Department of Fish and Wildlife has sole management authority over these introduced fish species. None is under joint management with another state, nor do federal agencies have authorities other than those implicit in their habitat management. In the Columbia and Snake Rivers, concurrent management of shared populations is desirable for practicality of enforcement, but each state maintains independent regulatory authority. Striped bass, shad, catfishes, perch and walleye, sunfishes, black basses, and bullfrogs are classified by statute as game fish and are managed for recreational fisheries by the Oregon Department of Fish and Wildlife. The only introduced species with statewide harvest restrictions are largemouth, smallmouth and striped bass, and the four species of salmonids.

Table III. General Regulations on Introduced Game fishes.

Species	Location	General Regulation
Striped bass	Coos and Umpqua Rivers	2/ day; 30 inch minimum
Largemouth bass*	Statewide	5/ day; no more than 3 over 15 in.
Smallmouth bass*	Statewide	5/ day; no more than 3 over 15 in.
Walleye	Columbia River only (not regulated elsewhere)	5/ day; 18 inch minimum; no more than 1 > 24 inches
Hybrid bass	Thompson Valley and Ana Reservoirs.	1/ day; 16 inch minimum
Atlantic salmon	Hosmer, East, Davis Lakes	Catch and release in Hosmer; otherwise part of regular trout bag
Lake trout	Deschutes Basin; Wallowa Lake	1/ day; 24 or 30 inch minimum, depending on location in Deschutes Basin; no size limit, part of regular trout bag in Wallowa Lake
Brown trout	Klamath, Deschutes, North Umpqua basins	Catch and release or 1, 2, , or 5 fish bag limits depending on location
Brook trout	Statewide in streams	None
Brook trout	Standing waters	General trout regulations except no limits in most NE Zone lakes
Sunfishes	Statewide	None
Crappies	Statewide	None
Catfishes	Statewide	None
Perch	Statewide	None
Shad	primarily Coos, Siuslaw, Umpqua and Columbia Rivers	None

Warmwater Game Fish

The Warmwater Fish Plan adopted by the Oregon Fish and Wildlife Commission in 1987 provides management direction for warmwater game fish. It sets the framework for development of the warmwater fish sections of basin fish management plans. The overall goal is to manage warmwater game fish and their habitats to provide optimum recreational benefits to the citizens of Oregon. Objectives are:

1. Provide a diversity of angling opportunities.
2. Expand distribution by stocking warmwater species where habitat is suitable and expansion is consistent with fish management programs.
3. Increase angling opportunities and use of warmwater species where desireable.
4. Maintain, restore and enhance populations of warmwater game fish in individual waters.

Most management since adoption of the plan has centered on improving existing fisheries. To provide a diversity of angling opportunities species in all waters are classified for management under one of four alternatives: basic yield, quality, high yield or trophy. Selection of appropriate alternatives must be consistent with public needs and biological constraints. Surveys, inventories and intensive investigations of fish communities and fisheries are conducted to provide the biological basis for management decisions. Management under the "quality" or "trophy" alternatives usually requires regulations that are more restrictive that those in general use. Angling regulations are intended to promote recreational benefits from popular fisheries.

More restrictive special regulations are in effect for largemouth, smallmouth and/or hybrid bass in 14 waters. Except for walleye in the Columbia River, the harvest of other non-native game fish species is not restricted. Other Management actions used to improve warmwater fish populations and fishing opportunities include:

1. Developing strategic plans and comprehensive management systems to provide long-term management direction.
2. Developing and stocking new waters or doing supplemental stocking after fish kills or where recruitment is limiting. Recent emphasis on increasing angling opportunity in urban areas.
3. Enhancing warmwater fish habitat to attract fish to anglers or to enhance fish populations.
4. Conducting research to evaluate management actions and answer long-term management questions (recent emphasis on species other that bass - Emigrant crappie).
5. Providing information on warmwater fish management to other agencies and the angling public.

Table IV. Special regulations for warmwater fish in effect in 1998.

Species	Water	Acres/Miles	Regulation	
			Bag	Size
LB	Lytle	69	0	Catch and Release
LB	Garrison	90	1	15" minimum
LB	Selmac	148	1	None
LB	Cottage Grove	1139	5	15" maximum
LB	Prineville	3136	5	12" min./3 over 15"
LB	Dog	189	3	15" minimum
LB	Lake of the Woods	1146	5	1 over 15"
LB	McKay	1316	3	15" minimum
SB	Prineville	3136	5	10-14" slot
SB	Umpqua Basin	286 miles	10	None
LB/SB	Hells Canyon	2400	5	12" minimum
LB/SB	Oxbow	1145	2	12-16" slot;spring C&R
LB/SB	Brownlee	15000	5	12" minimum
HB	Ana	60	1	16" minimum
HB	Thompson	1802	1	16" minimum
All WW	Davis	3906	*	*No limits

Introduced Trout

Brook Trout

Brook trout are an important component of high lake fisheries (e.g. Central Oregon Century Drive lakes). The primary concern is that stocking of lakes may contribute to stream populations that could compete with native species. The current thinking is that impacts on native fish occurred years ago and that stopping lake stocking now wouldn't help. Bag limits on brook trout in streams have been removed, but the benefits to native species will likely be negligible.

Brown Trout

Stocking is limited to the lower Owyhee River using brood fish from Wickiup Reservoir as an egg source. Brown trout do better than native redband trout in sections of the Deschutes River that are impacted by artificially manipulated flows. Though not abundant, brown trout provide the only trout harvest in this area and are protected by a 2-fish bag limit. Redbands in this area are protected by a catch and release regulation.

Lake Trout

Lake trout occur in only five Oregon lakes, Odell, Crescent, Summit and Cultus in the Cascade Mountains of Central Oregon, and Wallowa Lake in Northeast Oregon. A conservation concern is for bull trout in Odell Lake. A 30-inch minimum is in place to protect smaller bull trout that might be misidentified by anglers and kept for lake trout.

Atlantic Salmon

Atlantic salmon are currently stocked in only two lakes, Hosmer and East, neither of which has native fish concerns.

History and Distribution of Introduced Fish in California

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California Department of Fish and Game

Abstract- *Moyle and Williams (1990) listed 113 native California inland fishes that included 63 full species, of which 5 are extinct (Dill and Cordone 1997). Fish fauna categorized as gamefish consists of ten full species including four anadromous species; two salmonid species with both anadromous and resident forms; three resident salmonid species, and one warmwater species. A total of 81 full fish species not native to California have been introduced into the state for reasons that include 1) for food, 2) to improve sport fishing, 3) as a biological control of unwanted organisms, 4) as a control for aquatic weeds, 5) to provide a forage fish, 6) for humane reasons, 7) for political reasons, and 8) by accident. Of these 81 introduced species, 57 have been reported to have achieved lasting success. Goldfish, Carasius auratus, were the first non-native fish reported collected from the wild between 1860 and 1862. Several summaries have been completed on the history and status of introduced fishes in California of which Dill and Cordone (1997) is the most recent and complete. Six arbitrary phases of introductions starting in 1871 have been identified and are discussed that document various social, political, and economic periods of fish introductions. Introductions have been made throughout California of both non-native and native California fish. Presently, introduced fish are found in almost all waters containing fish. The few exceptions include waters with extreme habitat conditions or in very isolated areas.*

* Dennis chose to have only the abstract of his talk published in the Proceedings.

Distribution and Recent Management of Introduced Fishes in Idaho

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Idaho Department of Fish and Game

Abstract- *Past introductions of exotic species, purposeful, and accidental have established successful fisheries in Idaho, sometimes at the expense of native stocks. The Idaho Department of Fish and Game (Department) records, since 1913, documents over 1.2* ***BILLION*** *non-native fish of 48 different species stocked in Idaho. Recently, the Department has protected native species through restrictive regulations, reduced stocking rates, use of sterile fish, extensive marking programs, and in some cases elimination of non-native fish releases. Conservation agencies are faced with a real dilemma in that they are to preserve and protect native species, yet must provide recreational fishing opportunities for their constituents, sometimes in conflict with those native species.*

In the late 1800s, Idaho's pioneers from the east and midwest, longing for the kinds of fish they were used to catching, began shipping fish by railroad and stage lines for release into Idaho's lakes and rivers. Bass, crappie, perch, and brook trout were some of the first exotic game fish to arrive, with carp introduced as a potential food fish. Since that time, over 1.2 BILLION non-native fish of 48 different species have been stocked throughout all of Idaho's major drainage's to provide for recreational fisheries.

Introduced strains of rainbow trout were by far the most numerous and widely distributed fish released into Idaho waters. Nearly 585 million non-native rainbows (59%) have been released as documented by the Department records since 1913. In the past thirty years alone, over a half BILLION non-native fish have been stocked in Idaho's waters to provide recreational fishing. However, with increased emphasis for native species, degraded habitats, and increasing hatchery costs the numbers of stocked fish have been declining in Idaho since 1990 (Figure 1).

In 1975, the Department adopted in its 15-year policy plan, and again reiterated, in its 1996-2000 Fishery Management Plan, a policy that wild native salmonids would be given priority consideration in all management decisions.

As a result of that policy direction, the Department has been taking steps to protect its wild native fishes. Since 1970, the Department has protected native species through restrictive regulations and protective habitat requirements. Catch-and-release regulations have been effective in protecting native fish (westslope cutthroat) from overharvest in unproductive waters, restoring overharvested populations, providing quality and trophy fisheries, and redirecting consumptive angling efforts to other waters as well as providing "blue ribbon" fisheries for some introduced species. Where quality habitat has been maintained, restrictive regulations have been effective. The Department is also putting more emphasis on developing urban fishing ponds and concentrating non-native fish stocking in altered habitats (i.e., lakes and reservoirs) no longer capable of sustaining native fishes.

Idaho has 26,000 miles of fishable streams and over 3,500 lakes and reservoirs in which the Department manages fish and wildlife resources. There are 42 species of game fish now found in Idaho, of which, 13 are native species. The Department annually stocks approximately three million catchable size rainbow trout and over 14 million fingerlings. Hatchery programs are expensive and the majority of our releases are concentrated in waters with altered habitats (i.e., lakes, reservoirs, and ponds) and in areas with high concentrations of anglers (i.e., campgrounds and urban waters) thus maximizing the return-to-creel and the cost/benefit ratio. Except for some high mountain lakes, waters within designated wilderness areas are not stocked with exotic species and have been established as refugia for wild native populations.

Recent actions by the Department require <u>any</u> species introduction into a drainage that does not currently have that species must undergo the review process adopted by the American Fisheries Society for introductions of aquatic species. This process ensures that any species considered for introduction is prohibited until potential impacts on habitat alteration, trophic alteration, spatial alteration, gene pool deterioration, and disease introduction are assessed.

The Department has altered many fish stocking programs with introduced species in response to listing of native fish as threatened or endangered under the Endangered Species Act (ESA). For example, in some waters all stocked fish must be marked to distinguish them from wild native species. Size and or bag limit restrictions have also been lifted to favor listed species. Numbers of fish stocked have been reduced and release locations changed to minimize impacts on native fishes. Under our ESA permits, the Department is required to monitor impacts on listed fish from these releases and have found that our stocking program has negligible impacts of native stocks.

Idaho has implemented an extensive fish health-monitoring program to prevent the spread of diseases from hatchery fish to wild populations. Hatcheries are inspected regularly to assess the disease status of their fish prior to release, and diseased fish are not released while undergoing an epizootic. Of great concern is the impact pathogens released from wild fish residing in or above hatchery water supplies have on hatchery populations. It has been well documented that wild fish infect hatchery fish. Idaho is working hard to minimize impacts of diseases on both wild and hatchery fish.

Protecting genetic integrity of native fishes is critical in Idaho's fishery program. Of the 26,000 miles of fishable streams, the Department currently stocks less than 800 miles with hatchery fish. And in areas containing native populations, the Department has begun using sterile fish to provide supplemented recreational fisheries and minimize genetic impacts to wild stocks.

Hybridization has been identified as a real problem in certain waters. Introduced rainbow trout breeding with native cutthroat, and brook trout breeding with native bull trout, have been documented, but the long-term impacts are unknown at this time. The Department is currently taking steps to reduce or eliminate hybridization through physical removal programs (i.e., gillnetting, multipass-electrofishing) and also stocking sterile fish in areas that have native populations. Although sterile fish are more expensive to produce, we believe it is a small cost when managing fisheries with native fish populations. The introduced species, which has had the most widespread impact to Idaho's native fisheries, is the brook trout. They were widely distributed, are very prolific and adaptable to both lake and stream habitats.

Idaho's most notorious exotic species introduction was the introduction of mysis shrimp into large lakes in the northern part of the state. Mysis were introduced in Priest Lake to provide enhanced forage for an introduced species (kokanee), but resulted in the establishment of a classic predator trap through the increased survival of another introduced species, lake trout. This large lake trout population has adversely impacted the native cutthroat and bull trout stocks. In Upper Priest Lake, the Department has begun an experimental program to physically remove lake trout through gillnetting in hopes of enhancing cutthroat and bull trout. This has shown to be an effective way to remove lake trout while protecting native species, but is very costly and because of continued movement of fish from Priest Lake may not achieve the desired results.

Conservation agencies typically introduce fish for what they can provide in the way of recreational fisheries, not what they can do for the ecosystem. In Idaho, like most all states, it is illegal to introduce fish into public waters without a permit from the Department. However, illegal fish introductions by the public and escapees from fish culture facilities pose a real threat for future unwanted introductions. Overnight airfreight, easy accessibility to out-of-state commercial fish hatcheries, and an impossible enforcement situation has the potential for future disasters on native species.

Introduction of non-native fish during the past twenty years has caused concern with conservation agencies relative to the protection of wild native species. Past introductions, purposeful and accidental, of exotic species have established successful fisheries, sometimes at the expense of native stocks. In Idaho, an example of a successful, from a recreational fisheries point of view, yet illegal introduction is the northern pike into the chain lakes of North Idaho. Disgruntled fishermen took matters into their own hands when the Department would not yield to their requests of establishing pike and walleye fisheries. This illegal introduction established a thriving, trophy pike fishery at the expense of a native cutthroat population.

Conservation agency managers must ensure that decisions about future introductions are based upon sound ecological evidence and the potential impacts are properly evaluated. One thing for sure, once non-native fish are established they are sometimes very difficult if not impossible to eradicate, not only from an economic standpoint but also from a social or political view.

Stocking hatchery fish, both native and non-native, is merely a tool fish managers use to provide recreational fisheries or restore native populations. Like many tools, there is a right and wrong way to use them. We do not propose to eliminate the tool, but simply apply our acquired knowledge to use it correctly. Conservation agencies are faced with a real dilemma in that they are mandated to preserve and protect threatened and endangered species as well as perpetuating fishery resources for their constituents, often in conflict with each other.

Management Perspectives

Session Chair:

Kin Daily
Oregon Department of Fish and Wildlife

Introduced Species as a Factor in Extinction and Endangerment of Native Fish Species

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Abstract- *In a previous analysis of extinctions of 40 North American native fishes, habitat alteration was cited as a factor in 29 cases (73%), introduced species in 27 cases (68%), and contaminants in 15 cases (38%). The present analysis of factors cited in Endangered Species Act (ESA) fish listings revealed a similar pattern. Of the 92 species listed through 1991, 69 final listing notices provided sufficient information about factors contributing to endangerment to allow analysis in a manner similar to the extinctions analysis. In these 69 cases, habitat degradation was again the most commonly cited factor (63 listings, 91%); contaminants were cited in 28 listings (41%); and introduced species were cited in 48 listings (70%)-in 40 (58%) as a factor in species decline and in 8 others (12%) as a continuing threat. Of these 48 listings, 35 introductions related to sportfishing (i.e., introduced as game, forage, or bait species). As with extinctions, most ESA listings cited more than one factor, and most cases in which introduced species were cited appeared to have been the consequence of intentional introductions. A recently completed study by the U.S. Congressional Office of Technology Assessment concluded that a pattern of intentional introductions of fish and other species causing harm as often as do unintentional introductions reflects "a history of poor species choices and complacency regarding their potential harm." These patterns suggest the need for greatly improved decision making in species introductions if we are to reduce threats to native fish fauna and avoid this impression of complacency.*

The U.S. Congressional Office of Technology Assessment (OTA) concluded that nonnative species “are here to stay and many of them are welcome" (OTA 1993). However, in the same document OTA concluded that other nonnative species "have had profound environmental consequences, exacting a significant toll on U.S. ecosystems." In reviewing the data for this paper, the validity of both of these seemingly contradictory statements was apparent. In presenting the results in various forums it has also been apparent that there is strong resistance, both by those who would introduce and those who generally oppose introductions, to accepting this validity.

The importance and value of nonnative species, at least in the United States, is exemplified by their extensive use in research, biological control, the aquarium industry, aquaculture, and fisheries management. While the benefits of using nonnative species are recognized, in this paper, I will focus on problems associated with fisheries management uses of nonnative species.

Nonnative species have become a component of current sportfishing programs in most states. The brown trout *Salmo trutta*, for example, is native to Europe and and western Asia but was introduced across the United States and is now a popular recreational species. Large recreational fisheries have developed for Pacific salmon *Oncorhynchus* spp. introduced into the Great Lakes, although it should be noted that hatchery production is used to maintain yields for these fisheries. Anglers who fish for rainbow trout *0. mykiss* in Virginia, Colorado, and Pennsylvania, and the millions of anglers who fish for largemouth bass *Microptenes salmoides* outside its native range (e.g., Oregon, California. and Arizona) clearly depend on a nonnative species for their angling enjoyment. The introduction of several nonnative species, for all their sportfishing value, has also been the source of substantial problems for native species. In testimony before the U.S. Congress, for example, OTA noted that biodiversity has declined both by the loss of native species and the addition of nonnative species.

Fisheries managers have facilitated the demand for and expectation that nonnative fishes will continue to be available for recreational fishing. However, we have done a less thorough job of anticipating or understanding the potential consequences of introductions (e.g., predation, competition, habitat alteration, hybridization, and disease transfer) and their outcomes for native species. There is a growing literature on the uses of introduced species and their effects on native species to which readers may turn for additional information (see Rosenthal 1980; Garman and Nielsen 1982; Courtenay and Stauffer 1984; Crossman 1991; DeVoe 1992; Rosenfield and Mann 1992). This paper provides an analysis of some of the most severe results of managing with nonnative fishes.

Methods

Miller et al. (1989) compiled information from a number of sources to provide a review of factors associated with the extinctions of 27 species and 13 subspecies of North American fishes over the past 100 years. They also generally assessed whether cited factors played a major role in the demise of each taxon. All analyses of extinctions in this paper are based on information presented by Miller et al. (1989).

Endangered Species Act (ESA; 16 U.S.C.A. §§1531 to 1544) listings (i.e., determinations of Threatened or Endangered status) are published in the Federal Register and are now required to include a description of factors that led to the listing. Information on factors cited in the listing of fish species under the ESA was derived from the files of the U.S. Fish and Wildlife Service for all fish listings through 1991. Many early listings provided only the name of the species with no specific information on the causes of decline or continuing threat and, therefore, were not included in my analysis. Adequate information existed for 69 of 92 U.S. species listed at the time of the analysis. Unfortunately, ESA listings did not consistently state the relative importance of the cited listing factors as Miller et al. (1989) did for extinctions.

Results

Extinctions

More than one factor was cited for most of the 40 extinct taxa analyzed by Miller et al. (1989). Habitat alteration was cited as a factor in 29 of 40 cases (73%), introduced species in 27 cases (68%), and contaminants in 15 cases (38%). Though the importance of factors other than introduced species is recognized and is presented here to clarify the relative frequency with which they have been cited by the reviewed sources, the remainder of this analysis is limited to introduced species effects.

Among the 27 cases in which introduced species were cited as a factor in extinction, over two-thirds (19 cases) were apparently the consequence of intentional introductions. Intentional introduction is used here to refer to purposefully bringing a species into an ecosystem, including containment facilities within them, to which that species is not native. The term intentional introduction therefore includes those taxa that are introduced directly (though not always legally) or indirectly into an aquatic habitat beyond their natural range through such actions as stocking game or forage species, or releasing bait or aquarium species. Species that have escaped from containment (e.g., aquacultural and aquarium production, rearing, or holding facilities) are thus also intentional introductions because escape from such facilities is a consequence of the initial introduction.

Introduced species were cited by Miller et al. (1989) as a "major" or "primary" factor in extinction of the native species in 10 of the 27 introduced species cases examined (37%). All 10 of these cases appear to have been the result of intentional introductions, with 7 of the 10 involving sportfishing introductions (i.e., introductions of game fish, forage for game fish, or bait species likely used in sportfishing). According to the information presented by Miller at al. (1989), habitat alteration was not cited as a factor in the extinctions of 6 of these 10 species. While I recognize that species decline in many cases is likely due to a combination of factors, Miller et al.'s (1989) findings indicate that habitat alteration is not, as is often suggested, always a necessary precursor to severe impacts by introduced species.

ESA Listings

The OTA (1993) noted that "biological communities can be radically and permanently altered without extinctions occurring." The first stated purpose of the ESA (Section 2(b)) is to provide a means of protecting the ecosystems upon which Threatened and Endangered species depend. There is perhaps no clearer signal, short of extinction, of the disruption of ecosystem integrity than the listing of one of its component species under the ESA.

In the 69 fish listings analyzed (Table 1), habitat alteration was the most commonlv cited factor (63 species, 91%). Contaminants were cited in-28 species listings (41%), and introduced species were cited in 48 cases (70%)-in 40 (58%) as a factor in the decline of and in 8 others (12%) as a continuing threat to native species. Often several introduced species were cited and most ESA listings cited more than one factor. As with extinctions, most cases that cited introduced species appeared to have been the consequence of intentional introductions.

Among the 48 cases that cited introduced species as a listing factor, 7 involved ornamental species, 7 involved aquacultural species (other than ornamentals), and 6 related to pest control. Of the 48 cases, 35 involved sportfishing introductions; centrarchids were the most frequently cited taxon of sport fish.

The largemouth bass was the most frequently cited individual species (21 cases). Green sunfish *Lepomis cyanellus* was cited in nine cases. Other centrarchids included bluegill *L. macrochinis*, crappie *Pomoxis* spp., smallmouth bass *Microptents dolomieu*, and other sunfish. Ictalurids were also commonly cited: channel catfish *Ictalurus punctatus* was cited in 7 cases and a variety of bullhead species *Ameiurus* spp. were cited in 11 cases. Cited baitfish species included red shiner *Cyprinella lutrensis* and the fathead minnow *Pimephales promelas* and "other baitfish." Rainbow trout and brown trout were cited in seven and 31% cases, respectively, primarily for having caused problems through hybridization with native trout species or as predators of smaller species. In most cases, the listing information did not indicate whether the introduction was sanctioned by a public agency.

Discussion

Primack (1993) pointed out that whereas patterns of evolution have proceeded largely as a result of geographic isolation, "humans have radically altered this pattern by transporting species throughout the world." Any introduced species that survives the transfer necessarily affects the receiving ecosystem. In a recent text on biological pollution, Courtenav (1993) summarized that "every introduction will result in impacts to native biota, which may range from almost nil to major, including extinction, with time." Nonnative species can affect native species through a number of mechanisms including hybridization, competition, predation, pathogen transfer, and habitat alteration.

As noted earlier in this paper, prior habitat degradation is not a necessary precursor to severe impacts from introduced species. However, habitat degradation clearly can make a species and its supporting ecosystem more vulnerable to the effects of a nonnative species. This is apparently the case in the Colorado River where the combination of dams and introduced species has led to the endangerment of four native fish species adapted to large, flowing river systems (Minckley 1991). Moyle and Williams (1990) determined that large water projects, in concert with introductions of fish species better able to cope in altered habitats, were largely responsible for the decline of California's native fish fauna. In particular, the presence of introduced species was a “very important factor" or "principal factor" (Moyle and Williams 1990) in the status of 49% of species described as extinct, endangered, or in need of special protection.

Whether habitat has been altered or not, the decision to introduce must be made with great care. Unfortunately, the results of a recent investigation of a group of aquatic taxa (OTA 1993) suggests this may not have always been the case. Whereas the view is often expressed that unintentional introductions constitute the major source of problems to natural ecosystems, OTA (1993) found that intentional introductions, even using a narrower interpretation of intentional (*viz*, deliberate releases) than is used in this paper, are as likely to cause problems as are unintentional introductions. The OTA concluded that this pattern reflects "a history of poor species choices and complacency regarding their potential harm." Whereas the results of this analysis may support OTA's conclusion about fisheries management choices, I am less convinced that the source of our mistakes is complacency.

I suggest that the record of "poor species choices" is one of false assumptions and unrealistic expectations. For example, in situations where human activity has so altered ecosystems that native species have been lost or severely reduced, nonnative species or specific different life stages of native species have been used in efforts to restore some perceived ecosystem function. When an altered environment cannot support a particular life stage of a native species, culture techniques may serve a useful purpose in bridging the gap until the native species is again able to persist on its own. An example of this type is the reintroduction of cordgrass *Spartina alterniflora* for shoreline stabilization along the U.S. Atlantic coast. However, this same species was then used outside its native range and is now the source of increasingly severe problems in the Pacific Northwest. Though the same introduction decision was made, the outcome when the species was used outside its native range was very different.

Table 1. Analysis of factors cited in listing of fish species under the Endangered Species Act.[a] Names follow Robins et al. (1991).

		Listing factor(s)			Purpose of introduction			
Common name	Scientific name	Habitat alteration	Pollution	Introduced species	Sportfishing	Pest control	Ornamental	Aquaculture
Catfish, Yaqui	Ictalunts pricei	X		X	X			
Cavefish, Alabama	Speoplatvrhinus poulsoni		X					
Cavefish, Ozark	Amblvopsis rosae		X					
Chub, bonytail	Gila elegans	X		X	X			X
Chub, Borax Lake	Gila boraxobius	X		X[b]				
Chub, Chihuahua	Gila ingrescens	X	X	X	X	X		
Chub, humpback	Gila cypha	X		X	X			X
Chub, Hutton tui	Gila bicolor spp,	X	X[b]	X[b]				
Chub, Owens tui	Gila bicolor snvderi	X		X	X			
Chub, slender	Erimvstax cahni	X	X					
Chub. Sonora	Gila ditaenia			X	X			
Chub, spotfin	Cyprinella monacha	X	X					
Chub, Virgin River	Gila robusta semidnuda	X		X	X			
Chub, Yaqui	Gila purpurea	X		X	X			
Dace, Ash Meadows speckled	Rhinichthvs osculus nevadensis	X		X	X	X		
Dace, blackside	Phoxinus cumberlandensis	X		X	X			
Dace, Clover Valley speckled	Rhinichthys osculus oligoporous	X		X	X			
Dace, desert	Eremichrhvs acros	X		X[b]				
Dace, Foskett speckled	Rhinichthvs osculus spp.	X		X[b]				
Dace, Independence Valley speckled	Rhinichtirvy osculus lethopoms	X		X	X			
Dace, Moapa	Moapa coriacea	X		X			X	
Darter, amber	Percina antesella	X	X	X[b]				
Darter, bayou	Etheostoma rubrum	X	X					
Darter, Elk River	Etheostoma wapiti	X						
Darter, goldline	Percina aurolineata	X	X					
Darter, leopard	Percina pantheria	X	X					
Darter, Niangua	Etheostoma nianpae	X		X	X			
Darter, slackwater	Etheostoma boschungi	X						
Darter, snail	Percina tanasi	X						
Logperch, Conasauga	Percina jenkinsi	X	X	X[b]				
Loaperch, Roanoke	Percinu rex	X	X					
Madtom, Neosho	Noturus placidus	X	X					
Madtom, Scioto	Nottinis traurmani	X						
Madtom, Smokev	Notunis baileyi	X	X					
Madtom, vellowfin	Notunts flavipinnis	X	X					
Minnow, loach	Rhinichthys cobitis	X		X	X			
Pupfish, Ash Meadows Amargosa	Cyprinodon nevadensis mionectes	X		X	X	X	X	
Pupfish, desert	Cyprinodon macularius	X	X	X	X		X	X
Pupfish, Devils Hole	Cyprinodon diabolis	X						
Pupfish, Leon Springs	Cvprinodon bovinus	X		X	unclear			
Sculpin, pygmy	Cottus pygmaeus	X	X					
Shiner, beautiful	Cvprinella formosa	X		X	X			
Shiner, blue	Cyprinella caerulea	X	X					
Shiner, Cahaba	Notropis cahabae		X					
Shiner, Cape Fear	Notropis mekistocholas	X	X					
Shiner, Pecos bluntnose	Notropis simus pecosensis	X	X	X	unclear			
Silverside, Waccarnaw	Menidia extensa		X	x[b]	x[b]			
Spikedace	Meda fulgida	X		X	X			
Spinedace. Big Spring	Lepidorneda mollispinis pratensis	X		X		X		
Spinedace, Little Colorado	Lepidomeda vittata	X	X	X	X			
Spinedace, White River	Lepidomeda albivallis	X	X	X		X	X	
Springfish, Hiko White River	Crenichthys baileyi grandis	X		X	X		X	

Table 1 (continued).

		Listing factor(s)			Purpose of introduction			
Common name	Scientific name	Habitat alteration	Pollution	Introduced species	Sportfishing	Pest control	Ornamental	Aquaculture
Springfish, Railroad Valley	Crenichthys nevadae	X		X			X	X
Springfish, White River	Crenichthys baileyi	X		X	X		X	
Squawfish, Colorado	Ptvchocheilus lucius	X		X	X			
Sturgeon, pallid	Scaphirhynchus albus	X		X[b]				X[b]
Sturgeon, Gulf	Acipenser oxyrhynchus desotoi	X	X					
Sucker, June	Chasmistes lioris	X	X	X	X			X
Sucker, Lost River	Deltistes luxatus	X	X	X	X			
Sucker. Modoc	Catostomus microps	X		X	X			
Sucker, razorback	Xyraucheri texanus	X		X	X			X
Sucker, shortnose	Chasmistes brevirostris	X	X	X	X			
Sucker, Warner	Catostornus warnerensis	X		X	X			
Topminnow, Gila	Poeciliopsis occidentalis	X		X	X	X		
Trout, Apache	Oncorynchus apache	X		X	X			
Trout, greenback cutthroat	Oncorynchus clarki stomias	X			X			
Trout, Lahontan cutthroat	Oncorynchus clarki henshawi	X			X			
Trout, Little Kern golden	Oncorhynchus aguabonita whitei	X		X	X			
Trout, Paiute cutthroat	Oncorynchus clarki seleniris	X		X	X			

[a] Analysis limited to those species for which information in Fish and Wildlife Service ESA final rule file included the five ESA listing factors.
[b] Cited as continuing threat rather than cause of decline.

Use of nonnative species to maintain ecosystem function must rely on solid understanding and realistic expectations. To some extent, expectation and prediction can be improved by gathering information on both the species being considered for introduction and the receiving environment. However, I believe OTA (1993) identified a particularly important basis for false assumptions when it singled out fisheries managers for continuing to use the "erroneous concept" of the vacant niche (i.e., "filling" a perceived void in an ecosystem with an introduced species).

For example, the waters behind a new dam may concentrate detritus and silt-dwelling invertebrates where a previously abundant stream-dwelling native salmonid now survives only in low numbers. The ecosystem continues to function in some manner; we simply don't care for what the altered energy and nutrient use pattern is now producing as a result of the manipulation. Because we do not see the outputs of the altered system as anything of immediate use, some refer to the new pattern as having "voids."

In many past cases, species chosen to "fill the void" appear to have been selected without considering potential effects on the receiving ecosystem because those species were deemed to be of more immediate benefit to humans than what persisted of the native community in the altered ecosystem. Perhaps it was seen as simpler to look for ways to channel the altered resource use pattern into a product of more immediate human benefit than to address alternatives to the proposed manipulation seriously or even to look for ways to minimize its consequences. Often the choice has been instead to manipulate the system further by introducing new species to fill these illusory empty niches.

In the waters behind the new dam cited above, one biologist may see just a single "empty niche" and introduce carp to convert the detritus and invertebrate biomass into fish flesh, Another biologist (or creative but misguided angler) may imagine any number of "empty niches" to fill and decide, for example, to introduce a crayfish and a small catostomid to feed on the detritus now concentrated in that portion of the watershed, plus maybe a small centrarchid to prey on the newly abundant benthic invertebrates. Then a large predatory centrarchid or two may be introduced to feed on this prey base and create a new fishery. Some refer to this approach of filling imaginary empty niches by introducing a whole suite of species as "ecosystem management," though most often it involves only a portion of the ecosystem. I believe it is more akin to ecosystem recreation, with all of the attendant evolutionary ramifications for native species throughout that and any interconnected ecosystems. Because of the uncertainties of predicting a particular result in such cases, OTA appropriately warns that "application of this approach to natural communities is inappropriate."

One other issue that must be addressed to understand the record on introductions, one that clearly links introductions to activities that alter habitats, is that introductions have often been driven by required mitigation for federal activities (e.g., dams), The species chosen to meet mitigation demands could have been native but often has been a nonnative species. Often nonnative species are the simplest alternative because culture techniques for a few commonly used species are well understood. Because of their prior use in other environments, these commonly used nonnatives are also species the public has become accustomed to seeing portrayed as the preferred species.

Conclusions

Nonnative aquatic species have been and continue to be both a source of economic benefits and costs to many sectors of society and a major factor in the loss of biological diversity. Despite this importance, the implications of nonnative species introductions have in general been underrecognized. This may be changing.

Recent headlines have included such items as the following: “Exotic Plants, Animals Imperil U.S. Ecosystems" (Los Angeles Times); "Court Action is Studied to Shut CAP" (ArLona Republic, 21 January 1994-referring to the potential for nonnative species transported by the Central Arizona Project, to harm native species); "Biology That's Alien and Expensive" (Washington Post, 7 October 1993); and "Introduction of Nonnative Fish is Devastating Many Local Rivers and Lakes" (Oregonian, 28 November 1990). The articles have not projected positive images of fisheries management decisions, but I believe the increasing awareness of this issue within and outside the fisheries profession suggests the need to improve upon our record.

Though calls by Congress for further research have been used as a delaying or obstructionist tactic, additional research can help clarify the risks of nonnative species introductions, prioritize actions intended to minimize such risks, and enable and promote the use of native species. However, I believe the greatest need is a change in attitude from one dominated by value judgements based on immediate human benefit to one that values the integrity of native ecosystems and all of its component species, a huge long-term benefit to our children's children, indeed to the human species. Soule (1986) warned that "dithering and endangering are often linked;" let us not dither any longer.

Acknowledgments

This paper is in part the result of work done while the author chaired the Intentional Introductions Policy Review (review) Committee of the federal interagency Aquatic Nuisance Species (ANS) Task Force established under the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. Though much of the information and language used in this paper are directly adapted from the review, this paper is presented as the position of the author only, not the ANS Task Force or any of its member agencies.

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A Review of the Federal Policy for Conserving Species Listed or Proposed for Listing under the Endangered Species Act , While Providing and Enhancing Recreational Fisheries Opportunities

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Abstract- *On June 7, 1995, President Clinton signalled his strong support for recreational fishing as a valuable American past-time and important economic activity when he signed Presidential Executive Order (EO) 12962 (Appendix I). The EO recognizes the shared values of sport anglers and the broader conservation community and focuses Executive Branch attention on working with our partners on what can be done, instead of on what cannot. The EO is solidly based on an ecosystem approach and emphasizes habitat restoration as a key to sustainable recreational fisheries. One of several actions called for in the EO was the establishment of a joint U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) policy on Endangered Species Act (ESA) implementation that shared this focus with the recreational fishing community. The resultant policy (Appendix II) recognizes Tribal and State's rights to manage fish and wildlife and reaffirms federal trust and ESA responsibilities; but it also sets forth an ambitious agenda for change – in attitude and actions. The President has committed the NMFS and USFWS (jointly referred to as "the Services") to working better together as well as with our non-federal partners on actions to help preclude the need to list; on listing decisions; on recovery planning and implementation; and beyond recovery to restoration of sustainable aquatic ecosystems that can support recreational fisheries. Within the framework of the ESA, the policy focuses on working with partners to take advantage of opportunities that will help both listed species and recreational fisheries now and in the future.*

Introduction

The Endangered Species Act specifically charges the Secretaries of the Interior and Commerce with the responsibility to identify, protect, manage, and recover species of plants and animals that are in danger of extinction. It is the first stated purpose of the ESA to provide a means to conserve the ecosystems upon which threatened and endangered species depend (16 U.S.C. Sec. 1531(1)). In addition to the ESA, many federal laws recognize the importance of aquatic resources (e.g., Fish and Wildlife Coordination Act, Anadromous Fish Conservation Act, Clean Water Act, Federal Aid in Sport Fish Restoration Act, Magnuson Fishery Conservation and Management Act, and the National Environmental Policy Act among others). These laws outline the roles of federal agencies to protect, restore, and conserve aquatic resources, and to provide for and enhance fisheries and recreational uses; some apply only to activities undertaken, permitted, licensed, or funded by a Federal agency.

Most of North America's aquatic ecosystems have been significantly altered by human impacts. Degraded habitats and nonnative species introductions have reduced the capacity of aquatic ecosystems to support their former diversity and abundance of native species. As of January 31, 1999, within the United States, 109 taxa of fish, 97 species of molluscs, and 16 species of amphibians were on the federal threatened or endangered species list. Habitat alteration and introduced species are, in fact, the two most frequently cited factors contributing to population extirpation and decline among endangered and threatened fish species, including many native recreational fish species (see Lassuy 1995, reprinted in this same Proceedings). In 1996, the Oregon Chapter of the American Fisheries Society (AFS) recognized this pattern and recommended to the Oregon Fish and Game Commission that the Oregon Department of Fish and Wildlife adhere to the AFS protocol for introductions of aquatic species (Appendix III).

The Services recognize that fishery resources and aquatic ecosystems are integral components of our heritage and play an important role in the nation's social, cultural, and economic well-being. For example, nationwide in 1996, 35 million anglers (16 years and older) spent 626 million angler days afield, and nearly $38 billion on tackle, equipment, food, lodging, and other recreational fishing-related expenses. In that same year in Oregon alone, 658,000 anglers spent nearly 8 million angler days afield and over $620 million on these same expenses (DOI 1996).

In the past, resource managers may not have understood the effects of some management actions on ecosystems to the extent they do today. Habitat alteration and degradation, heavy fishing pressure, and introduction of non-native species often resulted in unexpected negative impacts to other ecosystem components. As today's managers realize more fully the impacts of their actions, they also realize that they must be more cautious in the activities they prescribe in natural ecosystems. The benefits gained by some actions may result in losses to non-target species or habitats. This has led to conflicts between some efforts to conserve native species and the ecosystems upon which they depend, and public expectations of aquatic resource managers to maintain and enhance recreational fishing opportunities. These issues have been of particular concern in those instances where the Services' responsibilities for recreational fisheries and recovery of federally protected species have presented conflicting options.

Successful future management of the Nation's aquatic resources must become more focused on an ecosystem approach. It will also require substantive cooperative partnerships and a willingness to resolve differences among federal, state, and Native American governments, and our private citizen partners. Executive Order 12962 and associated policy seek to provide a framework for federal participation in that process by clarifying our mutually recognized concerns and common goals.

EO and Policy Highlights

The purpose of EO 12962 is to conserve, restore, and enhance aquatic ecosystems to provide for increased recreational fishing opportunities nationwide. To accomplish this, the EO sets forth in its various sections the duties and expectations of federal agencies and outlines new mechanisms to move forward in achieving its purpose. Section 1 defines the duties of federal agencies under the EO and emphasizes the need to work with States, Tribes and others to improve aquatic resources for sustainable fishing opportunities. Section 2 creates the “Recreational Fishing Coordination Council,” essentially a federal interagency council responsible for implementing the EO; and Section 5 creates the “Sport Fishing and Boating Partnership Council,” a complementary forum for non-federal partners to contribute to EO implementation. Section 3 calls for the development of a “Recreational Fishery Resources Conservation Plan” to establish measurable objectives for aquatic ecosystem restoration and a mechanism for evaluating accomplishments. This plan has now been published and is available from any of the authors of this paper.

The focus of this paper, however, is on Section 4 of the EO which calls for the development of a joint (USFWS/NMFS) policy for administering the ESA. That policy (Appendix II) has now been completed and has already begun to prove a useful tool in melding the shared interests of the recreational fishing and broader conservation communities. The purpose of the joint policy is to promote compatibility and reduce conflicts between the administration of the ESA and recreational fisheries. The policy straightfowardly recognizes State and Tribal management jurisdictions, reaffirms federal trust and ESA responsibilities, and then describes activities to be undertaken to minimize and resolve conflicts.

The first outlined activity to help avoid or minimize conflict is to focus on mutually acceptable goals. One way to do this is to ensure consistency between the federal Services in our implementation of the ESA. For example, the Services now rely on a jointly-developed handbook for ESA Section 7 consultation. This greatly reduces occasions where the public and public land managers appear to get "different answers" to the same questions. Other measures to identify and act upon mutually acceptable goals include promoting cooperative actions with our non-federal partners; coordinating with partners on ESA listing actions that may affect recreational fisheries (e.g., through ESA Sec. 4(d) rulings, or as NMFS did in working with the State of Oregon to improve the Oregon Plan); and by focusing ESA education and outreach efforts on those sections of the ESA that most directly impact our non-federal partners (e.g., Secs. 6, 9, and 10).

Another area emphasized in the joint policy that has proven very effective in focusing the Services, together with our partners, on reducing ESA and recreational fishing conflict has been to invite direct partner participation in a range of recovery and restoration activities. It is now required of the Services to involve partners in developing new ESA Recovery Plans for listed species. Existing recovery plans developed under the ESA are also routinely re-evaluated and the joint policy now directs that when such re-evaluation is undertaken, strategies be identified to minimize the impacts of recovery actions on recreational fisheries.

The joint policy also calls on the Services to encourage restoration on public and private lands that benefits both recreational fisheries and listed species (e.g., by focusing on habitat actions that will benefit both). Other partner participation encouraged under the joint policy includes partner coordination on reintroduction efforts – for example, the USFWS worked extensively with BLM, the Izaak Walton League, and local grazers on the possible reintroduction of Lahontan cutthroat trout to Oregon Canyon Creek in southeastern Oregon. The effort, unfortunately in the authors' opinion, did not result in a reintroduction proceeding. However, the conclusion not to proceed was reached jointly and the process of working together has greatly improved partner relations on other conservation efforts.

Evaluations by the Services of the potential impacts of non-native species introductions must include analyses of the genetic, disease, competition, and predation impacts and, if listed species may be affected, also consider the impact the introduction may have on reaching recovery goals for such species. In many cases, this range of considerations had long been the practice of individual Service offices, but it is now required under the EO and resultant policy that the Services also consider the impact of the proposed introduction on recreational fisheries.

One of the most frustrating aspects of the "controversy" between recreational fishing and the ESA is how often this "us vs. them" portrayal obscures what are actually strong mutually beneficial interactions. For example, improving desert riparian habitat for a threatened neotropical migrant bird likely also improves conditions for the production (and thus catching!) of redband trout. The joint policy clearly recognizes this in calling on the Services to improve understanding of the relation between conservation and recreational fisheries. The policy highlights a range of existing mechanisms within the ESA that allow the Services to incorporate partner recommendations. However, perhaps the most important aspect of this part of the policy is that it calls on the Services to ask our partners to help identify actions that will benefit both ESA-listed species and recreational fisheries – not just to consider input that is offered during a public planning effort, but to go out and really ask for help. There is, in the authors' opinion, a very big difference, even if only as a reflection of a change in attitude, between a "planning exercise" and openly and honestly asking someone for help. Rather than offering a polite opportunity to be heard, this truly says "we are partners in this deal, let's see what we can come up with."

Finally, the joint policy calls on the Services to be accountable by evaluating and reporting on the actions undertaken to implement the EO and this policy. Copies of the full reports produced in fulfillment of this portion of the policy are available from any of the authors. The following section highlights just a few of the important actions already taken.

EO and Policy Accomplishments

The broader EO calls for the Service to engage in a range of restoration, mitigation and public service actions. In fiscal year 1997 alone, USFWS-funded partner projects re-opened 149 stream miles to fish passage and restored 106 miles of instream habitat, 460 miles of riparian habitat, and 39,000 acres of wetland. USFWS hatcheries distributed over 120 million fish for mitigation and recreational purposes. The USFWS also funded extensive research and monitoring work on whirling disease and other fish pathogens and stocked native fishes on 80

National Wildlife Refuges to restore recreational fishing opportunities on Service-managed public lands.

Under the joint ESA policy, the USFWS participated in mass-marking projects to help protect threatened or endangered salmonids while simultaneously helping maintain harvest options. By taking strong, scientifically sound positions in FERC negotiations, during the development of Habitat Conservation Plans with major industries, and in other water management forums, the Services helped secure better flows for fish passage thus benefitting both listed and other recreational fisheries species. The USFWS provides technical assistance, and in some cases funding (e.g., under the Partners for Fish and Wildlife program), to private landowners to help them help streams – again, improving the lot of both listed species and recreational fisheries. The USFWS Endangered Species program also produced and distributed over 200,000 threatened Lahontan cutthroat trout, providing a direct benefit to both recreational fishing and education programs while simultaneously contributing to the recovery of this listed species.

Summary

Perhaps the some of the most useful "nuggets" to take away from this discussion of Executive Order 12962 on Recreational Fisheries and the resultant joint policy on the ESA and recreational fisheries are that while this policy did not change any laws, it should change some minds, and definitely reflects a change in attitude. The EO and joint policy do not "trump" the ESA. Take is still take and there will continue to be biologically sound, if unpopular, ESA-driven decisions. This baseline is what the law requires. However, the EO and joint policy clearly signal that the Administration recognizes that recreational fishing does not always cause the decline of ESA-listed species and that many, many opportunities exist to support both recreational fishing and the ESA at the same time. The joint policy openly calls on our partners to help us identify those opportunities and focuses on what is "do-able" – with particular emphasis on improving habitat and on making better decisions. Finally, it should be noted that on this latter point in particular, some of the major decisions of interest to those who focus on the interface of recreational fishing and the ESA are those relating to the management of non-native species. Since the workshop was convened, President Clinton has issued a new Executive Order (13112, Appendix IV) defining the federal government's position and intent on "invasive species." Implementation of EO 12962 and the joint policy will be fully consistent with this newest EO.

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APPENDIX I

Recreational Fisheries

Federal Register: June 9, 1995
(Volume 60, Number 111)

Executive Order 12962

By the authority vested in me as President by the Constitution and the laws of the United States of America, and in furtherance of the purposes of the Fish and Wildlife Act of 1956 (16 U.S.C. 742a-d, and e-j), the Fish and Wildlife Coordination Act (16 U.S.C. 661-666c), the National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.), and the Magnuson Fishery Conservation and Management Act (16 U.S.C. 1801-1882), and other pertinent statutes, and in order to conserve, restore, and enhance aquatic systems to provide for increased recreational fishing opportunities nationwide, it is ordered as follows:

Section 1. Federal Agency Duties. Federal agencies shall, to the extent permitted by law and where practicable, and in cooperation with States and Tribes, improve the quantity, function, sustainable productivity, and distribution of U.S. aquatic resources for increased recreational fishing opportunities by:

(a) developing and encouraging partnerships between governments and the private sector to advance aquatic resource conservation and enhance recreational fishing opportunities;
(b) identifying recreational fishing opportunities that are limited by water quality and habitat degradation and promoting restoration to support viable, healthy, and, where feasible, self-sustaining recreational fisheries;
(c) fostering sound aquatic conservation and restoration endeavors to benefit recreational fisheries;
(d) providing access to and promoting awareness of opportunities for public participation and enjoyment of U.S. recreational fishery resources;
(e) supporting outreach programs designed to stimulate angler participation in the conservation and restoration of aquatic systems;
(f) implementing laws under their purview in a manner that will conserve, restore, and enhance aquatic systems that support recreational fisheries;
(g) establishing cost-share programs, under existing authorities, that match or exceed Federal funds with nonfederal contributions;
(h) evaluating the effects of Federally funded, permitted, or authorized actions on aquatic systems and recreational fisheries and document those effects relative to the purpose of this order; and
(i) assisting private landowners to conserve and enhance aquatic resources on their lands.

Section 2. National Recreational Fisheries Coordination Council. A National Recreational Fisheries Coordination Council (``Coordination Council'') is hereby established. The Coordination Council shall consist of seven members, one member designated by each of the following Secretaries--Interior, Commerce, Agriculture, Energy, Transportation, and Defense--and one by the Administrator of the Environmental Protection Agency. The Coordination Council shall:

(a) ensure that the social and economic values of healthy aquatic systems that support recreational fisheries are considered by Federal agencies in the course of their actions;
(b) reduce duplicative and cost-inefficient programs among Federal agencies involved in conserving or managing recreational fisheries;
(c) share the latest resource information and management technologies to assist in the

conservation and management of recreational fisheries;
(d) assess the implementation of the Conservation Plan required under section 3 of this order; and
(e) develop a biennial report of accomplishments of the Conservation Plan.

The representatives designated by the Secretaries of Commerce and the Interior shall cochair the Coordination Council.

Section 3. Recreational Fishery Resources Conservation Plan.

(a) Within 12 months of the date of this order, the Coordination Council, in cooperation with Federal agencies, States, and Tribes, and after consulting with the Federally chartered Sport Fishing and Boating Partnership Council, shall develop a comprehensive Recreational Fishery Resources Conservation Plan (``Conservation Plan'').
(b) The Conservation Plan will set forth a 5-year agenda for Federal agencies identified by the Coordination Council. In so doing, the Conservation Plan will establish, to the extent permitted by law and where practicable;

(1) measurable objectives to conserve and restore aquatic systems that support viable and healthy recreational fishery resources,
(2) actions to be taken by the identified Federal agencies,
(3) a method of ensuring the accountability of such Federal agencies, and
(4) a comprehensive mechanism to evaluate achievements. The Conservation Plan will, to the extent practicable, be integrated with existing plans and programs, reduce duplication, and will include recommended actions for cooperation with States, Tribes, conservation groups, and the recreational fisheries community.

Section 4. Joint Policy for Administering the Endangered Species Act of 1973. All Federal agencies will aggressively work to identify and minimize conflicts between recreational fisheries and their respective responsibilities under the Endangered Species Act of 1973 (``ESA'') (16 U.S.C. 1531 et seq.). Within 6 months o the date of this order, the Fish and Wildlife Service and the National Marine Fisheries Service will promote compatibility and reduce conflicts between the administration of the ESA and recreational fisheries by developing a joint agency policy that will;

(1) ensure consistency in the administration of the ESA between and within the two agencies,
(2) promote collaborationwith other Federal, State, and Tribal fisheries managers, and
(3) improve and increase efforts to inform nonfederal entities of the requirements of the ESA.

Section 5. Sport Fishing and Boating Partnership Council. To assist in the implementation of this order, the Secretary of the Interior shall expand the role of the Sport Fishing and Boating Partnership Council to:

(a) monitor specific Federal activities affecting aquatic systems and the recreational fisheries they support;
(b) review and evaluate the relation of Federal policies and activities to the status and conditions of recreational fishery resources; and
(c) prepare an annual report of its activities, findings, and recommendations for submission to the Coordination Council.

Section 6. Judicial Review. This order is intended only to improve the internal management of the executive branch and it is not intended to create any right, benefit or trust responsibility, substantive or procedural, enforceable at law or equity by a party against the United States, its agencies, its officers, or any other person.

BILL CLINTON, June 7, 1995

APPENDIX II

DEPARTMENT OF THE INTERIOR
Fish and Wildlife Service

DEPARTMENT OF COMMERCE
National Marine Fisheries Service

Notice of Policy for Conserving Species Listed or Proposed for Listing Under the Endangered Species Act While Providing and Enhancing Recreational Fisheries Opportunities

SUMMARY: The Fish and Wildlife Service and the National Marine Fisheries Service (Services) have adopted a policy that will address the conservation needs of species listed, or proposed to be listed, under the Endangered Species Act of 1973, as amended (ESA) while providing for the continuation and enhancement of recreational fisheries. This policy identifies measures the Services will take to ensure consistency in the administration of the ESA between and within the two agencies, promote collaboration with other Federal, State, and Tribal fisheries managers, and improve and increase efforts to inform nonfederal entities of the requirements of the ESA while enhancing recreational fisheries. This policy meets the requirements set forth in Section 4 of Executive Order 12962, Recreational Fisheries.

EFFECTIVE DATE: July 3, 1996.

ADDRESSES: The complete record pertaining to this action is available for inspection, by appointment, during normal business hours at the Division of Endangered Species, U.S. Fish and Wildlife Service, 4401 North Fairfax Drive, Room 452, Arlington, Virginia 22203 (telephone 703/358-2171).

FOR FURTHER INFORMATION CONTACT: Chief, Division of Endangered Species, U.S. Fish and Wildlife Service (703/358-2171), or Director, Office of Protected Resources, National Marine Fisheries Service (301/713-1401).

The Policy

The Services recognize the primary responsibility of State and Tribal governments for the protection and management of fish, wildlife, and plant resources within their jurisdictions. The Federal government, however, has public trust responsibilities and statutory responsibilities to conserve endangered and threatened species listed under the ESA and, to that extent, this policy does not diminish or abrogate that responsibility particularly as it applies to section 6 (Cooperation With the States), section 7 (Interagency Cooperation), section 9 (Prohibited Acts), and section 10 (Exceptions). This policy is to affirm the Services' intent to minimize and resolve conflicts between implementation of the ESA and activities to enhance recreational fishery resources and recreational fishing opportunities. This will be accomplished through cooperative partnerships with other Federal agencies, State and local governments, Tribal governments, recreational fisheries interests, conservation organizations, industry, and other interested stakeholders. Activities to be undertaken by the Services with respect to implementation of the ESA include the following:

1. The Services will increase efforts to develop mutually accepted goals and objectives among the involved Federal agencies, States, Tribal governments, conservation organizations, recreational fisheries communities, and other interested entities for the conservation of listed species by:

    A. Ensuring consistency in ESA implementation between and within the Services;

    B. Promoting cooperative interaction with other Federal agencies, States, Tribal governments, conservation organizations, and recreational fisheries stakeholders at appropriate organizational levels in implementing the ESA;

    C. Promoting collaboration and information sharing among Federal agencies, States, Tribal governments, conservation organizations and recreational fisheries stakeholders;

D. Coordinating with all affected stakeholders, partners, and interested parties throughout the decision-making processes on federally listed species issues that may affect recreational fisheries; and

E. Improving and increasing efforts to inform both Federal and non-Federal entities of the requirements of the ESA with particular reference to sections 6, 7, 9, and 10 of the ESA.

2. The Services will encourage participation of other Federal agencies, States, Tribal governments, conservation organizations, recreational fisheries stakeholders, and other interested parties in developing, implementing, and reviewing actions identified in approved recovery plans for listed species by:

A. Involving other Federal agencies, States, Tribal governments, conservation organizations, recreational fisheries stakeholders, and other affected or interested parties in recovery planning and implementation;

B. Encouraging proactive management and habitat conservation, restoration, and enhancement projects on public and private lands and waters to conserve federally listed or proposed aquatic species and to support similar measures to prevent further decline of species and loss of habitat to preclude the need to list additional species under the ESA;

C. Supporting management practices that are consistent with recovery objectives and compatible with existing recreational fisheries;

D. Identifying priorities for the restoration of aquatic habitats needed to conserve and recover federally listed and proposed species and, concurrently, to support increased recreational fishing opportunities to the extent possible;

E. Encouraging management actions that protect and conserve aquatic habitats, ecological processes and the diversity of aquatic communities;

F. Coordinating the reintroduction of listed species into former habitats within the species' historical range with other Federal agencies, States, Tribal governments, and other interested or affected entities, including recreational fisheries stakeholders;

G. Evaluating the potential impacts of proposed introductions of non-indigenous species or hybrids in drainages supporting federally listed or proposed species. Such introductions must be based on management plans incorporating genetics considerations, disease control, ecological principles, and listed species recovery objectives, as well as recreational fisheries and other socio-economic objectives;

H. Ensuring the effectiveness of actions taken to recover listed species and manage recreational fisheries by periodically evaluating conservation and recovery strategies and, where possible, adjusting those actions to minimize adverse effects on recreational fisheries;

I. Eliminating unnecessary recovery based restrictions affecting recreational fisheries. Priority will be given to cooperatively reviewing recovery based restrictions affecting recreational fisheries in areas currently unoccupied but within known historical range of listed species.

J. Encouraging States to increase their participation in listed aquatic endangered, threatened, and proposed species recovery through section 6 grants; and

K. Assisting the States and Tribal governments in meeting their recreational fishing goals.

3. The Services, in cooperation with other Federal agencies, State and local governments, Tribal governments, non-governmental organizations, and recreational fisheries stakeholders will provide the public with a better understanding of the relationship between conservation and recovery of federally listed and proposed species and recreational fisheries by:

A. Informing the fishing and non-fishing public about the ESA. Such efforts will include, but not be limited to, addressing topics such as the incidental take of listed species, the use of ESA 4(d) rules, habitat conservation planning, and other adaptive conservation tools;

B. Involving the public in identifying opportunities to enhance recreational fisheries while providing for the conservation of federally listed species, and in identifying and implementing solutions to aquatic systems degradation; and

C. Assisting to identify and provide, contingent on appropriations and other constraints, comparable alternative recreational angling opportunities when existing ones are altered or curtailed to meet objectives for conservation and recovery of federally listed or proposed species.

4. To meet particular mandates to conserve federally endangered, threatened, or proposed species while providing and enhancing recreational fishery resources and fishing opportunities, the Services will:

A. Work with the recreational fisheries community in evaluating accomplishments, including those of the Services, toward meeting the prescriptions of this policy; and

B. Restore and enhance aquatic habitats to conserve Federal endangered, threatened, and proposed species and increase recreational fishing opportunities consistent with agency missions, authorities, and initiatives.

Scope of Policy

This policy applies to all pertinent organizational elements of the Services and includes all efforts funded, authorized, or carried out by the Services relative to recreational fisheries and implementation of the ESA.

Author/Editor

The editors of this policy are David Harrelson of the Fish and Wildlife Service's Division of Endangered Species, Bob Batky of the Fish and Wildlife Service's Division of Fish Hatcheries, and Marta Nammack of the National Marine Fisheries Service's Endangered Species Division.

Authorities

Endangered Species Act of 1973, as amended (16 U.S.C. 1531-1544), Fish and Wildlife Act of 1956 (16 U.S.C. 742a-742j), Fish and Wildlife Coordination Act (16 U.S.C. 661-667e), Federal Water Project Recreation Act (16 U.S.C. 460 (L)(12)-460(L)(21), Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777k), Anadromous Fish Conservation Act (16 U.S.C. 757a-757g), Magnuson Fishery Conservation and Management Act (16 U.S.C. 1801-1862), National Environmental Policy Act of 1969 (42 U.S.C. 4321-4347).

Dated: May 14, 1996.
Mollie H. Beattie,
Director, U.S. Fish and Wildlife Service, Department of the Interior.

Dated: May 20, 1996.
Rolland A. Schmitten,
Assistant Administrator for Fisheries, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

APPENDIX III

RESOLUTION OF THE OREGON CHAPTER
AMERICAN FISHERIES SOCIETY
1996 ANNUAL MEETING

CONCERNING INTRODUCTIONS OF AQUATIC SPECIES IN OREGON[1]

WHEREAS the Oregon Department of Fish and Wildlife (ODFW) has fishery management responsibility in the waters of the State of Oregon, and

WHEREAS ODFW has acknowledged a "major concern" with the introduction of nonnative species into the State of Oregon, and

WHEREAS it is the policy of the State of Oregon (State Law ORS 496.012) to prevent the serious depletion of any indigenous (native) species, and

WHEREAS the Oregon Fish and Wildlife Commission (Commission) has directed ODFW to draft administrative rules designed to protect native species, and

WHEREAS the effects of introduced species are second only to habitat degradation as a factor cited in the endangerment and extinction of North American fishes, and

WHEREAS the majority of the federal Endangered Species Act (ESA) listings for threatened or endangered fish species in the State of Oregon, and throughout the United States, have cited the detrimental impacts or continuing threats of nonnative species introduced for purposes of sport fishing (e.g., bait, forage, game) as a factor in the determination to list, and

WHEREAS the published position of the American Fisheries Society (AFS) on introduced aquatic species (copy appended) provides a professionally endorsed research, public review, and interjurisdictional consultation protocol (hereafter, AFS protocol),

THEREFORE BE IT RESOLVED THAT the Oregon Chapter of the AFS commend the Commission and ODFW for publicly recognizing and acting upon a major threat to the biological integrity of Oregon's aquatic ecosystems, and

THEREFORE BE IT RESOLVED THAT the Oregon Chapter of the AFS recommend that ODFW abide by standards for all species introductions that are at least as rigorous as the administrative rules that are adopted by the Commission for application to the public, and finally

THEREFORE BE IT RESOLVED THAT for introductions of aquatic species, the Oregon Chapter of the AFS recommend that ODFW adheres to the AFS protocol in its entirety.

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[1] Source materials listed on following page.

The first three WHEREAS clauses are quoted from or directly based on information presented in the “Backgrounder” flyer entitled "Protecting the Integrity of Oregon's Native Species" that was provided by ODFW at a public informational meeting.

The second three WHEREAS clauses reflect information abstracted from:

Aquatic Nuisance Species Task Force. 1994. Report to Congress: Findings, conclusions, and recommendations of the Intentional Introductions Policy Review. 103rd U.S. Congress.

Lassuy, D.R. 1995. Introduced species as a factor in extinction and endangerment of native fish species. pp. 391-396. *In*: H.L. Schramm and R.G. Piper. Uses and Effects of Cultured Fishes in Aquatic Ecosystems. AFS Symposium #15.

Miller, R.R., J.D. Williams, and J.E. Williams. 1989. Extinctions of North American fishes during the last century. Fisheries 14(6):22-38.

U.S. Congressional Office of Technology Assessment. 1993. Harmful Nonindigenous Species in the United States. OTA-F-565.

For complete copy of AFS Protocol, see:

Kohler, C.C. and W.R. Courtenay, Jr. 1986. American Fisheries Society position on introductions of aquatic species. Fisheries 11(2):34-38.

APPENDIX IV

February 3, 1999

THE WHITE HOUSE

EXECUTIVE ORDER

13112

INVASIVE SPECIES

By the authority vested in me as President by the Constitution and the laws of the United States of America, including the National Environmental Policy Act of 1969, as amended (42 U.S.C. 4321 et seq.), Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, as amended (16 U.S.C. 4701 et seq.), Lacey Act, as amended (18 U.S.C. 42), Federal Plant Pest Act (7 U.S.C. 150aa et seq.), Federal Noxious Weed Act of 1974, as amended (7 U.S.C. 2801 et seq.), Endangered Species Act of 1973, as amended (16 U.S.C. 1531 et seq.), and other pertinent statutes, to prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause, it is ordered as follows:

Section 1. Definitions.

(a) "**Alien species**" means, with respect to a particular ecosystem, any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem.

(b) "**Control**" means, as appropriate, eradicating, suppressing, reducing, or managing invasive species populations, preventing spread of invasive species from areas where they are present, and taking steps such as restoration of native species and habitats to reduce the effects of invasive species and to prevent further invasions.

(c) "**Ecosystem**" means the complex of a community of organisms and its environment.

(d) "**Federal agency**" means an executive department or agency, but does not include independent establishments as defined by 5 U.S.C. 104.

(e) "**Introduction**" means the intentional or unintentional escape, release, dissemination, or placement of a species into an ecosystem as a result of human activity.

(f) "**Invasive species**" means an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health.

(g) "**Native species**" means, with respect to a particular ecosystem, a species that, other than as a result of an introduction, historically occurred or currently occurs in that ecosystem.

(h) "**Species**" means a group of organisms all of which have a high degree of physical and genetic similarity, generally interbreed only among themselves, and show persistent differences from members of allied groups of organisms.

(i) "**Stakeholders**" means, but is not limited to, State, tribal, and local government agencies, academic institutions, the scientific community, nongovernmental entities including environmental, agricultural, and conservation organizations, trade groups, commercial interests, and private landowners.

(j) "**United States**" means the 50 States, the District of Columbia, Puerto Rico, Guam, and all possessions, territories, and the territorial sea of the United States.

Sec. 2. Federal Agency Duties.

(a) Each Federal agency whose actions may affect the status of invasive species shall, to the extent practicable and permitted by law,

(1) identify such actions;

(2) subject to the availability of appropriations, and within Administration budgetary limits, use relevant programs and authorities to: **(i)** prevent the introduction of invasive species; **(ii)** detect and respond rapidly to and control populations of such species in a cost-effective and environmentally sound manner; **(iii)** monitor invasive species populations accurately and reliably; **(iv)** provide for restoration of native species and habitat conditions in ecosystems that have been invaded; **(v)** conduct research on invasive species and develop technologies to prevent introduction and provide for environ-mentally sound control of invasive species; and **(vi)** promote public education on invasive species and the means to address them; and

(3) not authorize, fund, or carry out actions that it believes are likely to cause or promote the introduction or spread of invasive species in the United States or elsewhere unless, pursuant to guidelines that it has prescribed, the agency has determined and made public its determination that the benefits of such actions clearly outweigh the potential harm caused by invasive species; and that all feasible and prudent measures to minimize risk of harm will be taken in conjunction with the actions.

(b) Federal agencies shall pursue the duties set forth in this section in consultation with the Invasive Species Council, consistent with the Invasive Species Management Plan and in cooperation with stakeholders, as appropriate, and, as approved by the Department of State, when Federal agencies are working with international organizations and foreign nations.

Sec. 3. Invasive Species Council.

(a) An Invasive Species Council (Council) is hereby established whose members shall include the Secretary of State, the Secretary of the Treasury, the Secretary of Defense, the Secretary of the Interior, the Secretary of Agriculture, the Secretary of Commerce, the Secretary of Transportation, and the Administrator of the Environmental Protection Agency. The Council shall be Co-Chaired by the Secretary of the Interior, the Secretary of Agriculture, and the Secretary of Commerce. The Council may invite additional Federal agency representatives to be members, including representatives from subcabinet bureaus or offices with significant responsibilities concerning invasive species, and may prescribe special procedures for their participation. The Secretary of the Interior shall, with concurrence of the Co-Chairs, appoint an Executive Director of the Council and shall provide the staff and administrative support for the Council.

(b) The Secretary of the Interior shall establish an advisory committee under the Federal Advisory Committee Act, 5 U.S.C. App., to provide information and advice for consideration by the Council, and shall, after consultation with other members of the Council, appoint members of the advisory committee representing stakeholders. Among other things, the advisory committee shall recommend plans and actions at local, tribal, State, regional, and ecosystem-based levels to achieve the goals and objectives of the Management Plan in section 5 of this order. The advisory committee shall act in cooperation with stakeholders and existing organizations addressing invasive species. The Department of the Interior shall provide the administrative and financial support for the advisory committee.

Sec. 4. Duties of the Invasive Species Council.

The Invasive Species Council shall provide national leadership regarding invasive species, and shall:

(a) oversee the implementation of this order and see that the Federal agency activities concerning invasive species are coordinated, complementary, cost-efficient, and effective, relying to the extent feasible and appropriate on existing organizations addressing invasive species, such as the Aquatic Nuisance Species Task Force, the Federal Interagency Committee for the Management of Noxious and Exotic Weeds, and the Committee on Environment and Natural Resources;

(b) encourage planning and action at local, tribal, State, regional, and ecosystem-based levels to achieve the goals and objectives of the Management Plan in section 5 of this order, in cooperation with stakeholders and existing organizations addressing invasive species;

(c) develop recommendations for international cooperation in addressing invasive species;

(d) develop, in consultation with the Council on Environmental Quality, guidance to Federal agencies pursuant to the National Environmental Policy Act on prevention and control of invasive species, including the procurement, use, and maintenance of native species as they affect invasive species;

(e) facilitate development of a coordinated network among Federal agencies to document, evaluate, and monitor impacts from invasive species on the economy, the environment, and human health;

(f) facilitate establishment of a coordinated, up-to-date information-sharing system that utilizes, to the greatest extent practicable, the Internet; this system shall facilitate access to and exchange of information concerning invasive species, including, but not limited to, information on distribution and abundance of invasive species; life histories of such species and invasive characteristics; economic, environmental, and human health impacts; management techniques, and laws and programs for management, research, and public education; and

(g) prepare and issue a national Invasive Species Management Plan as set forth in section 5 of this order.

Sec. 5. Invasive Species Management Plan.

(a) Within 18 months after issuance of this order, the Council shall prepare and issue the first edition of a National Invasive Species Management Plan (Management Plan), which shall detail and recommend performance-oriented goals and objectives and specific measures of success for Federal agency efforts con-cerning invasive species. The Management Plan shall recommend specific objectives and measures for carrying out each of the Federal agency duties established in section 2(a) of this order and shall set forth steps to be taken by the Council to carry out the duties assigned to it under section 4 of this order. The Management Plan shall be developed through a public process and in consultation with Federal agencies and stakeholders.

(b) The first edition of the Management Plan shall include a review of existing and prospective approaches and authorities for preventing the introduction and spread of invasive species, including those for identifying pathways by which invasive species are introduced and for minimizing the risk of introductions via those pathways, and shall identify research needs and recommend measures to minimize the risk that introductions will occur. Such recommended measures shall provide for a science-based process to evaluate risks associated with introduction and spread of invasive species and a coordinated and systematic risk-based process to identify, monitor, and interdict pathways that may be involved in the introduction of invasive species. If recommended measures are not authorized by current law, the Council shall develop and recommend to the President through its Co-Chairs legislative proposals for necessary changes in authority.

(c) The Council shall update the Management Plan biennially and shall concurrently evaluate and report on success in achieving the goals and objectives set forth in the Manage-ment Plan. The Management Plan shall identify the personnel, other resources, and additional levels of coordination needed to achieve the Management Plan's identified goals and objectives, and the Council shall provide each edition of the Management Plan and each report on it to the Office of Management and Budget. Within 18 months after measures have been recommended by the Council in any edition of the Management Plan, each Federal agency whose action is required to implement such measures shall either take the action recommended or shall provide the Council with an explanation of why the action is not feasible. The Council shall assess the effectiveness of this order no less than once each 5 years after the order is issued and shall report to the Office of Management and Budget on whether the order should be revised.

Sec. 6. Judicial Review and Administration.

(a) This order is intended only to improve the internal management of the executive branch and is not intended to create any right, benefit, or trust responsibility, substantive or procedural, enforceable at law or equity by a party against the United States, its agencies, its officers, or any other person.

(b) Executive Order 11987 of May 24, 1977, is hereby revoked.

(c) The requirements of this order do not affect the obligations of Federal agencies under 16 U.S.C. 4713 with respect to ballast water programs.

(d) The requirements of section 2(a)(3) of this order shall not apply to any action of the Department of State or Department of Defense if the Secretary of State or the Secretary of Defense finds that exemption from such requirements is necessary for foreign policy or national security reasons.

WILLIAM J. CLINTON

THE WHITE HOUSE,
February 3, 1999.

Introduced Fish issues in the West: An Overview

Ray Temple
Natural Production Program Manager, Oregon Department of Fish and Wildlife

This presentation is intended to summarize strategic management issues around the west related to introduced fishes. Subsequent presenters will describe in much greater detail the issues and challenges in trying to conserve native species while maintaining the public benefits from fisheries on introduced species. There are no surprises here for anyone paying attention to fish management in the west, and there is a remarkable similarity among states with anadromous fish species and those with exclusively resident fish species. Here is a quick look at the strategic issues:

Issues

- First, balancing increasing public demand for improved angling opportunities with the increasing need to restore native fish species affected by introduced fishes (as well as many other factors) is the fundamental challenge.

  Introduced trout and warmwater gamefish have been widely used in the west to provide popular resident fisheries, often in habitats altered by water development projects, but also in natural lakes and rivers. Natural expansion and illegal stocking has further distributed fishes and created fishable populations. The angling public has grown to depend on these fisheries, as well as the opportunities afforded by native fishes. The dependence on introduced fishes for recreational fisheries varies from state to state, but approaches 100% in Nevada and Arizona.

  Concurrently, native fish species are increasingly jeopardized by natural and man-caused conditions. Conditions caused by man include predation, competition, and genetic risk from non-native fishes. Managing native and introduced fishes together has always involved an element of risk, which is a matter of balancing the degree of impact with the extent of benefits in healthy populations. For many species in various areas, the issue is now conservation management, and the question is the extent to which introduced species impede recovery of native species, and, consequently, what remedial measures are now appropriate.

- Second, managing for the recovery of native species occurs under both state and federal policies and laws. We have begun to see an increasing federal presence, as more resident and anadromous native species are listed under the federal Endangered Species Act

  Policies and laws directing them to conserve native species guide most state fishery agencies. To varying degrees, states are applying those policies in their statewide management policies. Management of many species is now shared with the U.S. Fish and Wildlife Service and the National Marine Fishery Service due to ESA protections. The federal fishery agencies approaches to "take" issues associated with state management of introduced fishes is evolving in the Northwest, but has a longer history in states with listed non-game species. Joe Janisch will detail some new legal issues associated with take through management of introduced species.

- Third, the challenge is maintaining the maximum recreational, social, and economic benefits of fisheries on introduced fishes. These opportunities become increasingly valuable to offset lost opportunities in other fisheries or to provide opportunities where few existed naturally

  As we will hear later today, introduced fishes support very important fisheries, provide a basis for extensive economic activity, and offer far more management flexibility than would otherwise be available. Those fisheries offer opportunities to meet the growing public demand; in part resulting from lost angling opportunities on native salmon and trout. Most states rely on economic and political support from the public that use these fisheries in order to implement conservation management programs However, they are facing the unpopular position of telling those stakeholders they will no longer manage for some popular fisheries, but will manage instead to recover native species. Agencies are forgoing enhancement opportunities that have popular support and are looking for enhancements where there are no conservation issues.

- Fourth, there is uncertainty about the consequences of impacts in specific locations and there is uncertainty regarding effective management responses scaled to the seriousness of the impacts.

  Management agencies and stakeholders concerned with the availability of fisheries are reluctant to take measures against introduced species without strong evidence of potential benefits to native species in exchange for diminished angling opportunities. In addition, the tools available to state agencies are often problematic in their utility.

  Listings as “sensitive”, “candidate”, “threatened”, or “endangered” under state endangered species laws and other categorizations on state watch lists offer one approach to scaling responses and dealing with uncertainty. Over the next few months, ODFW will be working with a public advisory group to, among other tasks, evaluate a proposal that would apply different tests for risk and allow different levels of uncertainty along a scale from “secure” to “endangered”.

- Lastly, management is complicated further by unauthorized distribution of introduced species of fishes, shellfish, and plants, some of which are new to us, and all of which potentially pose new problems

Illegal introductions, primarily of warmwater game fish and some non-game fishes, have been a problem to fishery managers long before now. Many have compromised intended management options, and have sometimes required chemical treatment in order to maintain fisheries. Some have been the basis for subsequently popular fisheries that would not have been chosen by fishery agencies.

Uncontrolled introductions, including species not currently present but with potentially severe consequences will remain a chronic problem in the foreseeable future. This problem may become worse if we cannot educate anglers to avoid venting frustration through fish stocking. Today, the west is poised for invasion by hydrilla, zebra mussels, and other plants and animals with potentially severe ecological and fishery consequences.

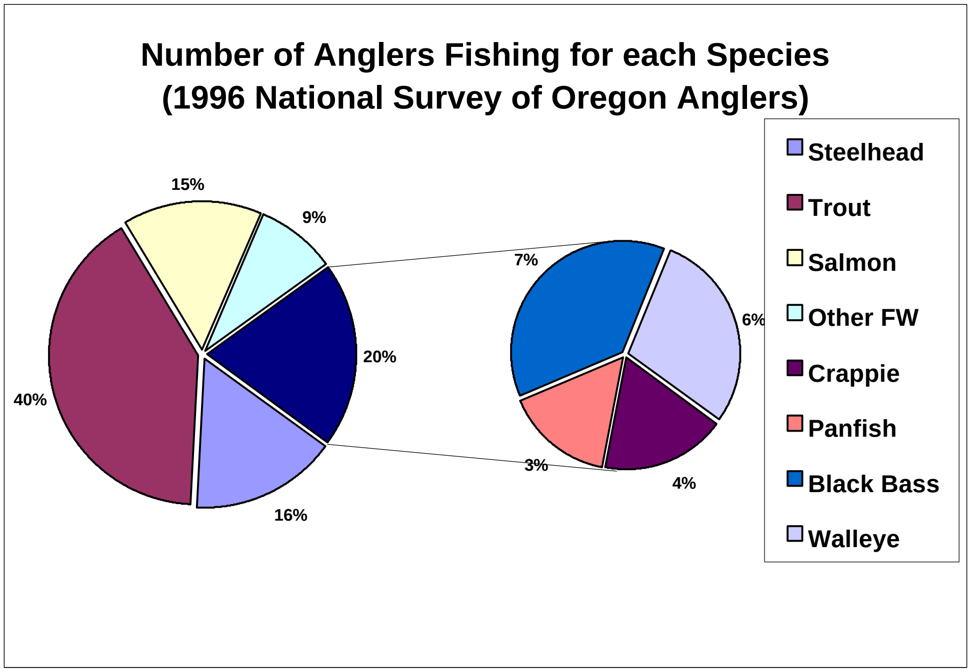
Recreational Fishery Management Issues in Oregon

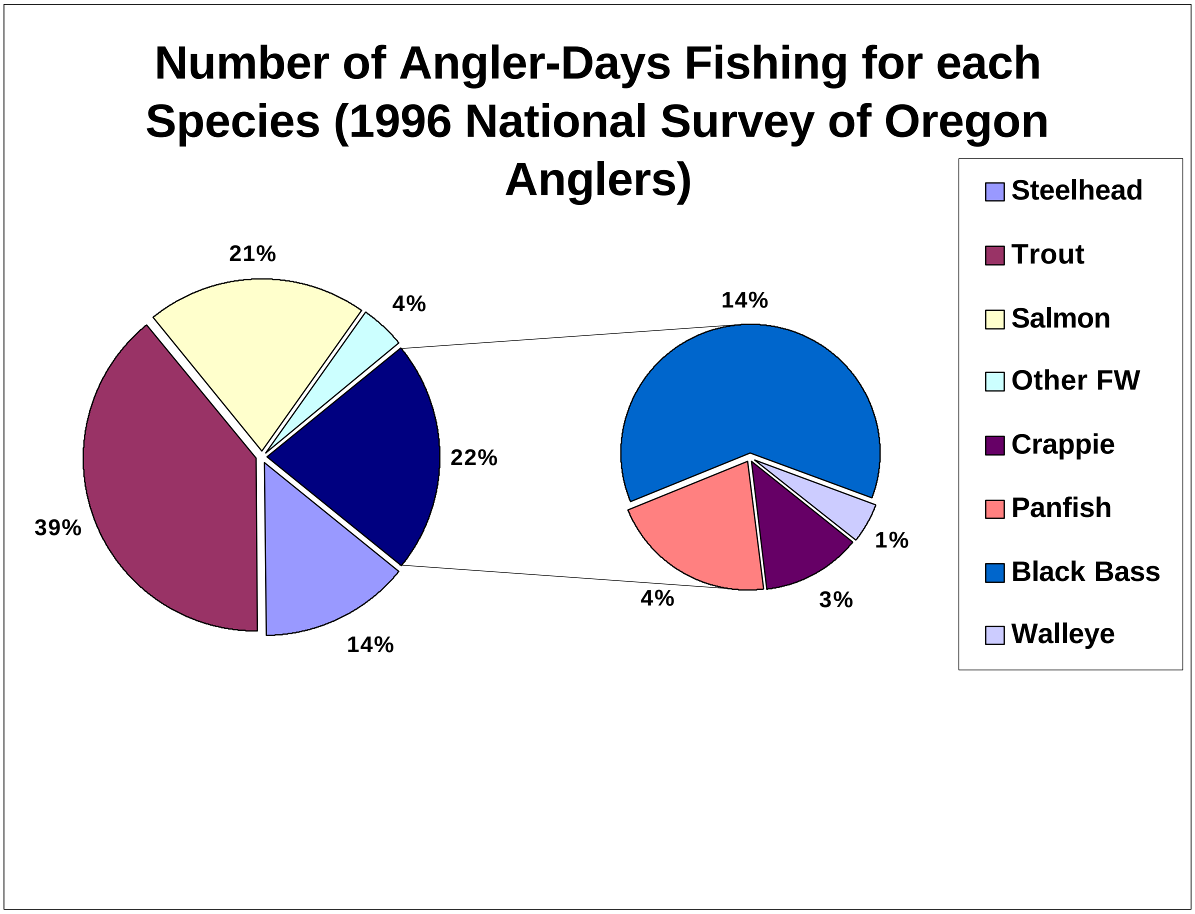
Kin Daily
Warmwater Fish Biologist, Oregon Department of Fish and Wildlife

Importance of Fisheries for Introduced Species

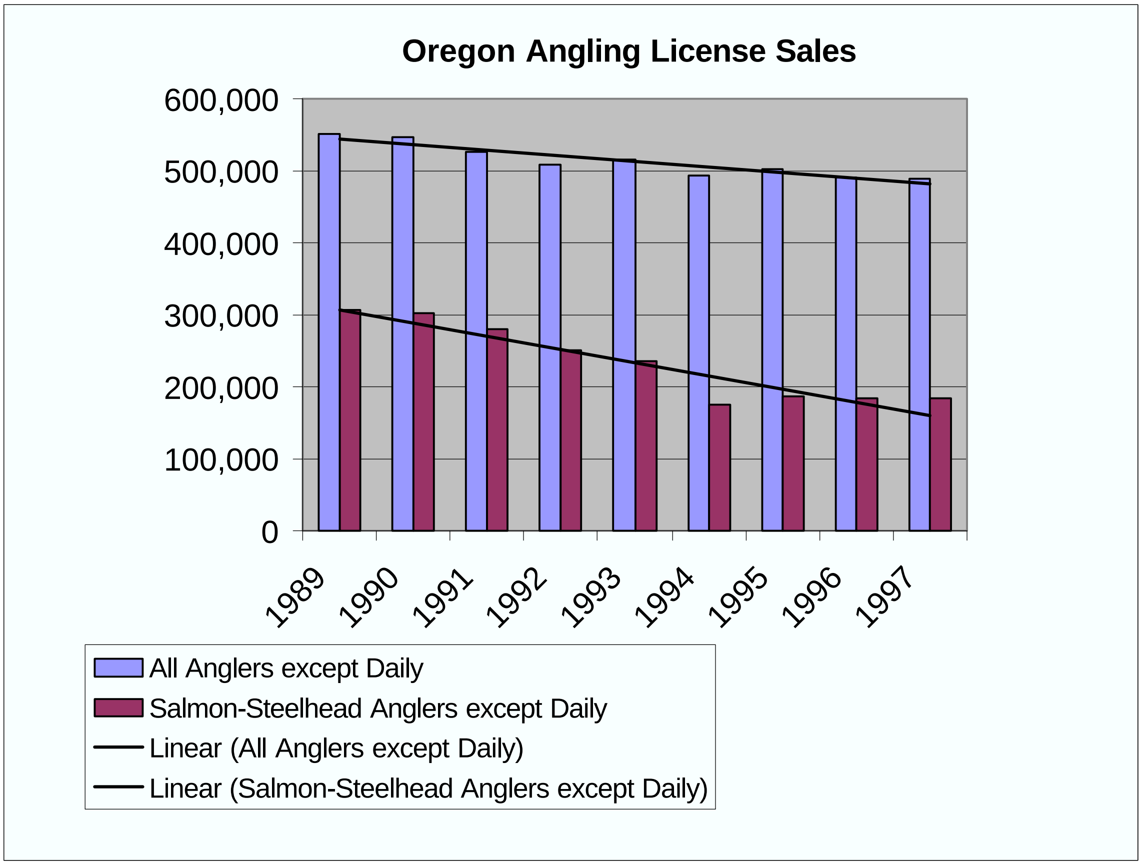
Warmwater game fish support extremely popular and economically important fisheries. Largemouth and/or smallmouth bass and panfish account for much of the angling activity in many lakes and reservoirs across the state. The coastal lakes are the most popular and productive largemouth bass fisheries in the state, and also receive heavy use by those seeking panfish. The Columbia, Willamette, Umpqua and John Day rivers provide important fisheries for smallmouth bass. Bass, crappie and channel catfish attract thousands of anglers to the Snake River and its impoundments. Walleye in the Columbia River are among the largest in North America and are sought by professional and sport anglers from throughout the nation. Striped bass provide trophy fisheries in the Coos and Umpqua estuaries, while American shad receive heavy angler use in the Columbia, lower Willamette, and Umpqua rivers. Non-native brook, brown and lake trout, and Atlantic salmon also provide significant or unique fisheries, adding to the diversity of angling opportunities available. A high percentage of the angling opportunity afforded by lakes and streams at higher elevations is for brook trout (e.g. Century Drive lakes in Central Oregon), as brooks do better than other trout species in these tough habitats. The brook trout stocking program in lakes provides an estimated $100 to $300 in benefits for every dollar expended. Brown trout support trophy type fisheries in streams and a few lakes in the upper Deschutes Basin. They often do better than other trouts in habitats impacted by flow fluctuations and high temperatures. For example, they provide the only consumptive fishery in sections of the upper Deschutes River where flow manipulations below reservoirs have impacted native redband trout. The stocking of browns provides a fishery in the Owyhee River below Owyhee Dam, which is subject to low flows and high temperatures. Their piscivorous food habits allow them to co-exist with and utilize non-game fish where other trouts fail to compete successfully. Lake trout provide a trophy fishery in four lakes in the upper Deschutes basin and in Wallowa Lake. Atlantic salmon offer another unique fishery in Hosmer and East lakes.

The 1989 Oregon Angler Survey estimated that warmwater game fish provided about 1,015,000 angler-days of recreation or 13% of the state total (trout = 49%; steelhead = 10%; salmon = 18%). Striped bass provided 24,415 angler-days of recreation or 0.3% of the state total. The 1996 national angler survey showed that 20% of Oregon anglers fished for bass, panfish, crappie or walleye. It also showed that these species accounted for 22% of the angler-days of recreation in the state.


Number of Anglers Fishing for each Species (1996 National Survey of Oregon Anglers)


Number of Angler-Days Fishing for each Species (1996 National Survey of Oregon Anglers)

Since 1989 the estimated number of paid angling license holders has decreased by 12% (1996 figures), due primarily to loss of salmon and steelhead anglers (40% decrease in sale of salmon and steelhead tags).



However, market data and membership in warmwater angling organizations shows that participation in warmwater angling has increased during the same period. Therefore loss of license sales and angler-days of recreation would be much greater if participation in warmwater angling had not been increasing. For example:

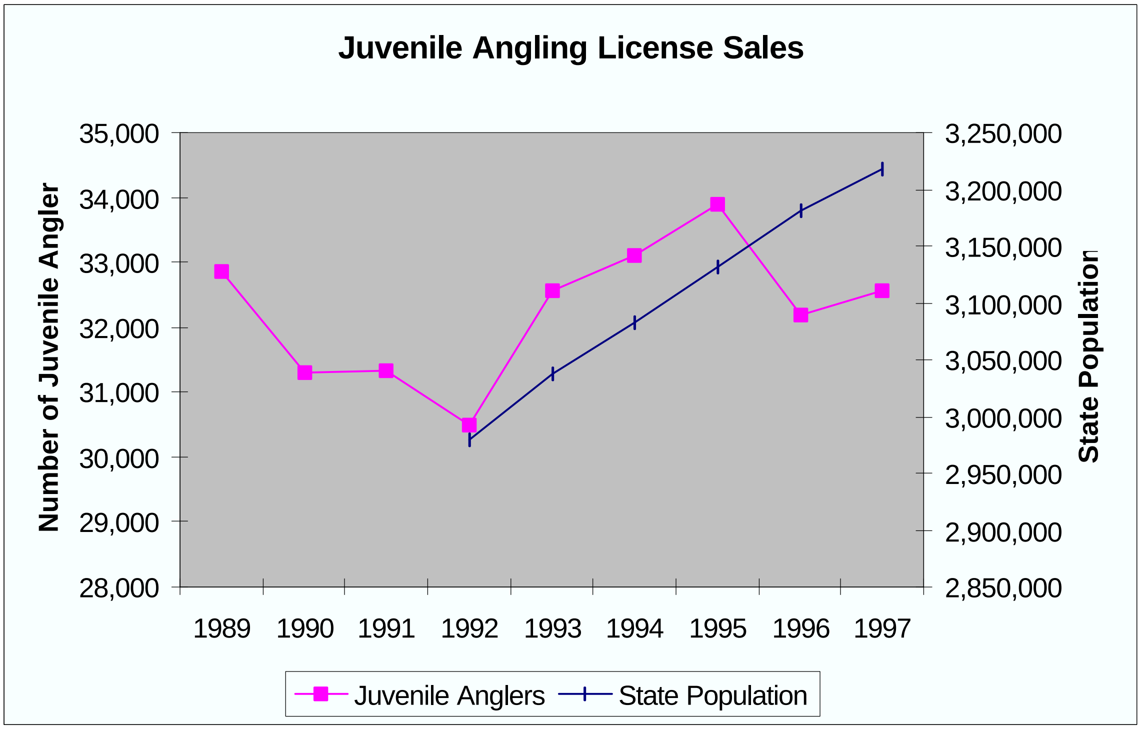
All Sports LLC of Clackamas, Oregon reports the largest increase in sales of warmwater tackle in its history (up 37.5%) occurred in 1997 while sales of salmon and steelhead tackle took the largest downturn ever. Sales of all fishing tackle were up 18%, due to the increase in warmwater sales.

The national Bass Anglers Sportsman Society (B.A.S.S.) reports their membership in Oregon grew 84% from 1987-1997.

Membership in Oregon B.A.S.S. Federation clubs grew 30% from 1993-1997. In 1997 the Oregon B.A.S.S. Federation received about 50 referrals per month from National B.A.S.S. from anglers inquiring about bass fishing in Oregon.

Angling for warmwater species offers one of the few avenues available for replacing angling opportunity lost because of restrictions on salmon, steelhead and trout fisheries to protect native species. The fishery value of warmwater species continues to increase as conservation necessitates the curtailment of these fisheries. Most streams in the Umpqua Basin were closed to trout fishing in 1998 to protect the endangered cutthroat trout, increasing the importance of the smallmouth bass fishery. Reduction of salmon and steelhead opportunities on the Columbia has caused some big boat owners to convert to walleye fishing.

"Panfish" provide important entry level fishing opportunities for kids and other potential new anglers because opportunities are usually available close to home, techniques are simple and some success is assured. As American society shifts from rural to urban, fewer youth have the opportunity to start fishing as a natural part of growing up. Sales of juvenile angling licenses in Oregon have declined in recent years, even as the state's population continued to grow rapidly. Warmwater fishing opportunities in urban areas could help offset this trend. A national survey showed that those who remain lifelong anglers usually start at an early age. Fewer anglers could mean less support for the protection and management of all fishery resources, including native species and their habitats.



Warmwater game fish are often the only species currently available capable of providing angling opportunity in human-altered habitats that no longer support native species, and where restoration as habitat for native species is not feasible. Examples are many reservoirs where fish passage for anadromous species was not provided and reservoir habitat is unsuited to native resident species. Warmwater game fish often provide the only summer angling opportunity in stream reaches which become too warm for salmonids. Examples are the Willamette, South Umpqua, Umpqua and John Day rivers. A number of licensed fishing guides focus their summer business on the smallmouth bass fisheries in the Umpqua and John Day rivers.

Issues

Issues related to maintaining recreational opportunities where native and introduced fishes co-occur include:

Public Support for Fish Management

The sacrifice of agency support from warmwater anglers because of an agency stance that may be viewed as anti-warmwater fish may not be necessary or wise if it doesn't advance the conservation of native species. Anglers are the traditional source of revenue and political support for agency programs. Alienation of warmwater anglers can be minimized by strong agency support for development of fisheries for non-native species where there are no native fish concerns.

Possible Deregulation of Introduced Species

ODFW is considering removing limits on non-native fishes in waters where they co-occur with native species that are listed or being considered for listing under state or federal endangered species acts. This action is strongly opposed by most warmwater angling groups who feel that they are being singled out or made "scapegoats" to bear the brunt of native fish restoration when more important issues, such as dams and other habitat degradation, aren't being addressed because of political considerations. The evidence of harm to native fish populations by exotic fishes is mixed and the prospects for relief from predation and competition through increased exploitation of non-native fishes are also mixed. In most cases it is predicted that there would not be measurable increases in the sustainability of native fish populations. Anglers have said that if the state is serious about reducing populations of non-native predatory fishes in the Columbia River, it should advocate restoring a riverine environment to make the habitat less suitable for the exotic predators and more suitable for native anadromous salmonids. In the face of these arguments and the opposition that deregulation of non-native fish species will generate, the state should consider whether the potential benefits outweigh the negatives.

Lack of consistency among states

Some western states are actively managing to improve fisheries for walleye, tiger muskellunge or other non-native predators while ODFW is opposed to any expansion of their distribution. This leads the angling public to question agency positions and actions.

Management of illegally introduced species

ODFW is reluctant to "reward" those who illegally stock new species by managing these populations for maximum public benefit. Nearly always the date and source of the new introduction is unknown, and often there is the possibility that the introduction was unintentional. In the past ODFW has generally tried to improve the resulting fisheries. However that response is being questioned. When largemouth bass appeared in Crane Prairie Reservoir, a premier trout lake, around 1980, the state retained the statewide limit on bass in the reservoir and eventually recognized them in the Fish Management Plan. However a recommendation from the Public Advisory Committee to manage the population as a quality fishery, with possible special regulations, was rejected by agency staff and the Commission. An illegal introduction in about 1994 of largemouth bass in Davis Lake, a fly-only trout lake in the Cascades, resulted in an agency decision to actively manage against bass by excluding them from statewide limits.

Catch and Release

Anglers are increasingly practicing voluntary catch and release on bass and walleye. This can improve angling quality but reduces the opportunity for managers to change populations through regulations to change exploitation.

Two Story Fisheries

Opportunities to manage for both trout and warmwater species may not be developed because of agency inertia/reluctance to endorse this relatively new and untested concept that may have merit for maximizing public benefits. An example again is Crane Prairie Reservoir bass and trout.

Lack of information on distribution of T&E species

This lack of information on the distribution or potential distribution of native species of concern limits the ability of managers to develop new fisheries for introduced fishes.

Recreational And Economic Importance of Introduced Fish in Washington

Bill Zook
Warmwater Fish Program Manager, Washington Department of Fish and Wildlife
600 North Capital Way, Olympia, Washington 98501

Abstract- *There were more than 550,000 licensed resident game fish anglers in Washington in 1994. They expended in excess of 18 million angler days. An estimated 80%, or nearly 14.5 million days, of this total effort was directed at introduced fish. Using an estimate expenditure of $50 per angler day, introduced resident game fish generated at least $725 million dollars in spending to boost Washington's economy in 1994. Fisheries for introduced species include those directed at warmwater game fish, trout fisheries supported by hatchery stocking of non-indigenous strains, and those for introduced trout species such as brook trout and brown trout.*

Warmwater game fish represent the fastest growing segment of resident sport fishery in Washington. The number of warmwater anglers has increased from an estimated 170,000 in 1968 to 334,000 in 1994. During this same period, the number of angler days expended has increased from 2.1 million to 6.2 million. The percentage of all resident game fish anglers fishing for warmwater fish increased from 52.3 to 62.7 between 1968 and 1994, and the number of Washington anglers indicating a preference for these species increased from 23.0 to 34.7 percent. During this same period, fisheries for introduced trout in lowland and alpine lakes has increased slightly, while stream fishing has declined.

Recreational fisheries for introduced fish are not only economically important, but also have great social and political import to the region. The ability to participate in these fisheries fosters a sense of public ownership and responsibility which is vital to maintaining public and political support for habitat protection and other sacrifices needed to conserve and protect native fish and wildlife resources. Washington and other state fish and wildlife agencies have a responsibility to maintain recreational angling opportunity unless those opportunities have significant adverse impacts on native fish and wildlife resources.

Introduction

Introduced fish species provide the vast majority of inland recreational angling opportunity in Washington. It is estimated that introduced species of warmwater game fish and trout and the extensive use of non-native trout strains to maintain hatchery stocking programs, account for over 80% of total inland fishing opportunities produced in Washington (Table 1).

Table 1. Importance of Introduced Fish Species to Inland Recreational Fisheries in Washington - Totals

Fishery	# Angler Days	% Dependent on Introduced Species	# Dependent on Introduced Species
Lowland Lake Trout	6,462,000	90	5,813,000
Warmwater	6,174,000	100	6,174,000
Resident Streams	2,430,000	50	1,215,000
High Lakes	1,350,000	95	1,282,500
Searun Cutthroat	1,584,000	20	316,800
Total	**18,000,000**	**82.9**	**14,804,000**

WDFW 1994
Does not include unlicensed anglers.

Recreationally Important Inland Fish Species

Table 2 includes a list of the top twelve inland fish species in Washington based on the percentage of anglers who indicated that they completed at least one trip for that species during 1994.

Table 2. Importance of Introduced Species to Inland Recreational Fisheries in Washington - Percent Fish For.

Species	% Fish For	Native	Introduced	% Exotic Stocks
Rainbow Trout	89.8	✓	✔	90
Black Bass	43.4		✔	
Brook Trout	42.6		✔	
Brown Trout	41.8		✔	
Resident Cutthroat	40.7	✔	✓	20
Kokanee	40.5	✔	✓	50
Steelhead	35.9	✔	✓	75
Lake Trout	35.8		✔	
Yellow Perch	31.6		✔	
Searun Cutthroat	28.4	✔	✓	10
Crappie/Sunfish	27.9		✔	
Walleye	24.1		✔	

WDFW 1994
Does not include unlicensed anglers.

Table 3 lists the percentage of those anglers surveyed in 1994 who preferred to fish for individual species/groups above all others.

Table 3. Importance of Introduced Species to Inland Recreational Fisheries in Washington - Percent Preferred.

Species	% Preferred	Native	Introduced
Rainbow Trout	42.6	✓	✔
Black Bass	15.7		✔
Steelhead	12.8	✔	✓
Kokanee	5.6	✔	✓
Walleye	5.3		✔
Lake Trout	3.2		✔
Resident Cutthroat	3.0	✔	✓
Searun Cutthroat	2.1	✔	✓
Brook Trout	2.0		✔
Brown Trout	2.0		✔
Crappie/Sunfish	1.7		✔
Catfish	1.1		✔

WDFW 1994
Does not include unlicensed anglers.

Recreational Importance of Warmwater Fisheries

The fastest growing segment of the recreational fishery in Washington is for warmwater fish species.

Table 4 summarizes the results of angler preference surveys completed by the Washington Department of Fish and Wildlife in 1968, 1986 and 1994. This table shows a steady and quite dramatic increase in utilization for this fishery, with a 3.2% average annual increase in the number of anglers participating and a 7.5% average annual increase in the number of days of recreation over the past seventeen years.

Table 4. Importance of Introduced Warmwater Fish Species to Inland Recreational Fisheries in Washington - Trends

Category	1968	1986	1994	Average Annual % Increased
Number of Anglers	170K	244K	334K	3.2
Number of Angler Days	2.1M	3.1M	6.2 M	7.5
Number of Trips/Year	12.3	14.8	18.5	1.9
Percent Fishing For	52.3	54.8	62.7	0.8
Percent Preferring	23.0	29.6	34.3	1.9

WDFW 1994
Does not include unlicensed anglers.

Economic Importance of Introduced Resident Fisheries

Fisheries for introduced resident fish species generate an estimated 14.5 million angler days of recreation annually in Washington. At an estimated $50.00 per angler day, the annual estimated expenditure on these fisheries is over 735 million dollars a year (Table 6).

Table 5. Estimated Economic Value of Recreational Fisheries for Introduced Fish Species in Washington.

Fishery	$50/Angler Day
Lowland Lake Trout	290,650,000
Warmwater	300,700,000
Resident Streams	60,750,000
High Lakes	64,125,000
Searun Cutthroat	15,840,000
Totals	**735,065,000**

WDFW 1994
Does not include unlicensed anglers.

Non-native Fish Issues and Management in California

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Abstract- *Non-native fish introduced into Califomia are categorized as either 1) purposeful legal introductions, 2) illegal introductions, or 3) unintentional introductions. Introduced fish include fish not native to California waters and introductions of native California fish to waters where they did not previously occur. Purposeful legal introductions include such species a non-native largernouth bass (Micropterus salmoides) and native rainbow trout (Oncorhynchus mykiss). Purposeful illegal introductions include non-native northern pike, (Esox lucius) and native Sacramento pikeminnow (Ptychocheilus grandis). Unintentional introductions include species such as non-native bigscale logperch, (Percina macrolepida) and yellowfin goby (Acanthogobius flavimanus). Many fish introduced into California have developed naturalized populations and provide valuable recreational, social, and economic benefits (Lee 1995). Issues regarding introduced fish generally center around effects of introductions on native fish species (Moyle 1976, Moyle et al. 1995). Of the 49 fish species identified by the California Department of Fish and Game (CDFG) as "species of special concern", habitat alteration including dams, water diversions, land use practices, and pollution was identified as a problem leading to declines in populations for 45 species. Competition and predation from introduced fishes were identified as a contributing factor for 20 species (one anadromous game species, 19 nongame species). In most of these cases, habitat alteration that favored introduced species with resulting negative consequences for native species was often cited. Other factors cited included climatic variations, (drought, flood, and fire), loss of genetic integrity, and exploitation. Management of purposeful legal fish introductions includes CDFG protocols for new species introductions, policy statements, harvest regulations, habitat enhancement, and research and monitoring. Management of illegal and unintentional introductions includes laws and regulations governing importation and movement of fish, research and monitoring, eradication, public education, and punishment of violators.*

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* Dennis chose to have only the abstract of his talk published in the Proceedings.

Bass Anglers Perspective on the Recreation and Economics of Oregon Black Bass Fishing: An Argument Against De-Regulation

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Introduction

The motivation for this workshop was the Oregon Department of Fish and Wildlife proposal to remove protective creel and size limits from all non-native species, including black bass. The objective is to reduce the number of non-native predators to improve survival of native fish species, primarily juvenile salmonids. B.A.S.S. is sympathetic with the challenges to maintain biological diversity and to preserve cultural heritage by restoring populations of native anadromous salmonids faced by Pacific Coast natural resource agencies. However, we do not think de-regulating black bass will achieve the desired objectives. In response to the Oregon de-regulation proposal, B.A.S.S. sent a letter on July 11, 1998 to the Oregon Fish and Wildlife Commission. We asked the Commission to:

> "...ask the Fish and Wildlife Department to withdraw its proposals to de-regulate black bass and instead concentrate their efforts on the larger habitat and resource issues that determine the future of Pacific salmon survival...".
>
> "...we have no confidence that de-regulating black bass will have any noticeable, or measurable impact on restoring native salmonid spawning runs..." "... The risks far outweigh the speculative rewards...".

Those statements were supported in the July 11th letter with the following rationale:

1. In larger rivers and reservoirs in Oregon, the existing levels of exploitation of black bass suggest there would be only minimal, if any, significant reduction of black bass population density and biomass by removing size and creel limits.

2. On smaller waters, the removal of size and creel limits on black bass may immediately stimulate increased angling pressure and harvest. However, as larger bass are taken by anglers the survival of younger bass would be enhanced. Therefore, long-term overall biomass of bass will not change, although the size-structure of the bass populations would be degraded towards smaller/younger fish. This means more predatory mouths to feed - - - a completely reverse affect than the regulation intended. The loss of larger, older bass would diminish the rewards of bass angling and lead to reduced angling pressure, less harvest and ultimate removal of fewer bass - - - counter to the regulation objectives.

3. Black bass are only one of the several native and non-native fish that prey upon juvenile salmonids. Total predatory pressure on the young salmonids may change very little if one species component of the overall predator population is reduced. Other species, may compensate by increasing population size and predatory pressure. There are too many predator fish species, in too many ecological niches, to suggest that angling regulation changes alone will reduce overall predatory pressure on salmonids.

4. Today, black bass angling in Oregon is of high quality and the numbers of bass anglers are increasing. Ecologically, Oregon may regret that black bass were ever introduced, but recreationally and economically bass are generating positive benefits from an avid angler group that buy fishing licenses and equipment and fuel that generate Federal excise tax dollars. Relaxation of regulatory protection on black bass populations will eventually translate into fewer

black bass anglers, not more, diminished support for ODFW and lost economic growth - - - without improving the salmonid populations.

5. The mere perception that the proposed bass de-regulations will degrade bass populations will generate a negative image of ODFW, regardless of the actual impact of regulation change on the black bass populations. The recognition that ODFW is willing to risk a large perceived negative impact on Oregon bass fishing quality to achieve a small, if any, gain in salmonid survival will destroy the credibility of ODFW to manage warmwater fisheries for a generation. This will be true particularly if increased juvenile salmonid survival cannot be clearly demonstrated and correlated with the bass population changes.

This paper adds to the above rationale. It examines the very positive recreational and economic contributions from Oregon bass fishing and argues both the futility and the risks of trying to improve native fish survival by de-regulating black bass.

This decision is much more complicated than merely balancing concerns and values of various stakeholder constituencies. Removing regulations on black bass may provide philosophical and ideological gratification for some who think any sacrifice is justified as long as "some" gains in native fish survival are achieved. That gratification would come at a high cost! We believe there will be minimal, if any, gain in native fish survival from de-regulating bass. And, bass fishing use will decline way out of proportion with any negative impacts caused by de-regulation on the quality or stability of black bass populations.

Black Bass Recreation

Black bass neither became America's most favorite and targeted species because of accident, nor by natural selection. According to the U.S. Department of Interior (USDI) 1996 National Survey of Fishing and Hunting and Wildlife Associated Recreation (1997), 44% of freshwater anglers fish for bass and bass anglers generated 40% of all U. S.
freshwater anglers days. Three major factors have catapulted bass to number one: 1). new reservoirs, 2). bass availability and, 3). marketing.

New Reservoirs

The reservoir building boom created new bass habitat. When reservoirs were built on coldwater streams and rivers, warmwater and/or two-story fisheries flourished, but often at the expense of native coldwater fishes. Fishery managers of the past should not be criticized for taking bold steps to manage these new reservoir ecosystems. Introduction of predator species exotic to a watershed may seem like an ecological crime to some observers, but in the 1930's through the 1960's it was considered imaginative fishery management. Upon reservoir completion, fishery managers had to plan fish communities and fill the new vacant ecological niches. In many cases there was no consultation between project designers and fishery managers before, or during, construction. Often fishery managers had little information and even fewer resources. Generally, they tried to introduce predators that could simply utilize the forage species indigenous to the watershed. Later in the reservoir management era, forage management became as important as predator introduction.

Bottom-line is that bass, and other non-native predators, have now become permanent residents of new watersheds. They are providing recreation and, unless very drastic ecological intervention is taken, they are here to stay.

The reservoir construction era was based upon the management philosophy of multiple use. Boat launch and public recreation facilities were planned components of the design and construction. The angling public now had new, focused destination points to gain access to free use of huge, navigable waterways. Black bass were destined to become the primary sportfish species in most of these new impoundment's, even though bass were not native to many of the reservoirs west of the Continental Divide.

Bass Availability

Human population growth and economic productivity of the 17 states of the American West required capturing and storing the sparse, seasonal rainfall and mountain snow-melt for distribution to agricultural land and urban centers. The taming of southern and mid-western U. S. rivers for flood control, hydro power and to enhance commercial navigation expanded the native range of black bass to millions of acres of new habitat. Because these water projects were built and/or managed by government agencies and public utilities and authorities, public boat and fishing access was guaranteed. In many cases these launch sites, marinas and public use facilities were the best anglers had ever seen.

By the 1960's and 1970's black bass became available and accessible coast to coast. At this stage in the evolution of bass fishing, the bass populations, and access to them, were way ahead of angler interest and use. Biological productivity of the new reservoirs and only light angler exploitation produced phenomenal catches of large bass for the relatively few anglers who pursued them.

Marketing

The "bass boom" began in 1967 when Ray Scott founded Bass Anglers Sportsman Society (B.A.S.S.). It is unequivocal within the sportfishing industry that Ray's vision, energy, enthusiasm and intellect sparked the rapid and phenomenal evolution in fishing boats, fishing tackle, angler clothing, TV angling shows, angling ethics and bass fishing passion we enjoy today. The chronology of bass fishing and the contribution of Ray Scott and B.A.S.S., Inc. are well chronicled in BASS Master magazine (1998) and other publications - - - I won't repeat them here.

Ray marketed bass fishing as a wholesome, exciting and competitive activity. He focused on competitive angling for marketing leverage. To successfully compete, anglers wanted an edge - - - the best stuff. Manufacturers eagerly produced the "winning" tackle, lures and boats. This niche market began growing. More and more anglers read about the "where to" and "how to" of great U. S. bass fishing. They watched on TV as America's best bass fishermen weighed-in glamorous tournament catches, endorsed new tackle and used efficient, fast and safe fishing boats that would have been considered whimsical dreams only a few years back.

The bass fishing market is still expanding - - - the peak is still in our future. New bass tournaments, bass fishing organizations and bass fishing publications are emerging to compete in the bass market. Today's bass fisherman enjoys high-quality angling toys that our grandfathers would never have believed. Bass fishing on TV is now presented for both national and regional markets. The fact that bass anglers generate more days of angling on waters where other sportfish species are numerically dominant is a prime example of the successful bass marketing phenomena.

Bass anglers handicap themselves by casting (and losing) expensive artificial lures when live-bait techniques would undoubtedly produce more action. Why do they do this? Because B.A.S.S. tournaments prohibit the use of live-bait and trolling. This has established the standards of fair-chase for dedicated bass anglers to emulate. They gauge their own skill and angling success against published catches of the pro anglers. They try to adapt the proven winning techniques and the lures of the pros to their local fishing.

The point of this marketing discussion is to illustrate that positive forces will generate angler enthusiasm while negative forces will depress them. Angling rumors and myths spread like oil on water. Reports of bad fishing can seriously magnify the drop-off in angling pressure. Fishery managers often witness "self-fulfilling prophesies" during angling regulation debates. The doomsayers generate enough negative publicity about their theory of the impact of proposed regulations to drive-off potential anglers. This loss of angling is usually disproportionate to the actual resource situation. Conversely, just announcing new management plans for a fishery can stimulate accelerated angling use and perceptions of "better" fishing long before the proposed management actions have had time to improve the fish population.

De-regulation of black bass in Oregon, regardless of the biological impact, will produce negative market forces that will reduce bass fishing use, depress the sale of boats, accessories, and fishing tackle, diminish expenditures in the hospitality industry and kill the enthusiasm of some of the biggest supporters of Oregon natural resources - - - Oregon bass anglers.

Just the perceptions of a degraded bass resource will cause this loss of use and support. If real negative biological impact occurs to bass populations from de-regulation, then it will cause even more drop in fishing use and expenditures. The really sad part of this situation is that the bass fishing market in the western and northwest U. S. still has not peaked. If negative market forces cause a drop now, the loss must be measured against "what could have been", not from what exists today.

Use and Economics

The discussion of angler use, expenditures and economic activity that follows is based on data from the U. S. Department of the Interior 1991 and 1996 National Surveys on Hunting, Fishing and Wildlife-Associated Recreation (1993) (1997) and analysis of those data by the American Sportfishing Association (1997).

Freshwater angling use in Oregon has been stable, or slightly declining. From 1990 to 1997 fishing license sales in Oregon declined by about 10% (751,945 in 1990 to 678,377 in 1997). During this period Oregon's population increased by 10%. Thus the proportion of Oregonians who fish actually dropped by 15% from 1990 to 1997.

The USDI survey (1993) estimates that 605,000 anglers fished Oregon freshwaters in 1991, generating 6,490,000 days of use. In 1996, 589,000 anglers fished 7,118,000 days (USDI, 1997). This represents a 2.3% drop in anglers from 1991 to 1996, but an increase in angler trips of 10%. The disparity of less anglers but more use is consistent with the national averages. The generally accepted explanation for this is that casual anglers comprise the drop-outs, but avid anglers are spending more time and money on their favorite pastime.

Black bass fishing in Oregon during the 1990's reflects a rate of growth similar to the national bass fishing boom in the 1980's. Bass fisherman are avid anglers! From 1991 to 1996 there was an overall increase of 628,000 days of fishing in Oregon (10% increase). The growth of Oregon bass fishing days went from 605,000 days in 1991 to 1,212,000 days in 1996 - - - a 602,000 day jump that made-up 95% of the total increase in angling days in Oregon over that five year period.

Bass anglers in Oregon obviously represent an enthusiastic, dynamic and vital portion of the Oregon sportfishing economy. They spent $199 million in 1996, up from $105 million in 1991, with state and Federal tax generation of $2.8 million and $5.3 million respectively. Average daily expenditures by Oregon anglers equal $86/day, and they generate an ultimate economic output of $164 per day.

It is impossible to predict how much bass fishing will decline from de-regulation. However, we believe the drop in use will be significant and each day lost can be multiplied against those daily expenditure and economic output figures. If bass fishing use grew by 600,000 days in five years, it can shrink that much just as quickly!

Certainly, improvement in native fish species populations like salmon and steelhead could generate increased economic output to off-set losses from bass fishing. But we don't believe that de-regulation of bass will cause any compensating improvement in native salmonid fishing quality.

Recommendation Summary

- The decision whether bass should be de-regulated involves much more than balancing concerns of interest groups. Removing regulations may provide ideological gratification to salmonid restoration enthusiasts, but without achieving the targeted biological benefits. That false gratification does not justify the risks to the Oregon bass fishery. Abandon this idea. There is no precedent to even suggest a positive impact on salmonids would occur.

- Continue managing Oregon black bass to provide quality fishing experiences for Oregon anglers.

- If, when and where it has been biologically and economically demonstrated that long-term reduction in population size of black bass will significantly enhance juvenile native salmonid survival, then the Oregon B.A.S.S. Federation will be willing to consider invasive intervention to remove bass, if that loss of bass fishing opportunity could be mitigated elsewhere. Well designed, small scale research proposals would also be well received by Oregon B.A.S.S. Federation.

- Black bass are so ubiquitous in large Oregon watersheds that it is futile to continue to treat them as unwelcome tourists. Bass are in the bigger watersheds for the long-haul. Their reproductive potential, adaptability and difficulty to capture combine to render their removal a very cost-ineffective venture.

- In smaller watersheds, periodic partial or total chemical reclamation, along with other habitat modification, may suppress bass populations enough to improve salmonid survival. But, this certainly will not eliminate bass. Whether the costs of this aggressive intervention could be justified long-term still remains to be tested.

- Oregon Department of Fish and Wildlife should conduct periodic (five year?), statewide, angler surveys to document and segregate types of angling use, preferred species, angler opinions and expenditures. This will facilitate benefit/cost fishery management decision-making.

- Threshold biological and economic criteria must be developed to expedite decisions on when, and if, non-native recreational fisheries could be, and should be, sacrificed to enhance native fish survival. These decisions should be made based on objective facts, not subjective feelings.

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Investigations and Case Studies

Session Chair:

Lance Kruzic
National Marine Fisheries Service

Umpqua Fisheries Concerns- Why not Blame it on the Bass?

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Abstract- *The Umpqua basin encompasses over 3 million acres and has over 4000 miles of streams. It has a great diversity of native fish species that have provided year-round inland recreational fisheries for Southwest Oregon for several decades. The Umpqua basin has also had its share of exotic species introduced into the system, both legally and illegally. Brook trout, brown trout, shad, striped bass, tui chub, bluegill, brown bullhead, green sunfish, golden shiner, and more. However, the most talked about and perhaps most controversial exotic species in the Umpqua is the smallmouth bass. This species has had an impact on the fish populations and fisheries in the Umpqua. Since the illegal introduction of the smallmouth bass in the 1960's, the population has established itself in the South Umpqua, mainstem Umpqua, Cow Creek, and other tributaries. A popular fishery in these areas brings several thousand anglers to the Umpqua each summer. Based on diet studies conducted in recent years, bass prey on a variety of animals, including fishes. Salmonids are a very small proportion of their overall diet throughout the year. Non-salmonid species appear to be more vulnerable and available to the bass during their peak feeding period. Available data for salmon and steelhead populations in the Umpqua basin do not indicate a direct correlation related to smallmouth bass presence in the basin since 1960's. Recent regulation changes allow a higher harvest of bass in the Umpqua, but overall affects to the current populations of fishes in the Umpqua appear to be insignificant.*

The Umpqua basin encompasses over three million acres and has over 4000 miles of streams. It has a great diversity of native fish species that have provided inland recreational fisheries for Southwest Oregon for several decades. The Umpqua chinook and coho stocks have also been important contributors to ocean commercial and sport fisheries off Oregon. The Umpqua basin has spring and fall chinook, summer and winter steelhead, coho, cutthroat trout, rainbow trout, as well as unique native species like the Umpqua pike minnow, Umpqua dace, and common species including lamprey, suckers, sculpins, and other non-salmonid fisheries.

The Umpqua has also had its share of exotic species introduced in the basin over the past several years. Brook trout, brown trout, shad, brown bullhead, green sunfish, striped bass, golden shiner, bluegill and more. However, the most talked about and perhaps most controversial exotic fish species in the Umpqua is the smallmouth bass. This species has made an impact on the Umpqua basin fisheries. We know there is a new and popular fishery! The major question(s) are how significant are the biological impacts to the native species and what, if anything, can we or do we want to do regarding this new species in the basin.

Smallmouth bass were stocked illegally in the South Umpqua basin in ponds and possibly directly into the river in the early 1960's. The Christmas storm of 1964 not only flooded the basin with the highest water seen in recent history; it instantaneously stocked several miles of the basin with a very predacious warmwater species. The smallmouth bass quickly took advantage of sections of the rivers that native coldwater species did not inhabit year-round. In 1977, smallmouth bass were "officially" documented as being established in good numbers and naturally colonized other sections of the South Umpqua basin and mainstem Umpqua. Shortly thereafter, a popular recreational fishery developed and by the 1980's there were several hundred anglers fishing for bass in the river. These aggressive fish provided a summertime angling opportunity in places where Huck Finn and other exploring kids like myself had only caught suckers and pikeminnows in the past.

Today, we have more anglers and commercial guides fishing for smallmouth bass from June through September in the mainstem Umpqua than there are fly fishers and bait anglers casting for the infamous North Umpqua summer steelhead. New boat ramps, recreational areas, and more "no trespassing "signs on private lands along the rivers signify the bass fishery is here to stay and will continue to draw anglers from all over the country to Douglas County. And contrary to accusations by some local guides, ODFW is not going to now take credit for the introduction of smallmouth bass and the development of a popular and economically important fishery.

There should be no questioning by anyone that during the past 30 years the Umpqua basin has seen many other changes besides the introduction of smallmouth bass. These issues are well known by fishery managers and the public, and continue to be widely discussed and sometimes heatedly debated in many circles as to "Who or What to Blame". So, "What about those smallmouth bass?" Have the bass actually caused the salmonid species in the Umpqua basin to decline or perhaps only made bad conditions worse? Are there other species that have declined because of the bass? Can we do anything about reducing the risk of further impacts to the native species, especially the ones that co-exist now with the bass? I will provide some examples of specific fish populations' status in the Umpqua basin to allow each of you to consider the impacts of the bass. First, I will share some information from a smallmouth bass diet study that the Umpqua District began in 1992.

Based on sampling the stomach contents from several hundred smallmouth bass caught in the mainstem Umpqua River from 1992 to 1998, bass eat other fish……And a whole lot of other animals. Crayfish and insects are the most common prey of the smallmouth bass (Figure 1). Fish are a common prey, but most species that were identified from the stomachs of bass were non-salmonids. Small-sized sculpins, suckers, chub, shad, pikeminnows, lamprey, and smallmouth bass were more frequently found in large (>6") smallmouth bass than salmonids. Crayfish, shad, and lamprey ammocetes are the most desired prey based on my personal observations throughout the years. The lamprey are like candy to the bass and even though the ammocetes are a small percent of the total diet, smallmouth bass will swim from several feet away to eat this 4-inch wiggling, worm-like fish. Salmonids are also highly desirable, but made up well below 1 percent of the total diet samples in the study. Lure and bait choices by the more successful anglers tend to support these conclusions.

Smallmouth bass inhabit most of the mainstem Umpqua (including the upper tidal area) and South Umpqua, Cow Creek, and lower reaches of Calapooya Creek, Elk Creek, and Lookingglass Creek. Smallmouth bass have been occasionally observed in the lower North Umpqua, but currently are not present in any significant numbers above the Winchester dam. A few reports of bass in Smith River have been received, but an extensive snorkel and electrofishing survey in did not document smallmouth bass anywhere in this subbasin. Overall distribution of smallmouth bass has remained relatively the same (205 to 235 miles) since the late 1980's. Population numbers also appear to be stable at this time.

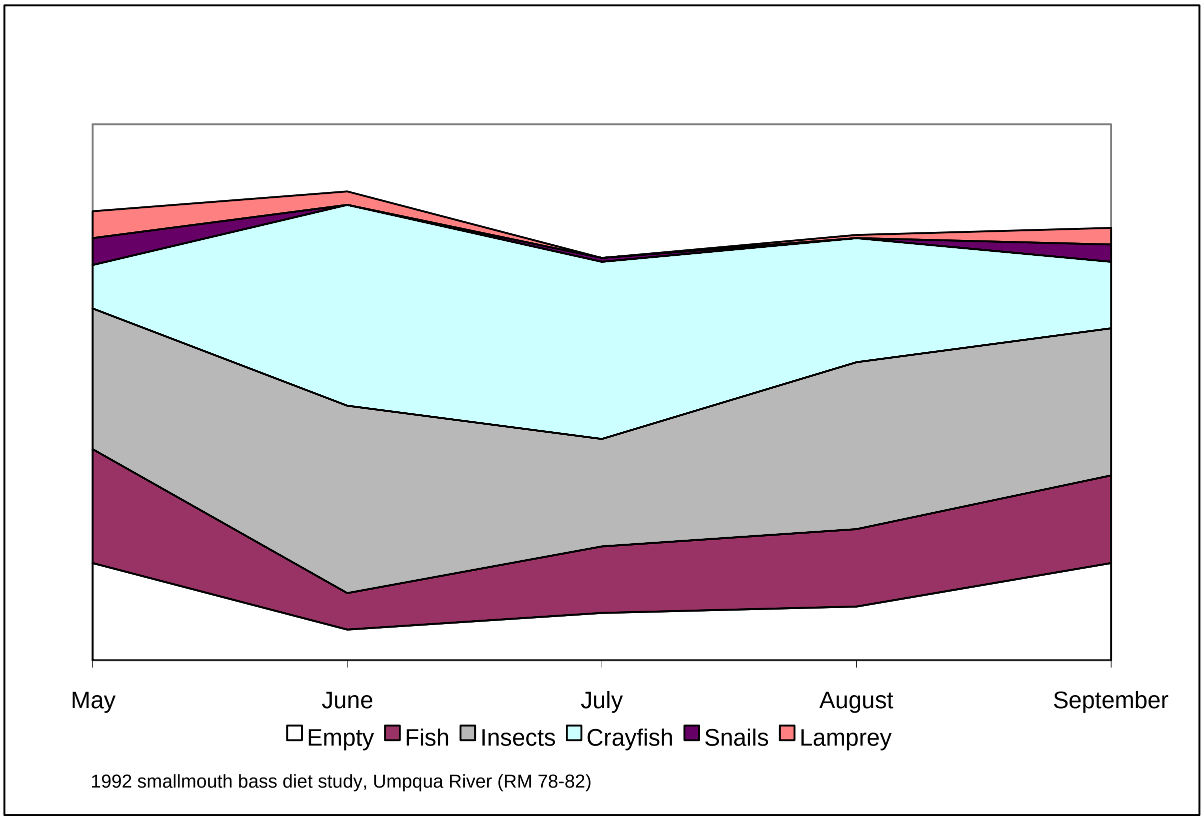
The highest risk to a salmonid population from bass predation would most likely be to a species that co-exists in rearing habitats or has peak outmigration of smolts during higher water temperatures (late spring through early fall) when smallmouth bass are actively feeding. These bass do not become active and start growing until the temperatures reach over 60 degrees F. and prefer water temperatures in the 70-80 degree F range. South Umpqua spring and fall chinook juveniles rear and migrate in the mainstem from March through July. The chinook status indexes, based on adult spawner counts suggest, however, that both populations have significantly increased since the 1980's (Figure 2). Other salmonid populations in the North Umpqua, mainstem Umpqua, and Smith River do not utilize the same habitat areas or migrate during the warmer water temperature period. After reviewing available trend counts from native winter steelhead, summer steelhead, spring chinook, fall chinook, and coho, there is not a significant decrease in any of these populations that can be directly attributed to smallmouth presence and/or predation (Figures 3 and 4). The biggest potential threat, though, may still to North Umpqua juvenile chinook and steelhead if smallmouth bass become established in the future in the upper reaches of the river.

Many native non-salmonid species are present year-round in the same mainstem reaches of the South Umpqua and mainstem Umpqua where the smallmouth bass are very abundant. Population estimates and trends are not available for many of these species. However, Winchester dam counts for suckers, pikeminnows, and lamprey migrating upstream from the mainstem Umpqua and lower 7 miles of the North Umpqua suggest all of these populations have decreased since the 1960's (Figure 5). There were less Pacific Lamprey adults migrating across Winchester dam than federally listed Umpqua cutthroat trout in the past 3 years.

The Umpqua pikeminnow is a voracious predator on other fish species, including salmonids smolts, and is more active during cooler temperatures than the introduced smallmouth bass. Reduction in overall numbers of pikeminnow could decrease the predation of salmonids smolts in earlier migration periods before the smallmouth bass become active. The net gain or loss of salmonid survival from other native fish species with smallmouth bass now present in the basin is unknown and inconclusive.

Angler creel surveys conducted in the Umpqua basin show that the smallmouth bass fishery has a high catch rate and many, many anglers. Most anglers release a high percentage (50-80%) of their catch due to the small average size of the fish. Less than 15% of the catchable-sized bass are over 10" in length. Also, it is common to catch over 5 bass an hour during the peak summer months. A recent regulation change that allows a higher harvest limit for bass (10 fish/day) in the Umpqua did not significantly increase the overall harvest of bass.

In summary, the Umpqua basin fisheries and native fish populations have changed due to the illegal introduction of exotic fish. Smallmouth bass are a relatively new predator to salmonid and non-salmonid species. The specific impacts attributed from the introduction of bass will most likely never be determined due to the complex and variable factors that determine overall native production in a basin the size of the Umpqua. The fisheries management plans and goals for the Umpqua must, however, now always include smallmouth bass. This species is now well established as one of the many fish populations in the Umpqua. It provides an excellent sport fishery when other salmon and trout fisheries are closed or never were even present. Bass should not be ignored, but there is not enough scientific evidence in the Umpqua to suggest blame be laid only on the smallmouth for overall concerns for the native species status. Fishing regulations may have very little effect on the overall bass population size and distribution; and most likely will not significantly reduce directed predation rates on salmonid species in the basin. Bigger concerns may be related to the non-salmonid species co-occurring with the bass in the mainstem rivers. The basin fisheries and all native populations will continue to be affected by the smallmouth bass in the future. I have no doubt the magnitude of the blame for many concerns will vary as much as individual people's accent on the word "NOT" in the English language.



1992 smallmouth bass diet study, Umpqua River (RM 78-82)

Figure 1. Presence of prey groups in stomachs of smallmouth bass (N=371) collected in the mainstem Umpqua River, May-September, 1992.

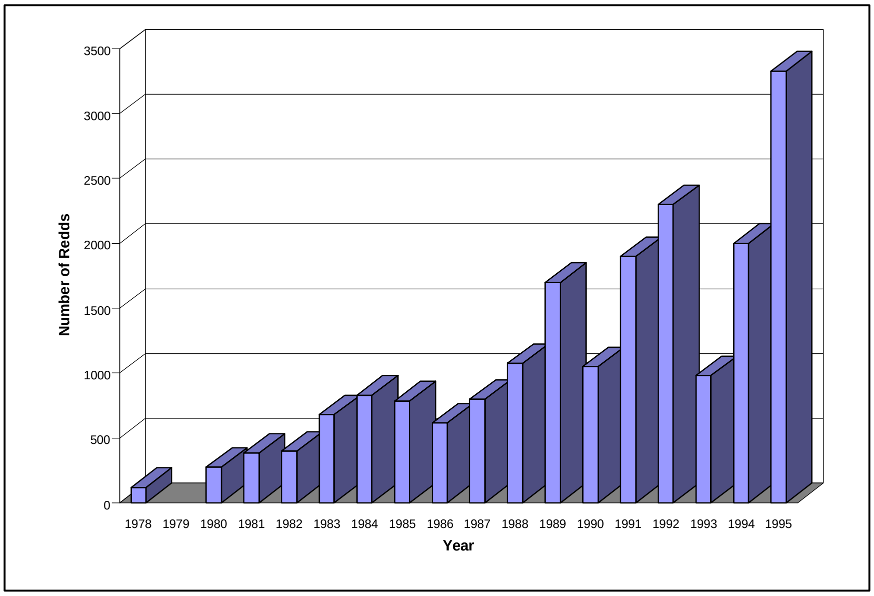


Figure 2. Yearly redd counts of fall chinook from 1978-1995 in the South Umpqua River Basin.

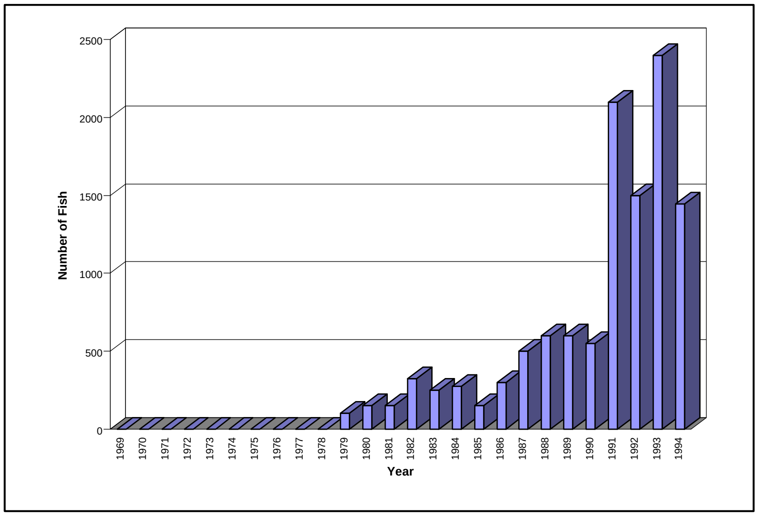


Figure 3. Yearly harvest estimates of fall chinook from 1969 to 1994 in the mainstem Umpqua River.

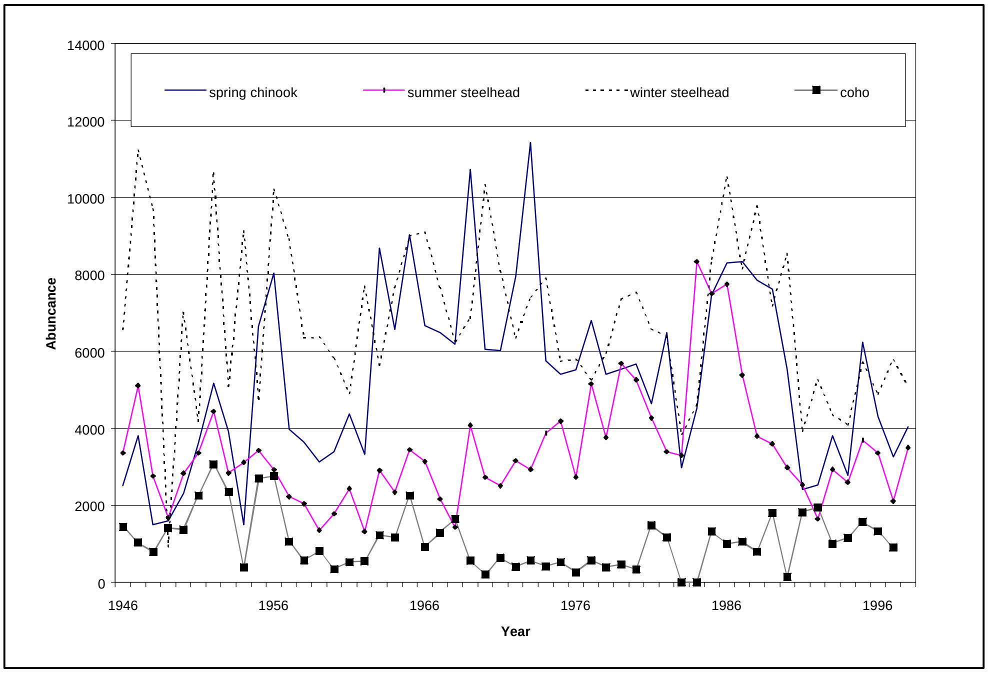


Figure 4. Yearly counts of wild spring chinook, summer steelhead, winter steelhead, and coho passing Winchester Dam on the North Umpqua River from 1946 to 1998.

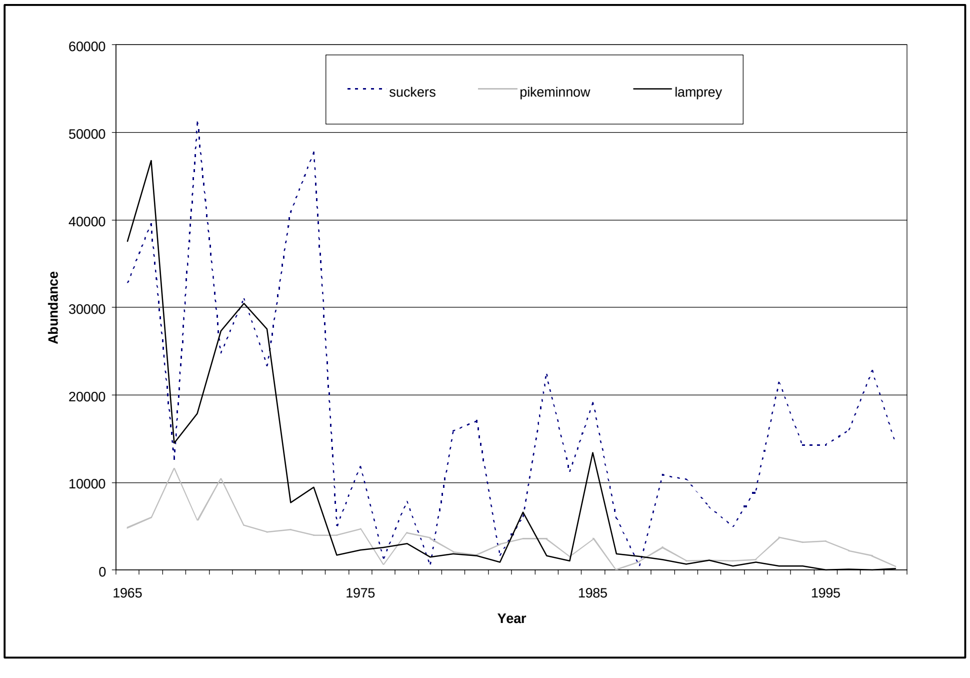


Figure 5. Yearly counts of suckers, pikeminnows, and lamprey passing Winchester Dam on the North Umpqua River from 1965 to 1998.

John Day River Smallmouth Study

Tim Unterwegner
Oregon Department of Fish and Wildlife

History of the Fishery

The John Day River Basin has been well known for its diversity of fish resources, particularly its spring chinook salmon and steelhead trout. The spring chinook population is the largest remaining totally wild run and the steelhead population is one of the largest in the entire Columbia River Basin. In recent years, the John Day River has been gaining notoriety for its smallmouth bass fishery. There have been articles published *in Outdoor Life, Sports Afield, Warmwater Flyfishing, Flyfishing,* and *InFisherman* describing the quantity and quality of the fishery. Outfitters on the Internet are advertising “100 fish per day averaging 3-5 pounds.” The John Day District office has received calls from Kansas, Illinois, Florida, Missouri, Colorado, Idaho, and California within the last year requesting information for the type of gear, the best time of year and the best areas to go catch smallmouth.

Smallmouth were first introduced into the John Day River in 1971, after intensive surveys showed that major portions of the lower river served only as migration corridors for anadromous salmonids. The lower river is inhospitable to salmonid rearing because of warm water temperatures and extreme flow fluctuations. This part of the river had virtually no spring or summer sport fishery and high densities of northern pike minnow (squawfish). Smallmouth existed in the Columbia River since the 1930’s but were apparently unable to negotiate Tumwater Falls at RM 10 (Figure 1). The decision to introduce smallmouth to the river took several years, because of concern for predation on the migrating salmon and steelhead. Eventually, the Oregon Wildlife Commission determined that the risk to salmon and steelhead would be minimal, and that the smallmouth could provide a significant fishery. In May of 1971, 62 adult bass from Willow Creek Reservoir (Morrow County) were planted in the John Day River near Service Creek and another 18 adult bass from Warm Springs Reservoir were planted that October near Kimberly. The fish planted in May spawned successfully the first year and the population rapidly expanded into all suitable habitat. Bass currently occupy the mainstem up to Dayville (RM 212) and the North Fork up to Wall Creek. Seasonal distribution may extend several miles up the North Fork to Highway 395 (RM 60) and up the mainstem as far as Mt. Vernon (RM 239). Salmonids occupy virtually all tributaries and much of the mainstem in the upper portion of the watershed.

Smallmouth habitat in the John Day River is fairly typical of most rivers occupied by bass, dominated by boulders, rock ledges, deep pools, shoal areas and gravel bars.

Management

The river is split into two management strategies, a Basic Yield area that has good access by roads and a Quality Fishery area that has limited public access. The Basic Yield area above Service Creek (RM 157) is readily accessed by State Highway 19 and the Kimberly/Monument Highway. The Quality Fishery area (between Service Creek and Tumwater Falls) is accessible only by boat or at a handful of scattered points. Minimum trip length for the most commonly floated sections is a full day from Service Creek to Twickenham, three days from Twickenham to Clarno, four days from Clarno to Cottonwood Bridge and two days from Cottonwood Bridge to McDonald Ferry. The Basic Yield area is where the greatest potential for overlap between anadromous salmonids and smallmouth is likely to occur.

The goal of the Basic Yield area is to provide a variety of sizes of fish to anglers. Quality Fishery areas are managed to increase the abundance of mid- to large-sized fish. The goal for the Quality Fishery area in the John Day River is to have at least 20% of the fish caught by anglers to be over 12”.

Statewide angling regulations apply to both management areas. Current bag limit is five fish per day with no more than three over 15 inches. In previous years the statewide bag and length limits have been sufficient to provide for a quality fishery, but with increased use we have become more concerned about angler exploitation and the decrease in average fish size.

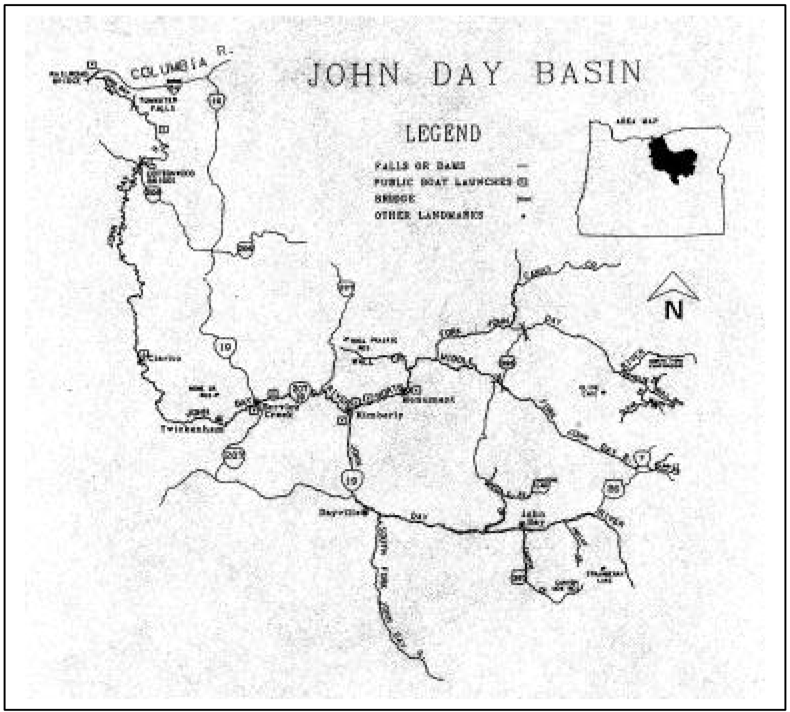


Figure 1. Map of John Day Basin, with major landmarks.

Annual Length-Frequency Sampling

Length-frequency sampling trips have been conducted on a consistent basis since 1985, with a primary objective of evaluating accomplishment of the “Quality” fishery goal. Bass are sampled with hook and line and measured for total length. Some years, scales and weights have been collected to assist with modeling the population. Length-frequency composition in the Quality Area varied during the 1991-1996 time period. The percentage of fish over 12 inches ranged from 7% to 36% with a decrease in percentage in recent years (Figure 2). This is particularly evident since 1993.

Growth and Population Age Structure

Scales were taken from bass during 1991 and 1994 sampling with a goal of ten samples per 10-millimeter length interval. Scales were impressed in acetate and aged by standard methods. Growth of bass in the John Day River is comparable to the Snake River above Brownlee Reservoir and the John Day Pool of the Columbia River, which is not particularly rapid. It takes approximately 5 years for a bass to reach 12”, which meets our “quality” requirement (Figure 3).

Creel Survey and Exploitation Study

Concern for an apparent decline in the size of smallmouth bass and increase in angling pressure on the lower John Day River led us to design an exploitation study to investigate those concerns. We did this by conducting a statistical creel survey and a reward tag program conducted in 1992 and 1993. The creel survey was conducted from late-May to the end of October in 1992, and from early June to mid-November in 1993. Creel survey information was used to generate estimates of total angler effort and harvest. A total of 998 reward tags was implanted into bass greater than 10” total length over the duration of the tagging study.

Creel data showed that total effort was 38,886 hours by 9,622 anglers and 38,945 hours by 11,456 anglers in 1992 and 1993 respectively. Estimated catch of smallmouth bass was 1,520 in 1992 and 3,691 in 1993. Adjusted exploitation rates for bass over 10 inches in the Quality Area was 10% or less in both 1992 and 1993. Greater than 60 percent of bass over 10" were released by anglers (Table 1).

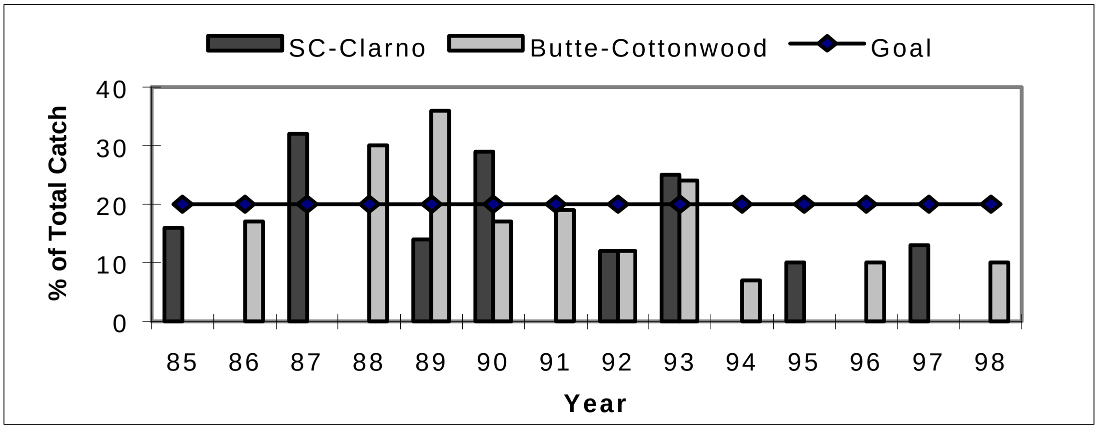
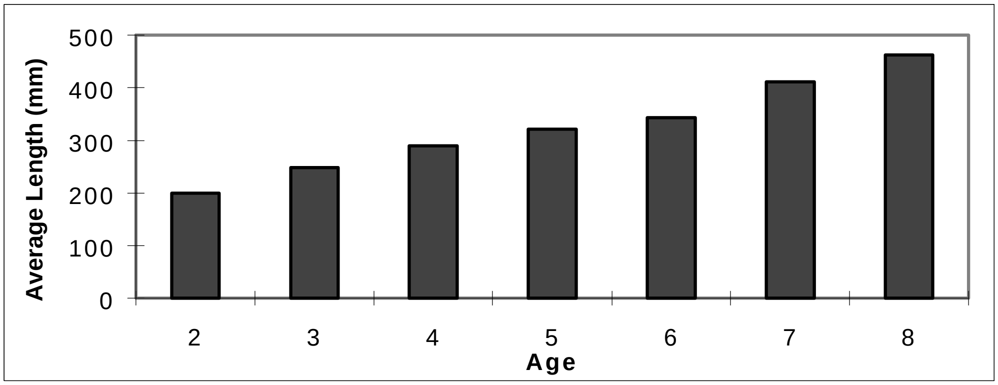


Figure 2. Percentage of smallmouth bass greater than 12" for annual length-frequency trips, 1985-1998.



The goal for the Quality Area is 20% >12".

Figure 3. Estimated average lengths of smallmouth bass for a given age, 1994.

District personnel conducted young-of-the-year sampling between 1978 and 1996 in an attempt to quantify annual spawning success. Each September, two sites were electroshocked using a drift boat mounted shocker and a catch per 1,000 seconds determined (Figure 4).

We determined there was no correlation between our young-of-the-year sampling and recruitment into the population the following year. We have since discontinued our fall sampling.

Although there is no baseline data to verify the increase in recreational use on the river, the number of commercial guided trips is probably representative of the overall trend in use. The number of guided customer days has shown a significant increase in the last 20 years according to Bureau of Land Management data (Figure 5).

Most of the mortality incurred by smallmouth bass in the John Day River is due to natural factors rather than angling, with total instantaneous mortality of 58.5%. Even though most of the bass die from natural causes, modeling indicates more restrictive regulations may provide a modest increase in the number of larger bass. Implementing a 12 inch minimum length limit would increase the percentage of fish caught over 12" to almost 20%, but with an 80% reduction in number of bass harvested. A slot limit that would protect bass from 12" - 16" would increase the number of bass over 12" by 8%, but only decrease harvest by 15%.

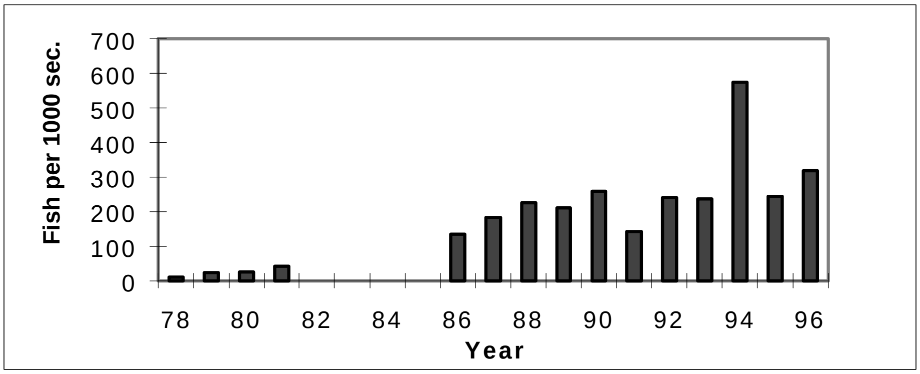


Figure 4. Catch rates during annual young-of-the-year electroshocking at the Service Creek site. Gear types changed between 1981 and 1986, so comparison of catch rates may not be valid.

Table 1. Reported smallmouth bass reward tags recovered in the John Day River. River mile 98 is near the mouth of Butte Creek, at Fossil.

Year Tagged	# Tagged	# Kept [/a]	# Released	RM > 98	RM < 98	Total # Recaps
1992	500	63	90	53	100	153
1993	498	37	62	50	49	101
TOTAL	998	100	152	103	149	254[/b]

[/a] For the purposes of this tally, a "kept" fish was either kept and killed, or released without the tag. Eighteen fish were released minus the tag.

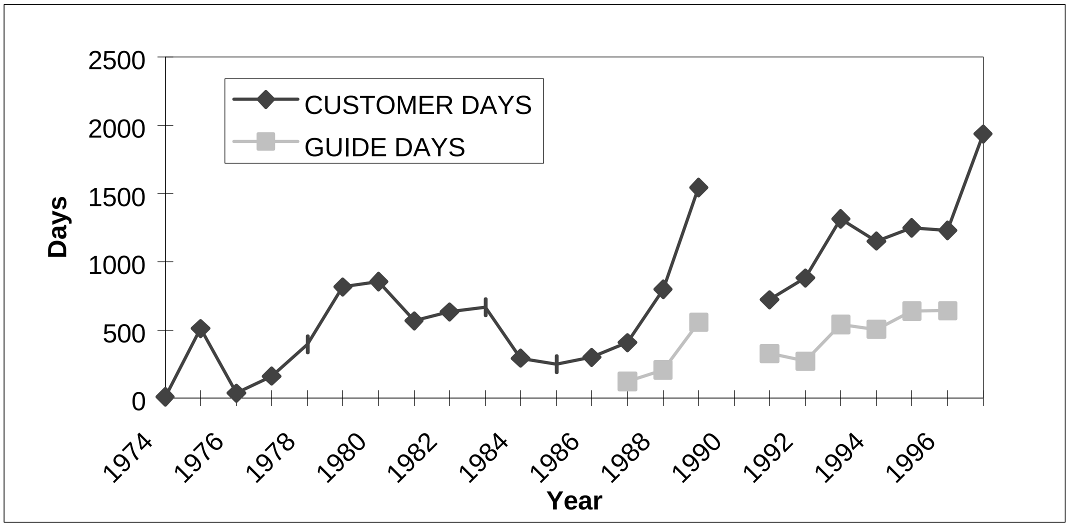


Figure 5. Number of customer days and guide days based on BLM commercial use reports, 1974-1997.

Food Habits

There has been much discussion about the impacts of smallmouth bass on native salmonids in the John Day River. In response to this concern, stomach contents of John Day River smallmouth bass captured during the period from April through August, 1977 and 1978 were analyzed to determine predation levels on juvenile salmonids. Stomach contents were also collected from smallmouth bass in April, 1996 to specifically examine predation on salmonid smolts. The second week of April is the peak outmigration time for spring chinook smolts. Stomach contents were collected either by sacrificing the fish and removing the entire stomach or by pumping contents with a fabricated stomach pump. Stomachs or their contents were immediately placed in 10% ethanol. Food items were later identified and categorized into major groups, and their frequency of occurrence determined. In 1977, the relationship between water temperature from which the fish were taken and the proportion of stomachs containing food was examined.

Crayfish, fish, and insects were the most common food items for smallmouth bass during the 1977-78 study (Figures 6 and 7).

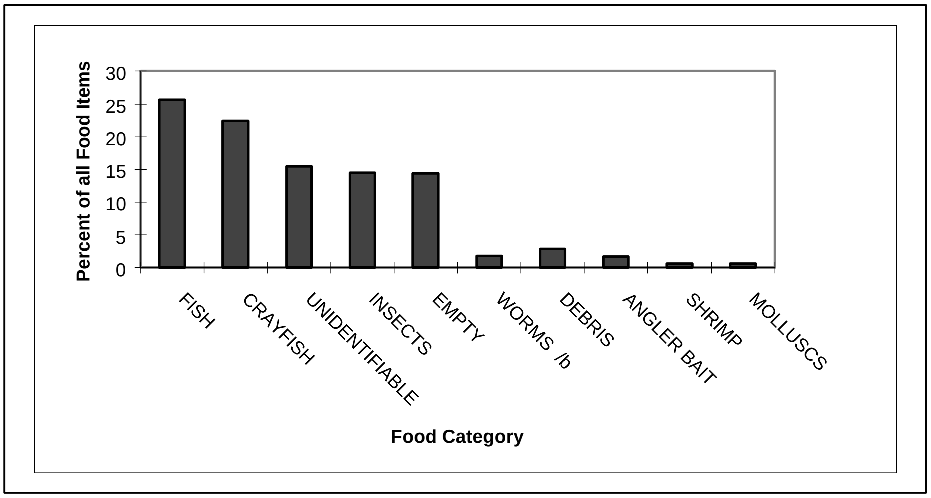


Figure 6. Percent occurrence of individual food items in smallmouth bass stomachs collected April through August, 1977. Fish=fish; Cray=crayfish; Unid=unidentified material; Insc=insects; Empt=empty; worm=non-bait annelids, cestodes, and nematodes; Debr=debris; Bait=angler's bait; shrp=freshwater shrimp; Moll=mollusk.

In April 1996 insects were by far the most important diet item (Figure 8). Inadvertent disposal of some of the 1996 samples reduced the number of stomach content samples examined for the occurrence of insects, plants, crayfish, and worms to 54 but all 60 samples were examined for the presence of fish and/or fish parts. An important difference should be noted regarding the size of bass sampled during April 1996. A higher percentage of bass collected during this time period exceeded the 12” quality fish goal (Figure 9).

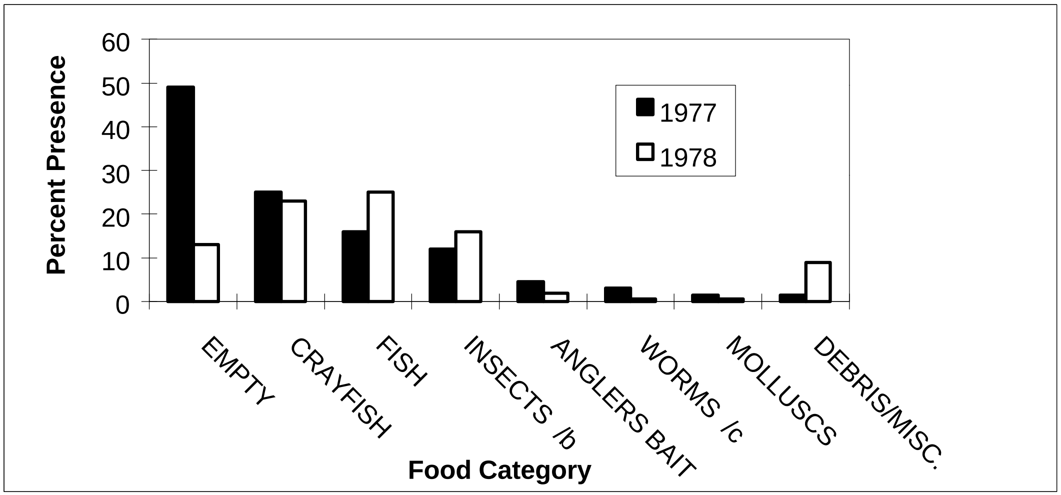


Figure 7. Observed frequency of occurrence of individual food items in smallmouth bass stomachs collected April through August, 1977 and 1978. (Fish=fish; Cray=crayfish; Unid=unidentified material; Insc=insects;; worm=non-bait annelids, cestodes, and nematodes; Debr=debris; Bait=angler's bait; shrp=freshwater shrimp; Moll=mollusk).

Figure 8. Incidence of different food items in smallmouth bass stomachs collected during April 1996.

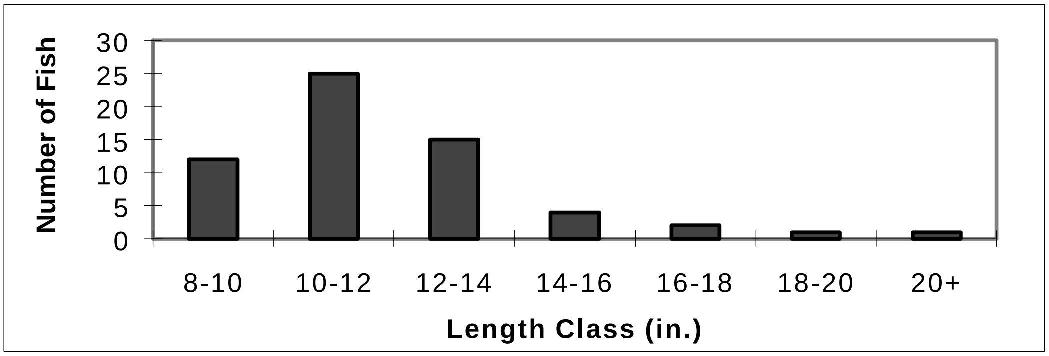


Figure 9. Length frequency of smallmouth bass collected for stomach content analysis, April 1996.

This is consistent with observations of guides, who indicate the best time to catch the larger fish is during April and early-May. A significant difference was noted in the proportion of fish with empty stomachs collected in 1977 at temperatures under 57° F and those over 61° F. The largest percentage of smallmouth bass examined that had empty stomachs occurred in April when water temperatures were below 57° F. No salmonids were identified in any of the samples collected during the 1977-78 study (Table 2).

Water temperatures during April 1996 sampling ranged from 48° F to 55° F and flow ranged from 4,300 to 4,500 cfs. Of the 60 stomachs examined 24 (40%) were empty and only 7 stomachs (12%) contained fish. Two of those fish were identified as suckers, two were non-salmonids (probably suckers), one was a lamprey, one a cyprinid, and one was unknown (possibly a salmonid).

Table 2. Percent occurrence is the number of an individual food item, divided by the total number of food items that month.

	Percent Occurrence By Month (1977)				
Food Item	April	May	June	July	August
Crayfish	44	21	12.5	12	36
Salmonids	0	0	0	0	0
Non-Game Fish	0	24	6	8	5
Unidentified Fish	0	8	19	14	19
Insects	0	6	12.5	26	15
Angler's Bait	0	0	0	2	5
Annelid	0	0	0	0	2
Mollusk	0	0	0	2	0
Debris	0	0	0	8	2
Empty	44	18	0	14	10
Lamprey	0	2	0	0	2
Fresh-Water Crustacean	0	0	0	0	2
Nematode	0	0	0	2	0
Flat Worm	0	0	0	0	2
Unidentified	12	21	50	12	0

In summary, the John Day River is providing a very popular and nationally renowned smallmouth bass fishery in a very scenic setting. Prior to the smallmouth bass introductions, a sport fishery in the river below Dayville did not exist during spring, summer, or early fall. Smallmouth bass in the John Day River exhibit growth patterns very similar to other riverine populations. The introduction of smallmouth bass into the John Day River does not appear to have a significant (if any) impact on native salmonids, based on analysis of over 500 smallmouth bass stomach contents and an analysis of salmon and steelhead spawning data. Chinook salmon spawning surveys show an increase in spawning densities over the last 20 years and summer steelhead spawning surveys follow trends similar to adjacent basins that have either no or very few smallmouth bass. Anecdotal observations of long-time river users indicate that the number of northern pikeminnows has declined since the introduction of smallmouth bass into the John Day River. Even though angler harvest accounts for a relatively small percentage of total mortality, more restrictive regulations could increase the number of bass over 12" with a modest decrease in number of fish harvested.

An Overview of Columbia River Predation Studies

Mark Zimmerman
Oregon Department of Fish and Wildlife

Fish assemblages in the lower Columbia and lower Snake rivers have been shaped by numerous exotic species introductions and extensive habitat alteration associated with hydropower development (Poe et al. 1994). Many introduced species such as centrarchid and ictalurid spp. have inhabited the basin for nearly a century, whereas others like walleye *Stizostedion vitreum vitreum* have become established more recently. Potential interactions between endemic and introduced species are undoubtedly complex and innumerable, and the consequences for the distribution and abundance of native fish populations are unknown.

What is known about the habits and potential impacts of exotic piscivorous fishes was largely derived from three research projects conducted in the lower Columbia Basin over the past 20 years. A review of their major findings is requisite to any consideration of management strategies aimed at minimizing the impacts of exotic fishes in the basin. The first was conducted in 1979 - 1981 by Oregon State University (Hjort et al. 1981). The primary research objectives included measuring distribution and abundance of various habitat types in John Day Reservoir, and quantifying habitat use by life stages of all fish species. Limited sampling was also conducted in Bonneville and The Dalles reservoirs. This project was notable in the lower Columbia Basin because it examined habitat and life history characteristics of nongame and game species.

After analysis of many physical and chemical variables in John Day Reservoir, Hjort et al. (1981) found that fish habitats were mainly distinguished by differences in velocity and depth. This is most apparent when contrasting the reservoir forebay (deep with slow water velocity) with the tailrace (relatively shallow with fast velocity), but also main channel versus backwater habitats. Backwaters were important spawning, rearing, and adult feeding areas for many exotic species. In contrast, native species including white sturgeon *Acipenser transmontanus*, mountain whitefish *Prosopium williamsoni*, and most cyprinids were associated with fast water in or near the tailrace, particularly for spawning. This generalization between exotic and native habitat associations probably holds true for other mainstem reservoirs, most of which have fast water exchange rates and small littoral zones that limit phytoplankton and zooplankton production.

A second extensive research study was conducted in John Day Reservoir from 1983-1986 to quantify impacts of resident fish predation on juvenile salmonids *Oncorhynchus* spp. The project targeted four predator species; northern pikeminnow *Ptychocheilus oregonensis* (known as northern squawfish prior to 1998; Nelson et al. 1998), smallmouth bass *Micropterus dolomieu*, walleye, and channel catfish *Ictalurus punctatus*. Major findings included predator distributions and abundance (Beamesderfer and Rieman 1991), population statistics (Beamesderfer and Rieman 1988), diets (Poe et al. 1991), and consumption rates on juvenile salmonids (Vigg et al. 1991).

Estimates of numerical losses of juvenile salmonids to each predator species showed that northern pikeminnow accounted for 78% of the losses attributable to resident predators, walleye accounted for 13%, and smallmouth bass accounted for the remaining 9% (Rieman et al. 1991). Northern pikeminnow were considered the major resident predator species by virtue of their opportunistic food habits, greater abundance relative to the other species, and their prevalence in the upper part of the reservoir where juvenile salmonids were considered most vulnerable. Smallmouth bass were most common in the lower part of the reservoir where their impact was largely restricted to summer-migrating chinook salmon *O. tshawytscha*. Walleye consumption of juvenile salmonids exceeded that of smallmouth bass, but their impact was limited by their low abundance in the reservoir. Predation by channel catfish was not estimated because of difficulties associated with determining their abundance in John Day Reservoir, although diet analysis showed that juvenile salmonids were commonly preyed upon by channel catfish.

The results of the predation study in John Day Reservoir led to the implementation in 1990 of the Northern Pikeminnow Management Program throughout the mainstem lower Columbia and lower Snake rivers, with the intent to enhance juvenile salmonid survival by selectively harvesting northern pikeminnow (Beamesderfer et al. 1996; Friesen and Ward, in press$_a$). The program was largely based on a population model developed by Rieman and Beamesderfer (1990). The model showed that population characteristics of northern pikeminnow were such that relatively modest but sustained reductions in their numbers result in a disproportionate benefit in juvenile salmonid survival. Predation management also grew out of a realization that juvenile salmonid mortality attributed to predation could be similar in magnitude to mortality associated with dam passage.

The Oregon Department of Fish and Wildlife's evaluation of the Northern Pikeminnow Management Program from 1990 through 1996 expanded the scope of predation research beyond John Day Reservoir to the entire lower and mid-Columbia and lower Snake rivers. Ward et al. (1995) showed that northern pikeminnow predation on juvenile salmonids was significant throughout the basin. Size selective harvest of northern pikeminnow has reduced the abundance of large individuals that exhibit the highest consumption rates on juvenile salmonids (Knutsen and Ward, in press; Zimmerman and Ward, in press). To date, predation by surviving northern pikeminnow and other predator species has not increased as a consequence of the predator control program (Ward and Zimmerman, in press; Zimmerman, in press).

The impact of introduced predators varies spatially throughout the basin, seasonally, and annually as a function of population abundance and variation in recruitment. Smallmouth bass are distributed systemwide, but their density increases in an upriver direction in the Columbia River and reaches a maximum in Lower Granite Reservoir in the Snake River (Zimmerman and Parker 1995). This is in direct contrast to northern pikeminnow which are most abundant downstream from Bonneville Dam and least abundant in the lower Snake River (Ward et al. 1995). Therefore, the relative impact of smallmouth bass predation is greater in the Snake River than was originally estimated in John Day Reservoir, assuming similar consumption rates between areas.

Consumption rates of smallmouth bass do not exhibit the marked increase with predator size that is characteristic of northern pikeminnow (Vigg et al. 1991), and past studies may have underestimated the impacts of smallmouth bass by restricting estimates of predation to individuals exceeding 200 mm fork length. Smallmouth bass consume smaller juvenile salmonids than northern pikeminnow at the same times and locations (Zimmerman, in press). Consequently, smaller wild stocks of chinook salmon are more vulnerable to smallmouth bass predation than larger hatchery stocks.

Walleye are distributed throughout the lower Columbia River, and appeared to be absent in the Snake River upstream from Ice Harbor Dam (Zimmerman and Parker 1995). However, several young walleye were captured in Lower Monumental Reservoir by an Oregon Department of Fish and Wildlife crew while electrofishing in 1998. Walleye abundance in the basin is driven by wide swings in year class strength and subsequent recruitment. Walleye abundance may have doubled in John Day Reservoir from the mid-1980's to the early 1990's based on year class strength analyses and sport harvest rates (Tinus and Beamesderfer 1994, Friesen and Ward, in press), and the original assessment of walleye predation relative to other predators was made during a period of low walleye abundance.

The relative magnitude of channel catfish predation on juvenile salmonids remains unknown. However, their impact on Snake River stocks may be significant because channel catfish abundance is far greater in lower Snake River reservoirs than Columbia River reservoirs (Zimmerman and Parker 1995). A thorough study of channel catfish abundance and consumption is needed to assess the impacts of their predation on juvenile salmonids throughout the basin.

While most of the region's attention regarding introduced fishes is directed toward potential losses of juvenile salmonids, the impacts of exotic predators extend to many other endemic fish and invertebrate prey populations. There is considerable overlap in the adult diets of the four predator species. Crayfish are important prey for all species, with the exception of walleye (Poe et al. 1991;). Cottids, cyprinids, catostomids, and sand rollers *Percopsis transmontana* are preyed upon by smallmouth bass and walleye to a much greater extent than by northern pikeminnow (Zimmerman, in press). Predation research has improved our understanding of introduced fish species in the lower Columbia Basin, and has raised many more questions. To what extent are northern pikeminnow diets a consequence of the presence of exotic predator species? What are the combined impacts of predators on prey populations, particularly uncommon ones such as sand rollers? What are the interactions among younger-aged native and exotic species and their fish and invertebrate prey? What factors regulate the distribution and abundance of exotic species in the basin?

Regarding the latter question, water temperatures in the Columbia and Snake rivers are generally cooler than the physiological optima for each species. Angling mortality on smallmouth bass and walleye appears modest relative to lakes and rivers in other parts of the country (Beamesderfer and Ward 1994; Tinus and Beamesderfer 1994). Habitat quality, quantity, reservoir productivity, and flow regimes in the Columbia Basin appear to regulate populations of smallmouth bass, walleye, and probably many other introduced warmwater species more than fishing mortality. Variation in spill, reservoir levels, and associated water temperatures probably limit their abundance by regulating recruitment, growth, and survival. Loss of backwater habitats as a result of proposed reservoir drawdowns may greatly reduce populations of exotic species.

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Lower Yakima River Predatory Fish Monitoring:
Progress Report 1998

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Abstract- *We began an effort to examine predation by fish on salmonids in the lower Yakima River in 1997. Based on the findings from 1997, we initiated a program in 1998 to determine predation indices for the three primary fish predators in the lower Yakima River; smallmouth bass, northern pikeminnow, and channel catfish. Bass and pikeminnow were captured primarily by electrofishing. Channel catfish were collected in drifting gill nets, hoop nets, traps, and by electrofishing and angling. Stomach samples were collected during the spring when emigration of spring chinook salmon smolts was estimated to be at its peak (mid-late April), and again during the last quartile (mid-May) of their emigration. Population estimates of smallmouth bass increased between April and May, as did the proportion of larger (> 200 mm) fish. A higher percentage of the bass sampled during May contained salmonids (16.9-33.3%) than during the April sampling (4.2-4.5%). Most of the smallmouth bass predation on salmonids was on fall chinook salmon parr and smolts. Only one spring chinook salmon smolt was found in a smallmouth bass. Smallmouth bass predation indices (PI) on all salmonids (predominantly fall chinook salmon) were five to ten times higher in May than in April. The smallmouth bass PI for spring chinook salmon was seven to 63 times lower than their PI for fall chinook salmon. A large number of smallmouth bass (N=2645) and channel catfish (N=2694) were tagged in 1997 and 1998. Recaptures of tagged fish as well as seasonal changes in length distributions indicated that there is a large exchange of adult smallmouth bass between the Yakima and Columbia rivers. We were unable to generate population estimates of northern pikeminnow due to low capture efficiency. Northern pikeminnow rarely consumed salmonids during the April sampling period, but during May, 21-29% of the northern pikeminnow stomachs contained at least one salmonid. During this period northern pikeminnow consumed both yearling and subyearling salmonids. We captured large numbers of channel catfish, and 2.9% of the stomachs examined contained at least one salmonid. One channel catfish contained 76 fall chinook salmon, and several other fish species in its gut. By extrapolating smallmouth bass numbers from the mouth of the Yakima River upstream to Prosser Dam, we estimated that smallmouth bass could consume about 18,840 salmonid smolts in the lower 68 km of the Yakima River daily during the smolt emigration period. Estimates of the number of salmonids consumed by northern pikeminnow above Prosser ranged from 35-390 salmonids/1000 predators/day throughout the emigration period. Predator control options are discussed, with the most promising being a 2 C decrease in water temperature in the lower Yakima River.*

Introduction

Predatory fish have been identified as strong interactors that could potentially limit the success of spring chinook salmon *Oncorhynchus tshawytscha* supplementation efforts in the Yakima basin (Busack et al. 1997; Pearsons et al. 1998). Predatory fishes have been implicated as a source of smolt mortality throughout the mid- and lower Columbia and Snake rivers (Vigg et al. 1991; Tabor et al. 1993; Ward et al. 1995). To date, little predatory fish work has been conducted in the Yakima River (McMichael et al. 1998). Low smolt survival through the Yakima River, especially between the city of Yakima and the confluence with the Columbia River, have been attributed to predation by large numbers of native and non-native piscivorous fishes in the lower reaches of the river (B. Watson, personal communication). Northern pikeminnow *Ptychocheilus oregonensis*, smallmouth bass *Micropterus dolomieui*, and channel catfish *Ictalurus punctatus* are the primary piscivorous fish species that are present in the lower Yakima River (McMichael et al. 1998).

Proliferation of non-native predators, exacerbated by alterations of the physical environment may have contributed to unnaturally high predation impacts to anadromous salmonids in the Yakima River. Introductions of non-native predatory fishes were done at times when anadromous fish populations were relatively high and the risks of such introductions to salmonids were unknown. Smallmouth bass were introduced into the Yakima River in 1925 by the Benton County Game Commissioners to increase angling opportunities (Lampman 1947). Channel catfish were introduced into the Boise River, Idaho, in 1893 (Lampman 1947) and probably dispersed into the Snake and Columbia rivers and then the Yakima River. Densities of both smallmouth bass and channel catfish are high enough to support popular recreational fisheries in the lower Yakima River.

High concentrations of the native piscivore, northern pikeminnow, have been observed below irrigation dams on the Yakima River during the spring smolt migration period (McMichael et al. 1998). Salmonids that migrate past dams may be particularly susceptible to predation because they are frequently concentrated in small areas and disoriented. In addition, unnaturally high water temperatures, caused by irrigation withdrawals and riparian vegetation removal can also increase digestion rates of predators, resulting in higher consumption. The abundance of these predatory fishes combined with the low salmonid smolt survival rates within the Yakima basin prompted our study to assess and develop methods that would be capable of determining the abundance of predatory fishes that might consume migrating spring chinook salmon smolts in 1997. Findings from the work conducted in 1997 showed that large numbers of large smallmouth bass migrated from the Columbia River into the Yakima River prior to the emigration of most salmonid smolts. We also observed salmonids in the guts of predatory fishes. Methods were developed that allowed us to capture sufficient quantities of the predatory species to attempt to develop predation indices for the three primary predatory species; smallmouth bass, northern pikeminnow, and channel catfish.

Busack et al. (1997) outlined the specific need for determining the abundance of predators and their consumption rates of spring chinook salmon smolts in the spring chinook salmon monitoring plan for the Yakima Fisheries Project. The overall goal of our study was to calculate predation indices for the main predatory fish species during the peak and the last quartile of spring smolt emigration in the lower Yakima River.

Methods

Study Area

The lower Yakima River flows through irrigated farm land in an otherwise arid area in central Washington State. Crops produced in the area are dominated by hops, wine grapes, hay, and fruits. During the late spring and summer, much of the water in the lower Yakima River has been utilized by irrigators and then returned to the river. Irrigation dams within the study area include Sunnyside Dam (river kilometer (rkm) 167.4), Prosser Dam (rkm 76), and Horn Rapids Dam (rkm 28.1)(Figure 1). Summer water levels can be extremely low below Prosser Dam. Water temperatures in the lower Yakima River often exceed the upper lethal limits for salmonids during summer (> 25^{o} C; Bidgood and Berst 1969). Non-native warm and cool water species such as smallmouth bass, channel catfish, pumpkinseed *Lepomis gibbosus,* bluegill *L. macrochirus*, yellow perch *Perca flavescens*, walleye *Stizostedion vitreum,* largemouth bass *M. salmoides*, black crappie *Pomoxis nigromaculatus*, brown bullhead *I. nebulosus,* carp *Cyprinus carpio*, and goldfish *Carassius auratus* are present in the lower Yakima River. Many of the native species previously found in this lower reach, such as sandroller *Percopsis transmontana* and Pacific lamprey *Lampetra tridentata* (Patten et al. 1970), are now very rare.

The habitat in the lower Yakima River corridor has been influenced by irrigation diversions and bank stabilization. Riparian vegetation is dominated by grasses, dogwoods, willows, black cottonwood, alder, and Russian olive. The gradient of the river decreases as the river nears its confluence with the Columbia River between the cities of Richland and Kennewick, Washington. The lower 6.4 km of the Yakima River are influenced by the pool elevation behind McNary Dam and the discharge out of Priest Rapids Dam on the Columbia River.

Population estimates were conducted by boat electrofishing in five sections. The two sections sampled by WDFW with an electrofishing drift boat were; 1. Grosscup Road to Van Geisen Road bridge (Vangie), and 2. Chandler Power House to Benton City (Benton). The Vangie section was 8.0 km long, while the Benton section was 7.8 km long. The YIN used a jet boat electrofisher to sample three areas: 1.

from Horn Rapids Dam upstream for 12.9 km (Horn), 2. approximately 2.1 km upstream of the Granger boat ramp to a point 2.0 km downstream of the boat ramp (Granger), and 3. a small area 0.18 km long immediately below Sunnyside Dam (Sunnyside). Additional locations that were sampled by electrofishing were between Van Geisen Bridge and Duportail Road, and Duportail Road to the Highway 240 bridge. Most of the gill netting of catfish occurred in the lower 5 km of the river, while catfish traps were operated in three reaches between rkm 2.5 and 19.0, between the I-182 and Grosscup Road bridges. The Kennewick traps were operated between rkm 2.5 and 4.1. The Duportail traps were located between rkm 7.1 and 12.0. The traps in the Vangie section were placed between rkm 15.2 and 19.0. Additional northern pikeminnow sites were sampled immediately below Roza Dam (WDFW) and near the outfall of the juvenile bypasses below Sunnyside and Prosser dams (YIN).

Population Estimates/Movement

Mark-recapture population estimates (Vincent 1971) were conducted on smallmouth bass and northern pikeminnow captured by boat electrofishing. Electrofisher settings were about 400 V pulsed DC (PDC; Coffelt's CPS setting) at between 2 and 5 Amps during spring sampling (through June) and 400-500 V PDC at 60Hz and 4-6 Amps during summer. All captured predatory fish over 100 mm FL were marked with a partial fin clip and/or tag (predatory fishes $\geq$ 200 mm) on successive runs down each bank. Recapture runs followed the same sequence 1 day (1998) or 7 days (1997) after the marking runs. Fish were processed every 1 km during both marking and recapture runs. The electrofishing runs were generally along the banks, especially during high water. The driftboat was often operated closer to the bank than the jet boat due to difficulty maneuvering the jet boat in swift water. The species composition was visually assessed and recorded by the netter. An additional 133 smallmouth bass captured by tournament anglers fishing in the Columbia River were tagged September 20-21, 1997, and released in the Columbia River at Richland. Correlations between water temperature and discharge in the Yakima River were examined and compared to water temperatures in the Columbia River to help explain fish movement.

Electrofishing was conducted during the estimated peak (April 20-23) and last quartile (May 11-14) of spring chinook salmon smolt emigration. The peak and last quartile were estimated by examining smolt emigration data collected at the Chandler juvenile fish facility between 1983 and 1996. Additional single electrofishing runs were conducted in early June (2-5) and August (19-20) to obtain additional catch per unit effort, diet, and movement data.

Catfish captured in baited slat traps and hoop nets were marked with anchor tags in three sections of river with 6 traps each (*see* McMichael et al. 1998 for details on traps). Catfish traps were operated from mid-April through June and were located primarily along deep outside bends in the river that contained some wood or rock structure. A jet boat was used to travel the section of river where the traps were located. Catfish traps were baited with rotten cheese and were checked every 24-72 h between April 6 and June 30, 1998.

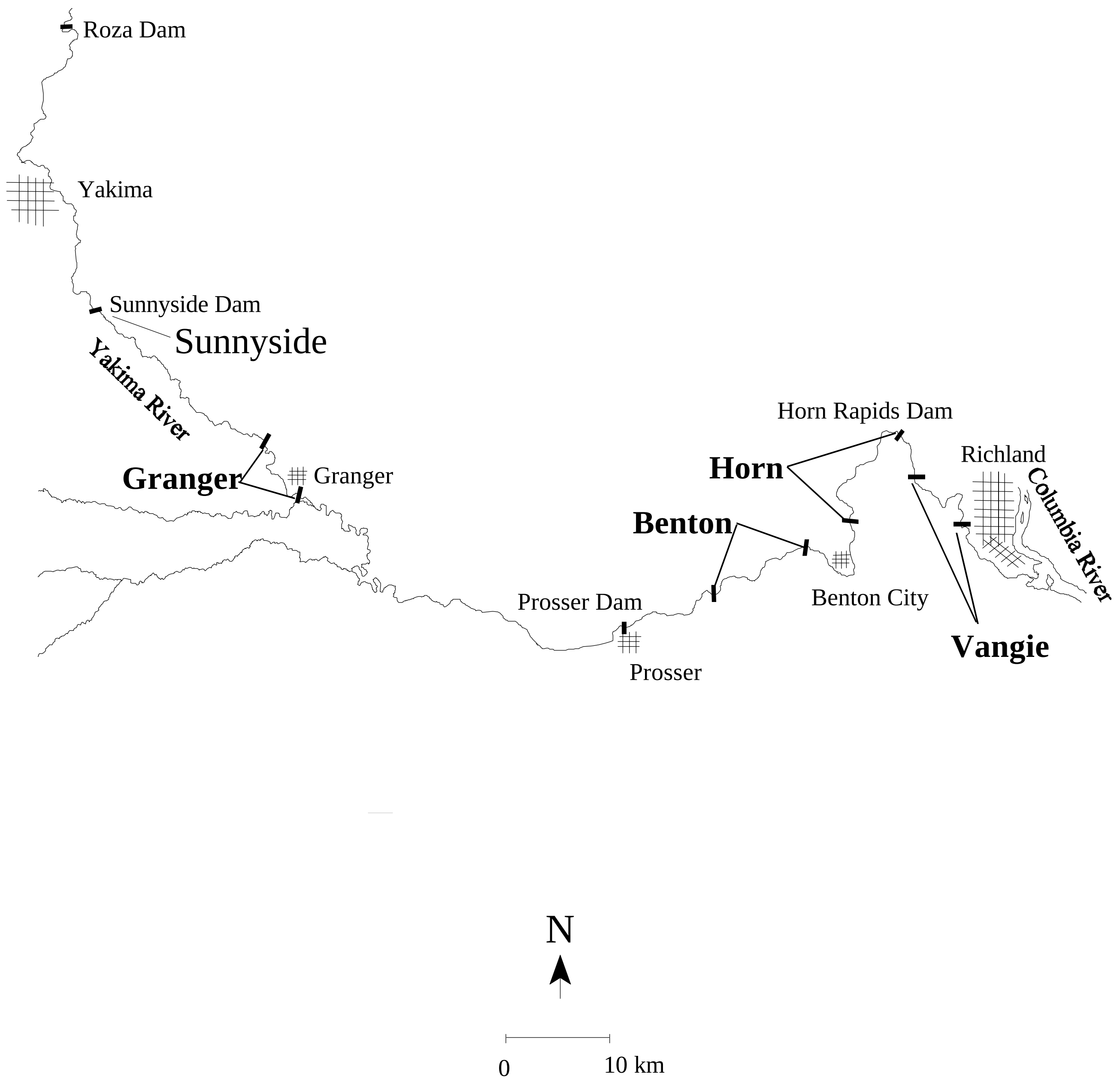

Figure 1. Map of the study area in the lower Yakima River showing index sections in bold type.

Diet Samples

Diet samples were collected from northern pikeminnow, smallmouth bass, and channel catfish. Northen pikeminnow and smallmouth bass sampled for diet were collected by drift and jet boat electrofishing. Most channel catfish collected for stomach samples were captured in drifting gill nets. Gill nets were made of monofilament with a 12.7 cm stretch (6.3 cm bar mesh) and were 15.2 m long and 3 m deep, with a lead line along the bottom edge and high floatation buoys along the top edge (smaller mesh nets were tried and abandoned in favor of the larger mesh). Drifting gill nets were stretched out perpendicular to the river bank in 1.8 to 4.3 m of water and allowed to float downstream for 5 to 30 min. A net was retrieved when it appeared to have entangled a fish, became snagged in debris, or the drift exceeded 30 minutes. A total of 59 sets averaging 12.4 minutes each were performed between April 7 and May 21, 1998.

Diet samples for smallmouth bass were obtained by gastric lavage (Light et al. 1983). Samples of lavaged bass were sacrificed to validate efficiency of the lavage technique. Digestive tracts were excised from channel catfish and northern pikeminnow. All diet samples were placed in whirl-paks with 10 cc of buffered solution and tagged with date, stomach number, species, length, weight, and the section where the fish was captured and then placed on dry ice. Samples were kept frozen until lab analyses (1 to 3 months).

In the lab, the diet samples were weighed to the nearest 0.1 g, then transferred into a pancreatin solution to digest soft tissues, revealing only bones, and finally placed in various size glass and nalgene containers. The analysis of the contents consisted of placing the contents of a single sample into a petri dish and identifying fish to lowest possible taxonomic classification based on diagnostic bones. For bone identification, a series of keys and sketches produced and provided by the Biological Resources Division station located in Cook, Washington, were used. Standard equations were used to calculate estimated length of each fish in the stomach samples based on dimensions of diagnostic bones (Hansel et al. 1988). Length-weight regressions based on live fish we collected concurrently with the predatory fishes, as well as equations presented by Vigg et al. (1991), were then used to calculate estimated weight of each prey fish at the time of ingestion.

We then used the equation presented by Vigg et al. (1991) to calculate digestion time (*DT*; hours) for smallmouth bass:

$$DT=268.529(E+0.01)^{0.696}S^{-0.363}e^{-0.138T}P^{-0.175} \quad [1]$$

E = prey mass evacuated [amount pumped out of gut](g),
S = prey meal weight [at time of ingestion](g),
T = water temperature (C), and
P = predator weight (g).

For northern pikeminnow we used the equation presented by Vigg et al. (1991) to calculate digestion time (*DT*; hours):

$$DT=1330.753E^{1.081}S^{-0.469}T^{-1.606}P^{-0.273} \quad [2]$$

For channel catfish, we calculated digestion time by the following equation (derived from data presented by Shrable et al. (1969)):

$$DT=4.93525+e^{4.07303-0.02289T-1.535966D} \quad [3]$$

D = % of prey weight digested.

To calculate estimated consumption rate C (salmonids per predator per day) we used the equation presented by Ward et al. (1995):

$$C = n(24/DT) \tag{4}$$

n = number of salmonids observed in predator's gut, and
DT = digestion time for a salmonid meal (hours) from equations 1 - 3.

Extrapolations

Population estimates of smallmouth bass $\geq$ 150 mm FL (the minimum size found to contain salmonids) were generated by mark-recapture techniques within the Benton and Vangie study sections during the April and May sample periods. To estimate the daily number of salmonids eaten within each study section by smallmouth bass (SE) we used the following equation:

$$SE = PExFxC \tag{5}$$

PE = population estimate of smallmouth bass $\geq$ 150 mm FL within the study section,
F = fraction of smallmouth bass stomachs examined that contained at least one salmonid, and
C = estimated daily consumption rate per predator from equation 4.

To estimate the number of salmonids consumed daily by smallmouth bass in the lower 68 km of the Yakima River (the range of high bass densities) (S_{tot}) we used the following equation:

$$S_{tot} = (PE/SL)xRLxFxC \tag{6}$$

SL = length of the study section (km), and
RL = length of river being extrapolated to (km).

Extrapolations were not performed on predation estimates for northern pikeminnow or channel catfish due to the lack of predator abundance data. Prey preference for smallmouth bass was examined by subtracting the percentage of a given prey species observed while electrofishing (availability) from the percentage of that species observed in smallmouth bass guts (use).

Predation Indices

The predation indices were calculated based on modified versions of the equations presented by Ward et al. (1995):

$$PI = AIxCI \qquad [7]$$

PI = predation index,
AI = abundance index, and
CI = consumption index.

We used a modified form of predator abundance that we felt better reflected the abundance of predators in the lower Yakima River and that we also believed was more sensitive to changes in capture efficiency that might be related to differing environmental conditions from year to year. Our measure of abundance was the catch per unit effort (CPUE; fish/minute) divided by the capture probability plus one. In cases where no fish were recaptured (thus no capture probability could be calculated), we used straight CPUE. Our measure of area differed from that used by Ward et al. (1995) also, in that we used a linear measurement of the river reach length that our index site represented multiplied by our CPUE data to arrive at the abundance index (AI) for each river reach:

$$AI_{ij} = D_i x S_j \qquad [8]$$

D
= CPUE of predatory-sized fish of species *i*, and
S = length of section j in km [the length of river that the index reach data is extrapolated to].

To calculate consumption indices we used *C* from equation 4 multiplied by the fraction of predatory fish that contained at least one salmonid:

$$CI_{ik} = C_{ik} x F_{ik} \qquad [9]$$

CI_{ik}
= consumption index by predator *i* of prey species *k*,
C_{ik} = consumption rate of prey species *k* by predator *i* (from equation 4), and
F_{ik} = fraction of predator species *i* found to contain at least one of prey species *k*.

Results

Population Estimates

Population estimates were attempted in five river sections in the third week of April, 1998, (peak of spring chinook salmon smolt emigration) and again in the second week of May (last quartile of smolt emigration).

Smallmouth Bass

Populations of smallmouth bass were generally higher during the second sampling period (May) and also in the lower section (Vangie). Data for smallmouth bass in the Benton and Vangie sections are presented in Table 1. Population estimates of smallmouth bass in the Horn section were not possible because no marked fish were recaptured during the recapture period. Future surveys will not use the Horn section due to these low capture efficiencies.

Table 1. Population estimate data for smallmouth bass (SMB) in two sections of the Yakima River. Dates (1998), species/size class (mm FL), estimate, 95% confidence intervals (CI), capture efficiency (Effic.), and validity of the estimate are shown for each river section/date.

Dates	Species/size	Section	Estimate	CI	Effic.	Valid
4/20-21	SMB/≥100	Benton	3528	419-29243	4.7%	yes
4/20-21	SMB/≥150	Benton	1528	221-10838	6.4%	yes
4/20-21	SMB/≥200	Benton	499	98-2970	10.6%	yes
4/22-23	SMB/≥100	Vangie	5092	569-46959	5.8%	yes
4/22-23	SMB/≥150	Vangie	3210	374-25580	6.1%	yes
4/22-23	SMB/≥200	Vangie	2952	152-14511	2.8%	no
5/11-12	SMB/≥100	Benton	5534	578-50024	4.7%	yes
5/11-12	SMB/≥150	Benton	3177	373-25395	5.5%	yes
5/11-12	SMB/≥200	Benton	1313	203-9244	7.9%	yes
5/13-14	SMB/≥100	Vangie	6048	949-76929	9.4%	yes
5/13-14	SMB/≥150	Vangie	4176	701-48307	9.6%	yes
5/13-14	SMB/≥200	Vangie	2490	456-25133	9.7%	yes

Larger bass were caught at a higher rate during May sampling than during the April samples (Figure 2). Figure 3 shows the proportional stock density (PSD) of the smallmouth bass in the Benton and Vangie sections between April and August, 1998.

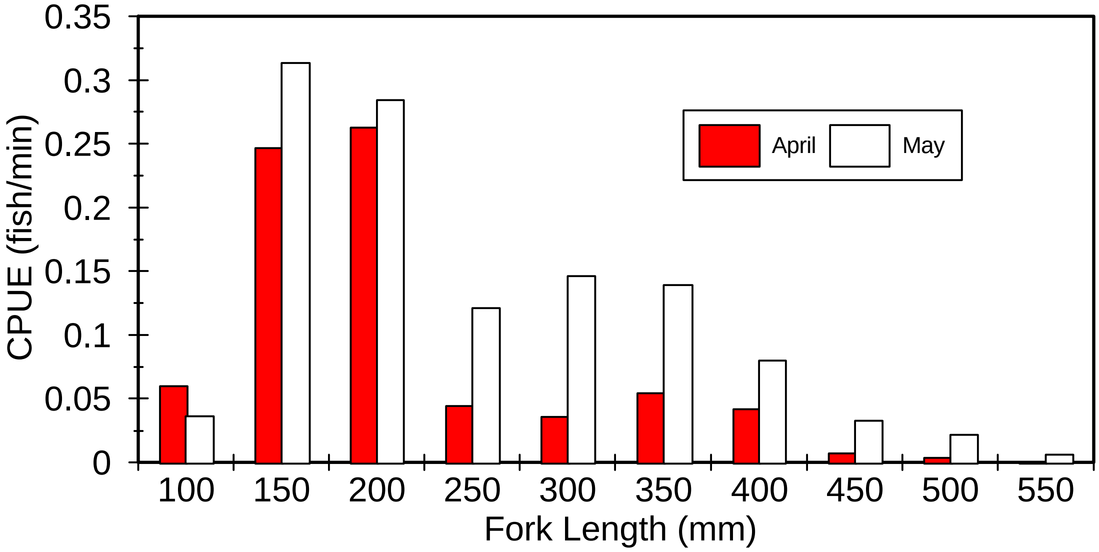

Figure 2. Catch per unit effort (fish/min) of smallmouth bass captured by electrofishing versus length in the Vangie section of the Yakima River in April and May, 1998.

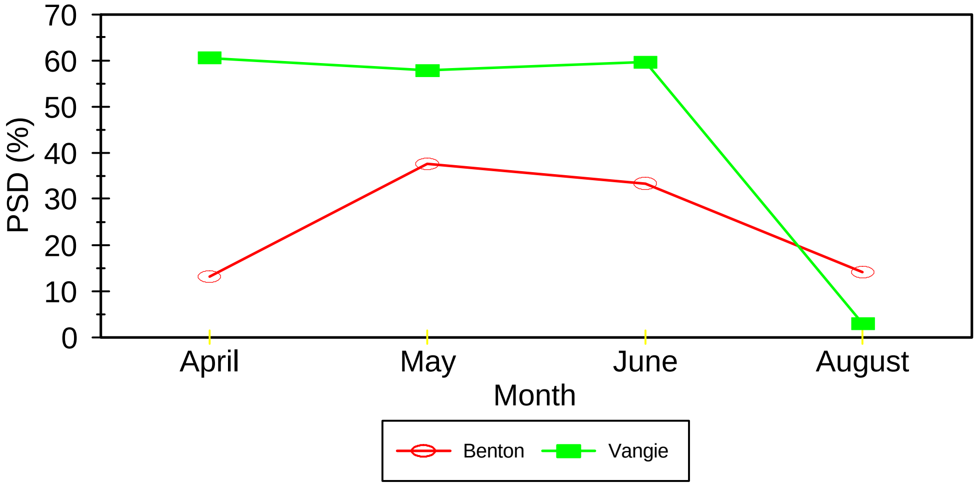

Figure 3. Proportional stock density (PSD; % > 280 mm/> 180 mm) of smallmouth bass captured in the Benton and Vangie sections of the lower Yakima River between April and August, 1998.

The smallmouth bass population estimates in 1997 were generally invalid due to low capture efficiencies related to high waters (McMichael et al. 1998). However, one of the valid estimates for the Vangie section in June, 1997 (6,954 smallmouth bass 100 mm and longer), was similar to the population estimates generated in 1998. Further, in 1997 similar relationships were observed between time period and the number and size structure of smallmouth bass captured.

Northern Pikeminnow

Low catch rates and lack of recaptures for northern pikeminnow prevented us from being able to calculate population estimates for this species in the Horn Rapids and Granger sections. A total of 18 and 57 northern pikeminnows were marked in the Horn Rapids and Granger sections for the season respectively; no marked fish were recaptured. The CPUE (fish > 150 mm fork length per minute) for smallmouth bass at the Horn Rapids section was approximately five times higher than for northern pikeminnow. However, the CPUE for northern pikeminnow at the Granger section was approximately five times higher than the CPUE for northern pikeminnow at the Horn Rapids section. These trends in relative abundance were similar between sampling periods, suggesting that northern pikeminnow abundance is higher in the Yakima River above Prosser than below Prosser throughout the spring chinook salmon smolt emigration period. This observation was also corroborated by visual estimates of the species assemblage for multiple sampling sections throughout the Yakima Basin (see Species Composition Section).

Channel Catfish

Channel catfish were difficult to capture by electrofishing during the spring period; only 2 were captured by electrofishing in 1997 and 27 were captured in 1998. Traps proved much more effective for capturing large numbers of fish, however, the stomach samples from trapped fish were usually unusable due to long periods of holding in traps prior to being removed. Also, the number of recaptures of tagged catfish were very low (Table 2). Channel catfish that were captured in drifting gill nets provided excellent stomach samples, but catch rates were low with this method (43 fish in 1997; 14 fish in 1998). Gill net catches appeared to have been better in 1997 when the river was higher, more turbid, and colder.

The catch of channel catfish in traps generally was higher in the lower traps early in the season, and was higher in the middle and upper section later in the spring (Figure 4), indicating a movement of channel catfish into the Yakima River form the Columbia River or the Yakima River delta. Most of the channel catfish captured in traps were between 200 and 350 mm (Figure 5), similar to the size frequency observed in 1997 (McMichael et al. 1998). Similar to 1997, hoop nets captured a wider size range than the slat traps.

Table 2. Channel catfish trapping data from the lower Yakima River in 1997 and 1998. The number of catfish captured in traps, number of tagged fish recaptured, and population estimates are presented. The length of river (km) where traps were located, and estimated number of channel catfish per km are also presented. Population estimates are crude and are not statistically valid, they are provided for discussion purposes only.

Year	No. Tagged	No. '97 recaps	No. '98 recaps	Pop. Est.	km	CCAT/km
1997	981	15	-	64,157	6	10,693
1998	1498	10	12	224,400	15.8	14,203

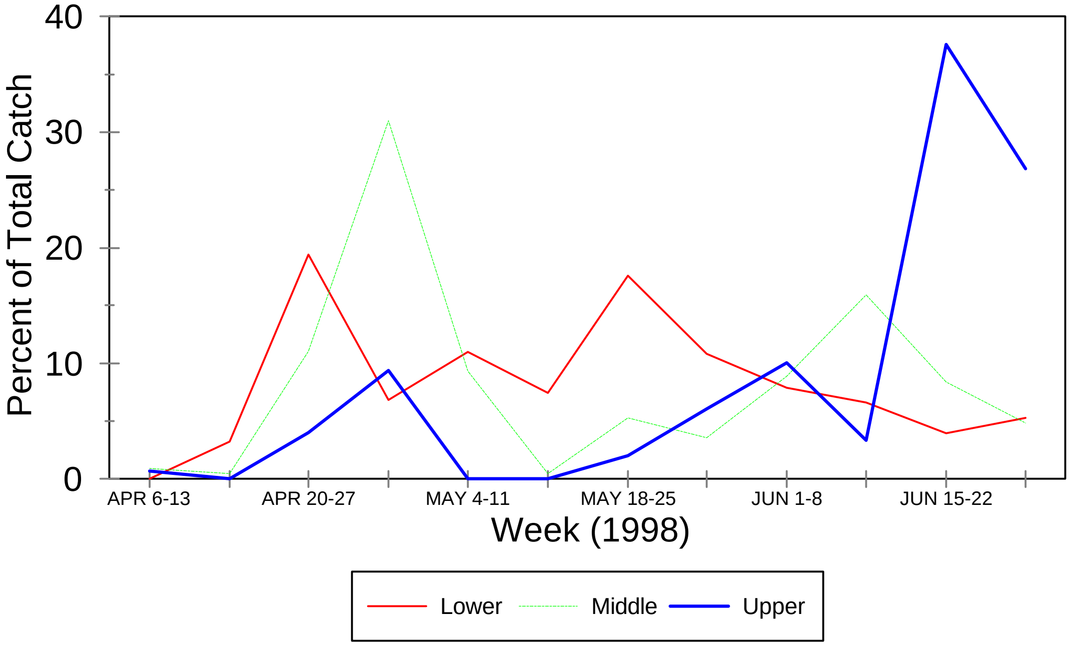

Figure 4. Percent of the total trap catch of channel catfish versus sample week in the lower Yakima River in 1998.

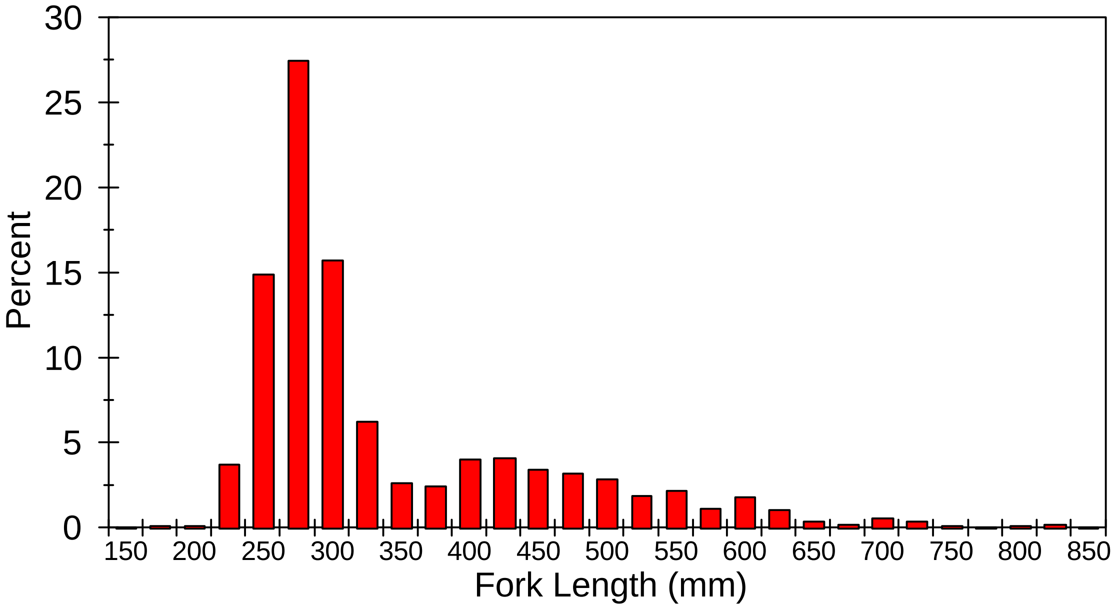

Figure 5. Length frequency of channel catfish captured in traps in the lower Yakima River between April 6 and June 30, 1998. Total sample size was 1,352.

Fish Movement

Tag recaptures and size structure information indicate that smallmouth bass migrated into the Yakima River from the Columbia River during the early spring and migrated out in the summer or fall. Tagged smallmouth bass that have been recaptured by anglers fishing in the Columbia River in the summer and fall indicate that bass tagged in the Yakima River in the spring moved out of the Yakima River in the late spring and early summer. A total of 28 smallmouth bass tagged in the Yakima River (over 1% of the number of fish tagged) have been recaptured by anglers fishing in the Columbia River. Further, five of 133 (3.8%) smallmouth bass tagged in the Columbia River in the fall of 1997 were recaptured in the Yakima River in the spring of 1998. A higher percentage of tagged smallmouth bass captured during spring months were recaptured upstream of the location where they were tagged than during the summer and fall months (Figure 6). Figure 7 illustrates the decrease in the presence of larger smallmouth bass in the Vangie section of the Yakima River between June and August, 1998. The percentage of smallmouth bass in the Vangie section that were greater than or equal to 300 mm FL decreased from 40.7% to 3.3% between June and August, indicating that most large fish present during the spring had emigrated from the section prior to August. This shift in size structure was not due to increased numbers of age-0 smallmouth bass, as we only included fish 100 mm FL or longer.

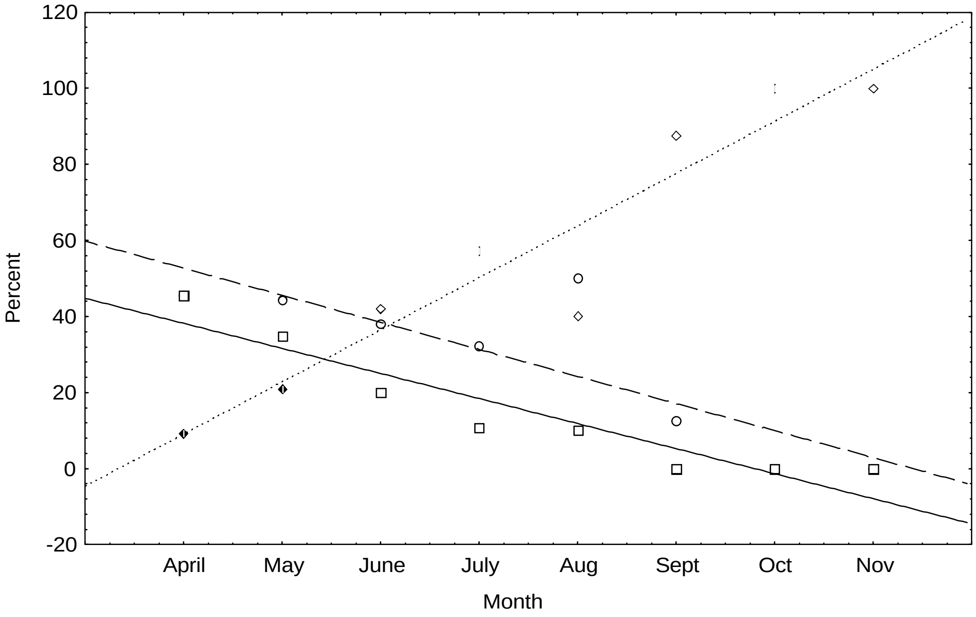

Figure 6. Frequency (percent) of recaptured smallmouth bass moving downstream (dotted line and diamonds), upstream (dashed line and circles) and showing no movement (solid line and squares) in the lower Yakima River in 1997 and 1998 combined. Only smallmouth bass recaptured between 2 and 250 days after tagging were used.

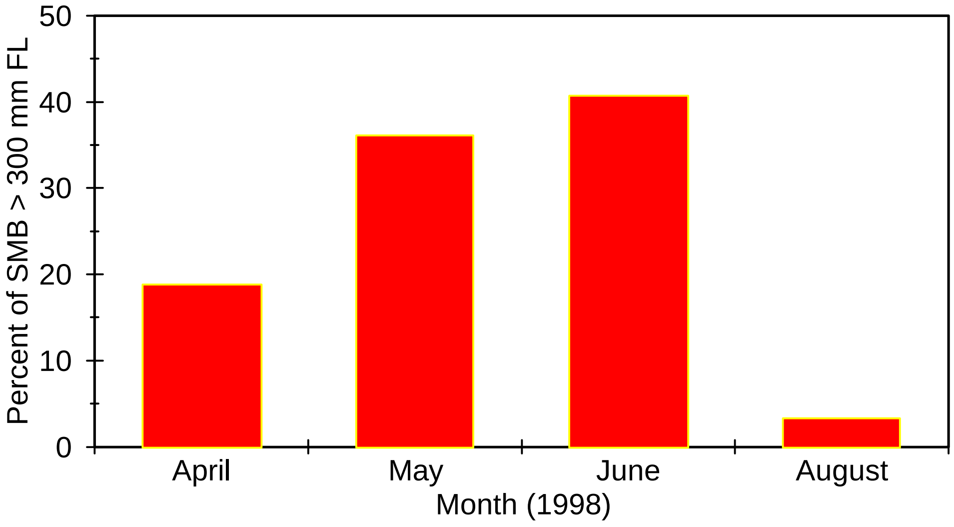

Figure 7. Percent of smallmouth bass captured by electrofishing in the Vangie section of the Yakima River that were greater than or equal to 300 mm FL versus month in 1998.

Warmer water and less drastic diel fluctuations in discharge in the Yakima River than in the Columbia River may be two reasons why adult smallmouth bass move into the Yakima River from the Columbia River in the early spring. The water temperature in the lower Yakima River was generally 1 to 4 C higher than the Columbia River during the early spring period (Figure 8). Within the Yakima River, there was a significant inverse relationship between discharge and water temperature ($R = -0.44$, $P < 0.001$). Increases in flow during the spring period coincided with drops in water temperature.

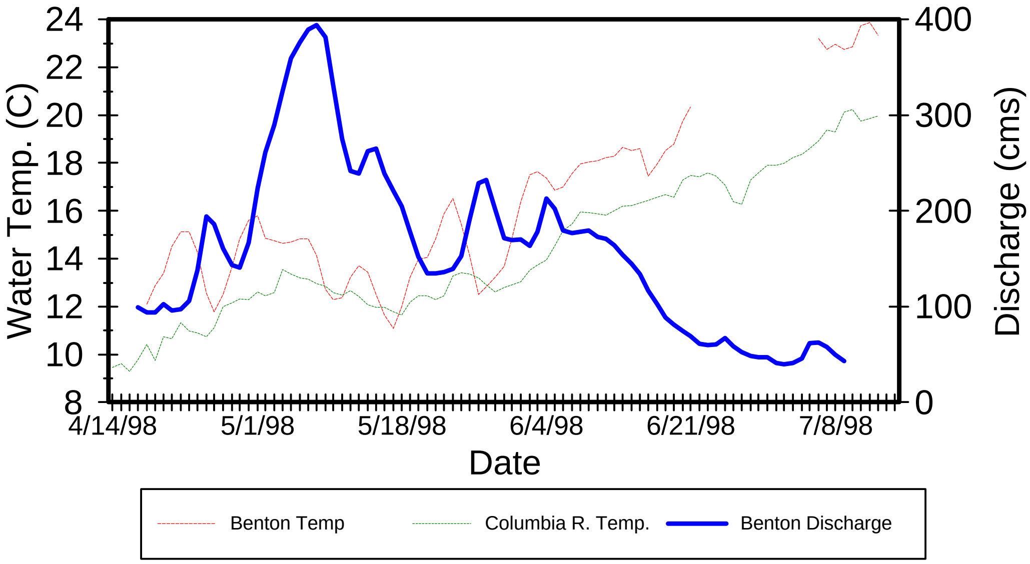

Figure 8. Daily mean water temperature and discharge (m^3/s) in the Benton section of the Yakima River and water temperature in the Columbia River above McNary Dam versus date during the spring and early summer of 1998.

Movement of northern pikeminnow and channel catfish did not exhibit as clear a pattern as smallmouth bass. We recaptured 41 northern pikeminnows in 1997 and 1998 ranging from 1-327 days after they were tagged. Most northern pikeminnows were recaptured in the Sunnyside and Granger sections (N = 18 and 11 respectively). Most northern pikeminnow (N = 37; 90.2%) were recaptured in the same section that they were initially marked. The average number of days between marking and recapture was 66.5 days. Three fish were recaptured at locations away from where they were originally marked. Three of these fish moved downstream after they were initially marked at Sunnyside, Granger and Benton (8/29/97, 8/20/97 and 8/13/97 respectively). The fish marked at Sunnyside and Granger were recaptured at the Chandler Juvenile Monitoring Facility at Prosser Dam in December, 1997. The fish tagged in the Benton section was recaptured near the Yakima River/Columbia River confluence by an angler. A single northern pikeminnow exhibited substantial upstream movement after marking.

With a few exceptions, most channel catfish were typically captured in the same general area where they were tagged. Two channel catfish tagged in the lower Yakima River were recaptured in the lower Snake River. Trapping data (Figure 4) and a limited number of recaptures of tagged fish weakly indicate channel catfish initiate an upstream migration from the Columbia River or Yakima River delta into the Yakima River as the water warms in the spring. Trap catches peaked April 19 in the Kennewick section (rkm 2.5-4.1), May 4 in the Duportail section (rkm 7.1-12.0), and June 15 in the Vangie section (rkm 15.2-19.0).

Species Composition

A total of 30 species of fish were observed in the lower Yakima River during sampling for predacious fishes. Suckers (largescale *Catostomus macrocheilus* and bridgelip *C. columbianus* were common, mountain *C. platyrhynchus* were rare) and chiselmouth *Acrocheilus alutaceus* were present and relatively abundant in all sample sections during all sample periods. Introduced warmwater species such as smallmouth bass and common carp were abundant in the lower four sections and rare above Prosser Dam (Figure 9; Table 3). Conversely, native cool/coldwater species such as northern pikeminnow and mountain whitefish were relatively rare in the lower four sections and much more abundant above Prosser Dam. Two sandrollers, a rare species that had not been documented in the Yakima River for at least 30 years, were captured in the Vangie section in April, 1998.

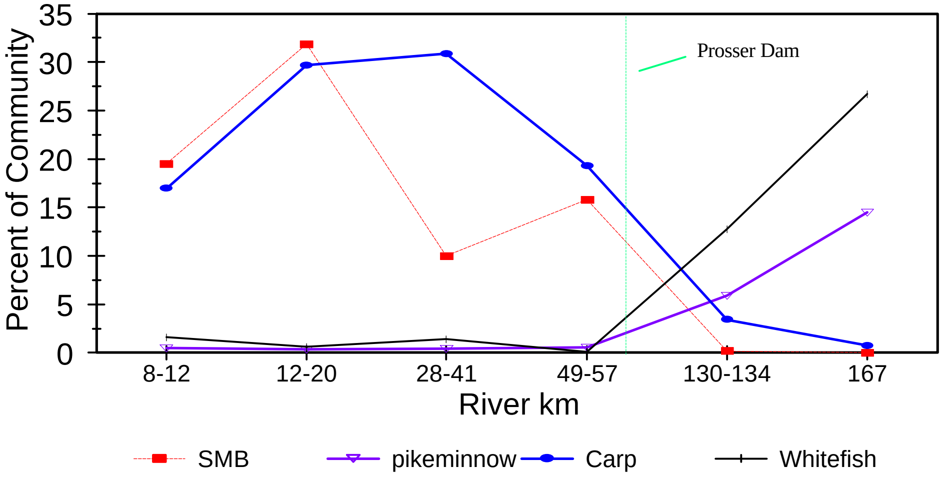

Figure 9. Species composition of smallmouth bass (SMB), northern pikeminnow, common carp, and mountain whitefish versus distance from the mouth of the Yakima River in 1997.

Table 3. Visually estimated fish species composition in total number and percent composition (in parentheses) for April 1998, in lower Yakima River study sections (river km from mouth are shown in parentheses below section names). Data were collected by boat electrofishing.

Species.[a]	Vangie (12.2-20.2)	Horn (28.1-41.0)	Benton (49.3-57.1)	Granger (130.0-134.4)	Sunnyside (167.4)
CCF[b]	5(0.12)	0(0.00)	0(0.00)	0(0.00)	0(0.00)
CCP	1347(31.84)	632(25.34)	939(31.20)	156(4.04)	3(0.92)
CHM	566(13.38)	343(13.75)	178(5.91)	214(5.54)	0(0.00)
COH	3(0.07)	55(2.21)	26(0.86)	56(1.45)	0(0.00)
DAC	2(0.05)	20(0.68)	92(3.06)	0(0.00)	2(0.62)
FCH	64(1.51)	18(0.72)	35(1.16)	18(0.47)	0(0.00)
MWF	21(0.50)	279(11.87)	92(3.06)	755(19.55)	240(73.85)
NPM	16(0.38)	31(1.24)	26(0.86)	59(1.53)	8(2.46)
PMK	0(0.00)	0(0.00)	2(0.07)	0(0.00)	0(0.00)
PMO	4(0.09)	0(0.00)	0(0.00)	0(0.00)	0(0.00)
RSS	19(0.45)	1(0.04)	2(0.07)	41(1.06)	0(0.00)
SCU	1(0.02)	0(0.00)	0(0.00)	0(0.00)	1(0.30)
SMB	887(20.96)	169(6.78)	723(24.02)	1(0.02)	0(0.00)
SND	2(0.05)	0(0.00)	0(0.00)	0(0.00)	0(0.00)
SPC	9(0.21)	231(9.26)	110(3.65)	42(1.09)	0(0.00)
SUK	1241(29.33)	689(27.63)	695(23.09)	2517(65.17)	70(21.54)
WCR	0(0.00)	0(0.00)	1(0.03)	0(0.00)	0(0.00)
WSH	16(0.38)	28(1.12)	71(2.36)	3(0.03)	1(0.31)
YLP	0(0.00)	0(0.00)	1(0.03)	0(0.00)	0(0.00)

[a] CCF(channel catfish), CCP(common carp), CHM(chiselmouth), COH(coho salmon), DAC(dace spp.), FCH(fall chinook), MWF(mountain whitefish), NPM(northern pikeminnow), PMK(pumpkinseed), PMO(peamouth),RSS(redside shiner), SCU (prickly sculpin), SMB(smallmouth bass), SND (sandroller), SPC(spring chinook), SUK(sucker spp.), WCR(white crappie), WSH(wild steelhead), YLP(yellow perch).

[b] Channel catfish are relatively unsusceptible to capture by electrofishing, therefore, they represent a larger but unknown proportion of the total fish community than is represented by these data.

Table 4. Visually estimated fish species composition in total number and percent composition (in parentheses) for May 1998, in lower Yakima River study sections (river km from mouth are shown in parentheses below section names). Data were collected by boat electrofishing.

Species.[a]	Vangie (12.2-20.2)	Horn (28.1-41.0)	Benton (49.3-57.1)	Granger (130.0-134.4)	Sunnyside (167.4)
CCF[b]	18(0.33)	0(0.00)	3(0.06)	0(0.00)	0(0.00)
CCP	756(14.02)	900(22.86)	518(11.12)	151(4.00)	13(6.53)
CHM	616(11.42)	613(15.57)	703(15.09)	228(6.04)	20(10.05)
COH	35(0.65)	52(1.32)	52(1.12)	436(11.55)	40(20.10)
DAC	39(0.72)	0(0.00)	367(7.88)	1(0.02)	0(0.00)
FCH	1222(22.66)	432(10.97)	962(20.65)	221(5.86)	0(0.00)
MWF	250(4.64)	176(4.47)	135(2.90)	745(19.74)	50(25.13)
NPM	20(0.37)	37(0.93)	72(1.55)	127(3.37)	12(6.03)
PMK	3(0.06)	0(0.00)	1(0.02)	0(0.00)	0(0.00)
PMO	4(0.07)	0(0.00)	0(0.00)	0(0.00)	0(0.00)
RSS	0(0.00)	1(0.02)	1(0.02)	188(4.50)	0(0.00)
SMB	1266(23.48)	214(5.44)	773(16.59)	0(0.00)	0(0.00)
SPC	6(0.11)	63(1.60)	13(0.28)	21(0.56)	0(0.00)
STG	0(0.00)	1(0.02)	0(0.00)	0(0.00)	0(0.00)
SUK	1155(21.42)	1447(36.68)	1058(22.71)	1656(43.88)	64(32.16)
WCR	1(0.02)	1(0.02)	0(0.00)	0(0.00)	0(0.00)
WSH	1(0.02)	0(0.00	0(0.00)	0(0.00)	0(0.00)
YLP	0(0.00)	0(0.00)	1(0.02)	0(0.00)	0(0.00)

[a] CCF(channel catfish), CCP(common carp), CHM(chiselmouth), COH(coho salmon), DAC(dace spp.), FCH(fall chinook), MWF(mountain whitefish), NPM(northern pikeminnow), PMK(pumpkinseed), PMO(peamouth),RSS(redside shiner), SMB(smallmouth bass), SPC(spring chinook), STG(sturgeon),SUK(sucker spp.), WCR(white crappie), WSH(wild steelhead), YLP(yellow perch).
[b] Channel catfish are relatively unsusceptible to capture by electrofishing, therefore, they represent a larger but unknown proportion of the total fish community than is represented by these data.

Diet Sampling

The modified lavage technique worked well for obtaining food habits information for smallmouth bass. The relatively small sample (N = 12) of smallmouth bass examined to estimate lavage efficiency for fish remains revealed no fish remains were missed by this technique. Consumption of salmonids by smallmouth bass was much lower in April than it was during May (Tables 5 and 6). The May samples for the Benton and Vangie sections showed that smallmouth bass consumed large numbers of salmon smolts, primarily fall chinook salmon. Only one of the salmonids in the April samples was identified as a spring chinook salmon, while the remainder were fall chinook salmon. All of the salmonids identified in the guts of smallmouth bass in the Benton and Vangie sections in May were fall chinook salmon. Table 6 shows the estimated predation rates for the Benton and Vangie sections during April and May, 1998. Table 7 shows the species of fish consumed by smallmouth bass in both sections and time periods. Table 8 shows the predation indices smallmouth bass for the river reaches and times when both abundance and consumption data were available.

Table 5. Summary results of diet analyses for smallmouth bass ($\geq$ 150 mm FL) sampled in the Benton, Horn and Vangie reaches on April 21-23, May 12-14 and June 4-5, 1998. The number of stomachs examined (N), the number (percent) of fish's guts in each sample that were empty, or contained invertebrates, fish, anadromous salmonids, and/or spring chinook salmon (SPC). The fish category includes salmonids.

Date	Section	N	Empty(%)	Invert.(%)	Fish(%)	Salmonids(%)	SPC(%)
4/21	Benton	48	21(43.8)	17(35.4)	12(25.0)	2(4.2)	0(0)
4/22	Horn	39	23(59.0)	14(35.9)	1(2.6)	0(0)	0(0)
4/23	Vangie	67	40(59.7)	16(23.9)	12(17.9)	3(4.5)	1(1.5)
5/12	Benton	93	25(26.9)	35(37.6)	33(35.5)	31(33.3)	0(0)
5/12	Horn	25	8(25.0)	5(20.0)	10(40)	4(16.0)	0(0)
5/14	Vangie	118	62(52.5)	24(20.3)	35(29.7)	20(16.9)	0(0)
6/5	Horn	92	34(37.0)	39(42.4)	17(18.5)	5(5.4)	0(0)

Table 6. Estimated consumption rates of anadromous salmonids (primarily fall chinook salmon) within a section, based on smallmouth bass ($\geq$ 150 mm FL) population estimates, and gut analyses performed on samples collected during April and May, 1998. Total daily consumption refers to the estimated number of salmonids that would be eaten by all the smallmouth bass of predatory size ($\geq$ 150 mm FL) in one day. The estimated daily number of anadromous salmonids that would be consumed by 1000 smallmouth bass (S/1000) is also provided for comparison to the other predator species.

Section/Month	Pop. Est.	%w/ salmon	daily consumpt. rate	total daily consumpt.	S/1000
Benton/April	1528	0.042	3.79	243	159
Vangie/April	3210	0.045	2.80	404	126
Lower Yak/April [a]	19088	-	-	4085	-
Benton/May	3177	0.333	2.59	2740	862
Vangie/May	4176	0.169	1.95	1376	330
Lower Yak/May [a]	27676	-	-	18840	-

[a] Total average for the time period, calculated by using Vangie data for the Yakima River below Horn Rapids Dam and the Benton data for the reach between Horn Rapids and Prosser dams.

The relative abundance of spring chinook salmon smolts based on visual counts made by the electrofishing crew showed that they were most abundant during the April sampling period, but were still quite rare in comparison with other fish species/stocks (Figure 10, Table 3). Fall chinook were relatively abundant during the May and June sampling dates (Figure 10, Table 4).

Smallmouth bass appeared to show preference for fall chinook salmon and mountain whitefish (Figure 11). The appearance of preference for channel catfish is probably incorrect due to the low capture efficiency for channel catfish. It also appeared that sucker species and chiselmouth were not preferred prey species. The lack of preference for sucker species and chiselmouth may be explained by the large size of the juveniles (that were included in the 'availability' estimates); as they may have been too large for most smallmouth bass to prey upon.

When we use the Vangie data to extrapolate consumption by smallmouth bass to the portion of the Yakima River below Horn Rapids Dam (28.1 km) and the Benton data to extrapolate to the portion of the Yakima River between Horn Rapids and Prosser dams (39.9 km), the total daily consumption of juvenile fall chinook salmon during the May sampling was estimated to be 18,840/day. The data from the Horn section was not used in expansions for 2 reasons; 1) low capture efficiencies give us low confidence in the abundance estimates, and 2) future sampling will not be conducted in the Horn section. When we incorporate the entire data set (both sections for both time periods, i.e., four data sets) into these calculations, we estimate that a total of 524,300 salmon smolts were consumed between April 15 and May 30, 1998. The total estimated number of fall chinook salmon pre-smolts and smolts emigrating past Prosser Dam in 1998 was 486,573 (B. Watson, YIN, Personal communication). If we assume 75% of the fall chinook salmon production in the Yakima River occurs below Prosser Dam, then a crudely expanded estimate of wild fall chinook salmon juveniles available to predators in the lower Yakima River would be about 1.9 million. So, smallmouth bass may have consumed about 27% of the wild fall chinook produced in the Yakima basin in 1998. An additional 1.2 million hatchery-reared fall chinook salmon were released by the Yakama Indian Nation Fisheries Program below Prosser Dam beginning on the evening of May 29, however, all of the sampling used to conduct these extrapolated consumption estimates was conducted prior to the release of the hatchery fish. The average number of adult fall chinook salmon passing Prosser Dam between 1983 and 1996 was 1,251/yr. Again, if we assume 75% of the Yakima basin fall chinook salmon production is below Prosser Dam, the total estimated return of fall chinook salmon to the Yakima River might have averaged slightly over 5,000 fish. If this is the case, the smallmouth bass may be consuming enough juvenile salmon to reduce the return of adult fall chinook salmon to the Yakima River by about 1,350 adults (0.27 x 5000)(however, hatchery production has accounted for some unknown portion of the adult returns of fall chinook salmon to the Yakima River since 1984).

When we used the formulas to estimate daily consumption of spring chinook salmon smolts we predicted that 206/d were eaten in the lower 68 km. If we assume 30 days of relatively high availability of spring chinook salmon smolts, the expanded consumption estimate would be 6,180 (4.3% of the estimated spring emigration numbers (142,821; March 15 - June 30)).

Salmonid consumption by northern pikeminnow was higher during the period of sampling that was intended to coincide with the last quartile of the spring chinook salmon emigration than during the period of the estimated peak of emigration (Tables 9 and 10). The percentage of northern pikeminnow that contained salmonids ranged from 21 to 25% for the Horn and Granger sections during May. Northern pikeminnows consumed yearling and subyearling salmonids in the Granger section, however, northern pikeminnow in the Horn section consumed only subyearling fall chinook. During the peak and last quartile sampling periods, 82% of all salmonids consumed were subyearling salmonids (Table 9). The only northern pikeminnow stomach samples that contained spring chinook were collected at Granger during the period of sampling intended to coincide with the last quartile of the spring chinook emigration. Based on diagnostic bones, we identified 11 species of prey fish that were consumed by northern pikeminnow in the Horn and Granger sections from April to June (Table 11). Most (87.5%) of the fish prey items consumed by northern pikeminnow were soft-rayed species (Table 11).

Table 7. Species composition of fish found in smallmouth bass stomachs collected in the lower Yakima River April through August, 1998. Total number of prey fish in sample (N), and number of each prey species are presented for each date in each section. Numbers in parentheses represent the number of fish placed in that category based on size and bone information but are not positively identified using diagnostic bones and are included in the total number. The number in parentheses in the SMB and FAC species groups represents fish that were not positively identified to be in those groups but were placed in them by a weight of evidence approach. The numbers in parentheses are included in the total number for the species groups.

							Prey Species[a]										
Date	Section	N	DAC	SUC	NPM	CHM	SMB	CCF	YLP	FAC	SPC	MWF	CCP	PMK	MOS	SAL	NSA
4/21	Benton	21	4	2		2	3(1)	2		3(1)		5					
4/22	Horn	1															1
4/23	Vangie	14	1			1	1(1)	1		3	1	6					
5/12	Benton	51	2	2			2			44(7)							1
5/12	Horn	19		1				1		10		4					3
5/14	Vangie	41				1 1	1		22(6)		9		1	3		3	
6/3	Benton	17	8	1			1(1)	1		6(3)							
6/4	Horn	22	1	2	1			1		6			1			1	9
6/4	Vangie	10					1(1)			7(3)		2					
8/19	Benton	9	2		1	1	1						4				
8/20	Vangie	17	5				2	6	1							2	1

[a] DAC = dace spp., SUC = sucker spp., NPM = northern pikeminnow, CHM = chiselmouth, SMB = smallmouth bass, CCF = channel catfish, YLP = yellow perch, FAC = fall chinook salmon, SPC = spring chinook salmon, MWF = mountain whitefish, CCP = common carp, PMK = pumkinseed, MOS = mosquitofish, SAL = salmonid spp., NSA = non-salmonid spp.

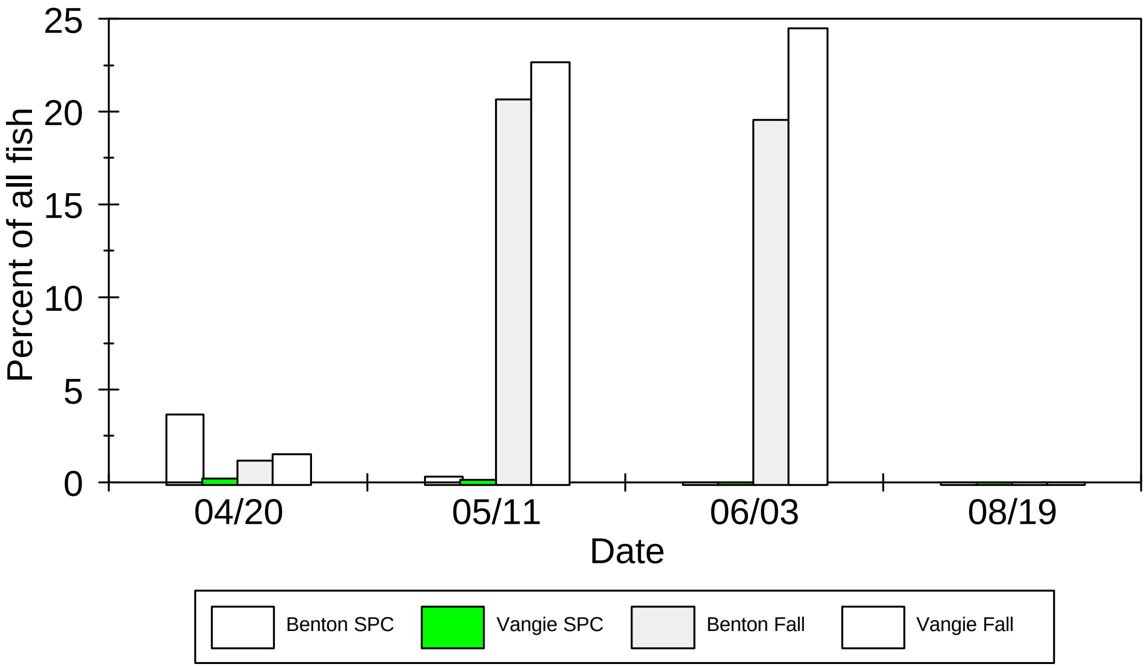

Figure 10. Relative abundance (percent of all fish observed) of spring chinook salmon smolts in the Benton and Vangie sections of the lower Yakima River versus sample date (1998). Relative abundance of fall chinook salmon parr and smolts is also shown for the Benton and Vangie sections.

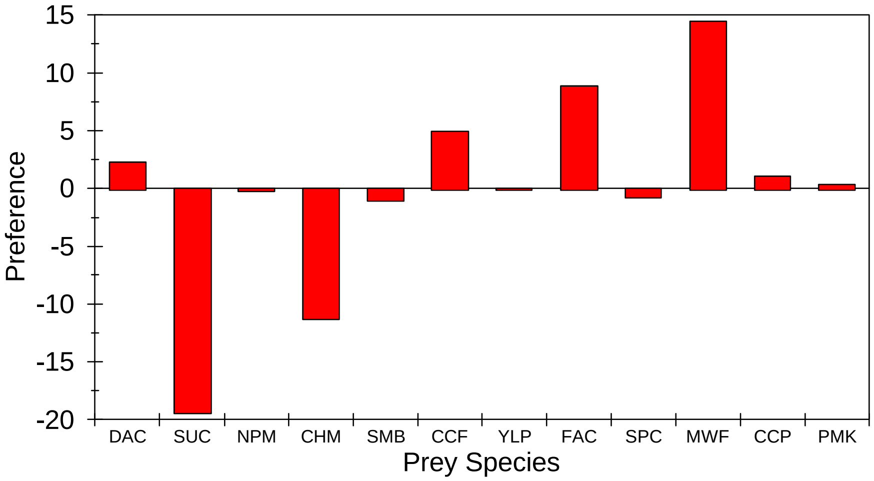

Figure 11. Prey species preference of smallmouth bass in the lower Yakima River during the spring of 1998. Preference was determined by subtracting the percent of a given prey species observed during electrofishing (availability) from the percent of that prey species observed in smallmouth bass guts (use). A positive value suggests a preferred prey species, while negative values suggest prey items that were not preferred.

The predation indices for northern pikeminnow predation on salmonids were generally much lower than the predation indices for smallmouth bass (Tables 10 and 8 respectively). The predation indices for northern pikeminnow were highest during the sampling period that was intended to coincide with the last quartile of the spring chinook emigration for all sampling periods for the Sunnyside, Granger and Horn sections. The predation indices for northern pikeminnow during the last quartile of spring chinook emigration for the Horn and Granger sections were similar (Table 10), although, the abundance index was higher for the Granger section and the consumption index was highest for the Horn section (Table 10). The only sampling period that produced a predation index for spring chinook salmon was the period intended to coincide with the last quartile of the spring chinook emigration (Table 10). We found no evidence of spring chinook predation by northern pikeminnow during any other sampling period or location. The estimated number of salmonids consumed per 1000 northern pikeminnows was highest for the Horn section during the period of the last quartile of spring chinook emigration (Table 10). However, lack of estimates of northern pikeminnow abundance for all sampling periods and locations preclude estimates of total number of salmonids consumed by northern pikeminnow.

Table 8. Predation index data for smallmouth bass predation on anadromous salmonids in the lower Yakima River reaches sampled during the estimated peak and last quartile of spring chinook salmon smolt emigration in 1998. The catch per unit effort (fish/min) of smallmouth bass ≥ 150 mm (D), the length of the extrapolated river reach (S) and the abundance index (AI) are shown for date and reach. The mean digestion time (DT), the mean number of salmonids/gut (SAL), the fraction of gut samples that contained at least one salmonid (F), the consumption index (CI), and the predation index (PI) are also shown for each reach and sample date. The predation index data for consumption of spring chinook salmon are also shown.

Date	Section	D	S	AI	DT	SAL	F	CI	PI
					Total Salmonids				
					Peak				
4/21	Benton	0.24	39.9	9.58	10.2	1.50	0.042	0.15	1.44
4/23	Vangie	0.43	28.1	12.08	17.76	1.33	0.045	0.08	0.97
4/24	Horn 0.15	12.9	1.97	N/A	0	0	0	0	
					Last quartile				
5/12	Benton	0.56	39.9	22.34	19.29	1.41	0.333	0.58	12.96
5/14	Vangie	0.77	28.1	21.64	18.21	1.11	0.169	0.25	5.41
5/12	Horn 0.15	12.9	1.31	13.90	2.25	0.160	0.66	1.31	
					Spring chinook salmon				
					Peak				
4/21	Benton	0.24	39.9	9.58	N/A	0	0	0	0
4/23	Vangie	0.43	28.1	12.08	33.18	1.00	0.015	0.01	0.12
4/24	Horn 0.15	12.9	1.97	N/A	0	0	0	0	
					Last quartile				
5/12	Benton	0.56	39.9	22.34	N/A	0	0	0	0
5/14	Vangie	0.77	28.1	21.64	N/A	0	0	0	0
5/12	Horn 0.15	12.9	1.31	N/A	0	0	0	0	

Table 9. Summary results of diet analyses for northern pikeminnow (≥ 150 mm FL) sampled in the Granger and Horn reaches on April 17-24, May 12-19, and June 4-5, 1998. The number of stomachs examined (N), the number (percent) of fish's guts in each sample that were empty, or contained invertebrates, fish, anadromous salmonids, and/or spring chinook salmon (SPC). The fish category includes salmonids.

Date	Section	N	Empty(%)	Invert.(%)	Fish(%)	Salmonids(%)	SPC(%)
4/17	Granger	19	8(42.1)	2(10.5)	4(21.1)	1(5.3)	0(0)
4/22	Horn	15	9(60.0)	4(26.7)	2(13.3)	0(0)	0(0)
5/12	Horn	8	2(25.0)	3(37.5)	2(25.0)	2(25.0)	0(0)
5/19	Granger	33	12(36.4)	16(48.5)	14(42.4)	7(21.2)	2(6.1)
6/5	Horn	13	5(38.5)	6(46.2)	2(15.4)	1(7.7)	0(0)

Table 10. Predation index data for northern pikeminnow on anadromous salmonids in the lower Yakima River reaches sampled during the estimated peak and last quartile of spring chinook salmon smolt emigration in 1998. The catch per unit effort of northern pikeminnow ≥ 150 mm (fish/min; D), the length of the river reach (S) and the abundance index (AI) are shown for date and reach. The mean digestion time (DT), the mean number of salmonids/gut (SAL), the fraction of gut samples that contained at least one salmonid (F), the consumption index (CI), the predation index (PI), and the estimated number of salmonids consumed per 1000 northern pikeminnow per day (S/1000), are also shown for each reach and sample date. The predation index data for consumption of spring chinook salmon are also shown.

Date	Section	D	S	AI	DT	SAL	F	CI	PI	S/1000
						Total Salmonids Peak				
4/16	Sunnyside	0.33	0.18	0.06	N/A	0	0	0	0	0
4/17	Granger	0.13	4.1	0.52	17.8	1	0.05	0.04	0.02	35
4/24	Horn	0.15	12.9	1.97	N/A	0	0	0	0	0
						Last quartile				
5/28	Sunnyside	0.55	0.18	0.10	48.2	2	0.29	0.37	0.04	376
5/19	Granger	0.28	4.1	1.14	34.6	2.5	0.21	0.39	0.44	390
5/12	Horn	0.04	12.9	0.46	11.2	1.5	0.25	1.06	0.48	1058
						Spring chinook salmon Peak				
4/16	Sunnyside	0.33	0.18	0.06	N/A	0	0	0	0	0
4/17	Granger	0.13	4.1	0.52	N/A	0	0	0	0	0
4/24	Horn	0.15	12.9	1.97	N/A	0	0	0	0	0
						Last quartile				
5/28	Sunnyside	0.55	0.18	0.10	N/A	0	0	0	0	0
5/19	Granger	0.28	4.1	1.1.4	61.9	2.0	0.06	0.12	0.14	80
5/12	Horn	0.04	12.9	0.46	N/A	0	0	0	0	0

Table 11. Species composition of fish found in northern pikeminnow stomachs collected in the lower Yakima

River April through June, 1998. Total number of prey fish in sample (N), and number of each prey species are presented for each date in each section.

			Prey Species[a]											
Date	Section	N	DAC	SUC	CHM	SMB	RSS	FAC	SPC	MWF	COH	CCP	STB	NSA
4/17	Granger	4								1	1	2		
4/22	Horn	2					2							
5/12	Horn	4				1		3						
5/19	Granger	21	1	2	1		2	3	4	2	2		1	3
6/4	Horn	1						1						

[a] DAC = dace spp., SUC = sucker spp., CHM = chiselmouth, SMB = smallmouth bass, RSS = redside shiner, FAC = fall chinook salmon, SPC = spring chinook salmon, MWF = mountain whitefish, COH = coho salmon, CCP = common carp, STB = stickleback, NSA = non-salmonid spp.

Sample size and quality of channel catfish stomach samples was relatively low in comparison to the data for smallmouth bass and northern pikeminnow. A small percentage of the catfish guts examined contained salmonids (Table 12), however, one catfish that consumed a large number of salmonids (76 fall chinook salmon), which increased the mean number of salmonids consumed per catfish (Table 12; mean number of salmonids/catfish = 20, for the catfish that contained at least one salmonid).

Table 12. Diet composition of channel catfish stomachs collected in the lower Yakima River, April through June 1998. Total number of stomachs in sample (N), and number of times (percentage) each category was found in a stomach is presented. Anadromous salmonids are included in the fish category. The invertebrate (Invert.) category includes crayfish.

	Food Category							
N	Empty	Fish	Salmonid	Invert.	Crayfish	Seeds	Bird	Rodent
137	70 (51.0)	26 (19.0)	4 (2.9)	43 (31.3)	31 (22.6)	21 (15.3)	3 (2.2)	2 (1.5)

Table 13. Species composition of fish found in channel catfish stomachs collected in the lower Yakima River April through June 1998. Total number of fish in stomachs (N), and number (and percentage in parentheses) of prey species is presented.

	Prey Species[a]												
N	CCF	CCP	CHM	DAC	FAC	SUC	MWF	NSA	NPM	SAL	SCU	SMB	WSH
121	8 (6.6)	3 (2.5)	2 (1.7)	1 (0.8)	77 (63.6)	8 (6.6)	3 (2.5)	7 (5.8)	2 (1.7)	2 (1.7)	1 (0.8)	6 (5.0)	1 (0.8)

[a] CCF = channel catfish, CCP = common carp, CHM = chiselmouth, DAC = dace spp., FAC = fall chinook salmon, SUC = sucker spp., MWF = mountain whitefish, NSA = non-salmonid spp., NPM = northern pikeminnow, SAL = salmonid spp., SCU = sculpin spp., SMB = smallmouth bass, WSH = wild steelhead.

The potentially large population of channel catfish could consume a substantial number of salmonids annually if even a small portion of the population consumes salmonids at the rate we observed. For every 1,000 channel catfish in the lower Yakima River we estimate that 580 salmonids/d would be eaten. If we assume the same period of high availability for fall chinook salmon juveniles that we used for smallmouth bass extrapolations (April 15-May 30) we estimate that 26,100 salmonids would be consumed for every 1,000 channel catfish in the lower Yakima River. Our data indicates there was a minimum of 2,664 channel catfish between the mouth and Horn Rapids Dam in the spring of 1998 (based on raw capture data). Our mark-recapture ratios from trapping data suggest the numbers may be much higher (Table 2; 10,693-14,203/km). Thus, our wide ranging estimates of seasonal salmonid consumption by channel catfish extend from 69,530/year to 10.4 million/year.

“Hot Spot” Sampling

Success at capturing northern pikeminnows at ‘hot spots’ was very low. Hook and line sampling for northern pikeminnow immediately below Roza Dam yielded low catch rates, and none of the pikeminnows examined had eaten any salmonids (Table 14). Mean catch rate (fish/min) was much lower during the sampling period intended to coincide with the peak of spring chinook salmon smolt emigration past Roza Dam than it was in the period intended to cover the last quartile of emigration. Most of the northern pikeminnows captured below Roza Dam were sexually mature adults (sample 1: 86%; sample 2: 88%).

Mean catch rates (fish/min) using jet boat electrofishing gear were higher at Sunnyside Dam than at Roza Dam due to sampling gear (Table 14). However sample sizes during the mark and recapture efforts were low, and never exceeded 7 northern pikeminnow. Only the April sampling period which was intended to coincide with the peak of the spring chinook salmon smolt emigration at Sunnyside Dam yielded a population estimate of the total number of northern pikeminnows present (25; 95% CI = 6-49). Two of the seven pikeminnows sampled during the period intended to coincide with the last quartile of the spring chinook salmon emigration had consumed coho salmon, although none of the northern pikeminnow sampled during the earlier sampling period had consumed salmonids. Most (79%) northern pikeminnows captured at Sunnyside Dam were >300 mm fork length. Sampling efforts at the outfall of the Chandler juvenile fish facility did not yield any predatory fish.

Table 14. Data from northern pikeminnow 'hot spot' sampling in the Yakima River during 1998. Mean catch per unit effort (CPUE (fish/min)), number marked (M), number recaptured and number of marked fish (R) in the recapture sample (C), and summary of gut contents of fish in the recapture sample are presented for Roza and Sunnyside sites. Data collected at Roza is based on hook and line sampling and data collected at Sunnyside Dam is based on jet boat electrofishing.

Dates	Site	CPUE	M	R/C	%Empty	%Invert.	%Fish	%Salmonids
3/31-4/2	Roza	0.013	16	0/14	50	36	43[a]	0
4/27-29	Roza	0.043	37	0/16	63	13	25[b]	0
4/14-16	Sunnyside	0.330	6	1/6	33	0.5	50[c]	0
5/27-28	Sunnyside	0.550	5	0/7	71	0	29	29[d]

[a] All sculpins.
[b] Two suckers, one sculpin, and one unknown, non-salmonid.
[c] All whitefish.
[d] Two coho salmon based on length frequency data.

Discussion

Our results indicate that predation on juvenile salmonids by predaceous fishes in the lower Yakima River is substantial. Smallmouth bass alone are estimated to be able to consume about half a million smolts per year, resulting in the annual loss of an estimated 1,350 adult salmon. Channel catfish and northern pikeminnow also consume large numbers of salmonids, however our data for those species is not readily expandable due to our difficulty in assessing their abundance. We were, however, able to estimate the number of anadromous salmonids that might be consumed by every 1000 northern pikeminnow and channel catfish. Based on the estimated mean numbers of anadromous salmonids that might be consumed by every 1000 predators of each species, it appears that the predatory species' potential to impact fall chinook salmon might be ranked as follows; 1) smallmouth bass, 2) northern pikeminnow, and 3) channel catfish. Because we found very few spring chinook and coho salmon and steelhead in guts, our ability to rank the predatory species by their potential impact on those prey species is limited. If we consider timing and distribution of both predators and prey, as well as the limited diet information we have regarding spring chinook salmon, we would rank the predators' potential to impact spring chinook salmon as follows; 1) northern pikeminnow, 2) smallmouth bass, and 3) channel catfish.

Some sampling adjustments will be made, beginning in 1999. We will sample weekly throughout the spring chinook salmon smolt emigration period (April 1 to May 21). We will no longer sample the Horn section (primarily a smallmouth bass section), and will instead focus more effort on northern pikeminnow in the section of the river between Sunnyside and Prosser dams. We will not operate traps for channel catfish and will rely instead on a limited amount of data we can obtain by incidental electrofishing captures and a limited number of gillnet sets. We will discontinue hook and line sampling at the Sunnyside and Chandler hot spot areas.

Smallmouth bass abundance and the consumption rates in the lower Yakima River are substantially higher than other studies have reported for large rivers and reservoirs in the Columbia basin. Figure 12 shows the estimated density of smallmouth bass 200 mm long and larger in the Yakima River sites and in the John Day Reservoir on the Columbia River (Beamesderfer and Rieman 1988).
The smallmouth bass we sampled in the lower Yakima River also consumed salmonids more frequently than most other smallmouth bass populations that have been sampled in the Northwest. Figure 13 illustrates the variability of the incidence of predation on salmonids by smallmouth bass within the Yakima River, as it is affected by sampling date, as well as the relation of the incidence of predation in the Yakima River to that which has been reported for other waters in the area (data from Bennett et al. 1991).

The combined effect of high predator densities and high consumption rates of salmonids in the Yakima River indicates a significant annual loss of salmonid production to piscine predators. This is particularly true when predation impacts are unnaturally high due to the introduction of non-native species and the alteration of the physical habitat (e.g., dams and irrigation effects) that favors these introduced fishes. When managers are presented with this information, many will begin to consider what types of management actions could be undertaken to reduce this loss of anadromous fish production to predators. There are a wide variety of actions that have the potential to reduce unnaturally high predation impacts (Table 15).

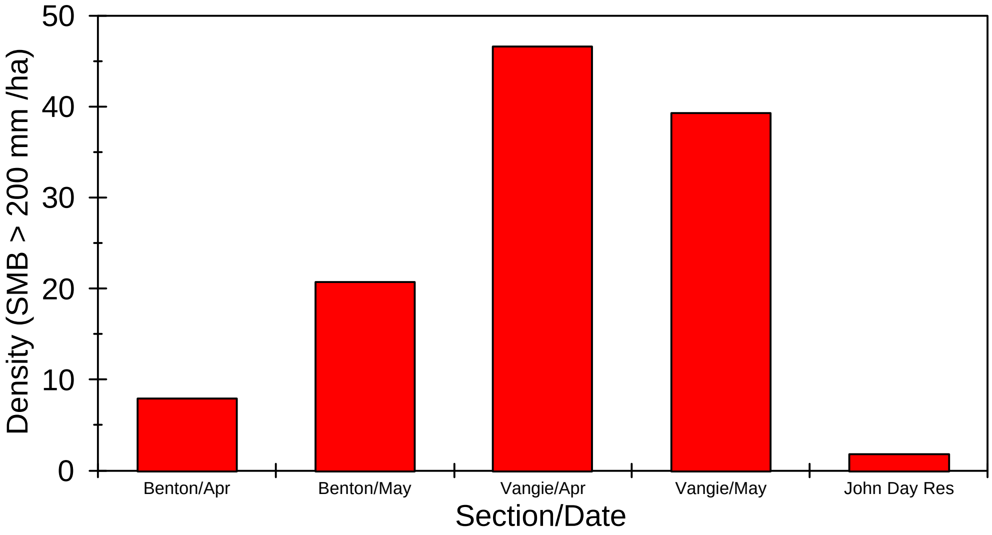

Figure 12. Density of smallmouth bass (estimated number 200 mm and longer per hectare) in two sections of the lower Yakima River during two time periods in 1998 and in the John Day Reservoir (spring samples, data from Beamesderfer and Rieman 1988).

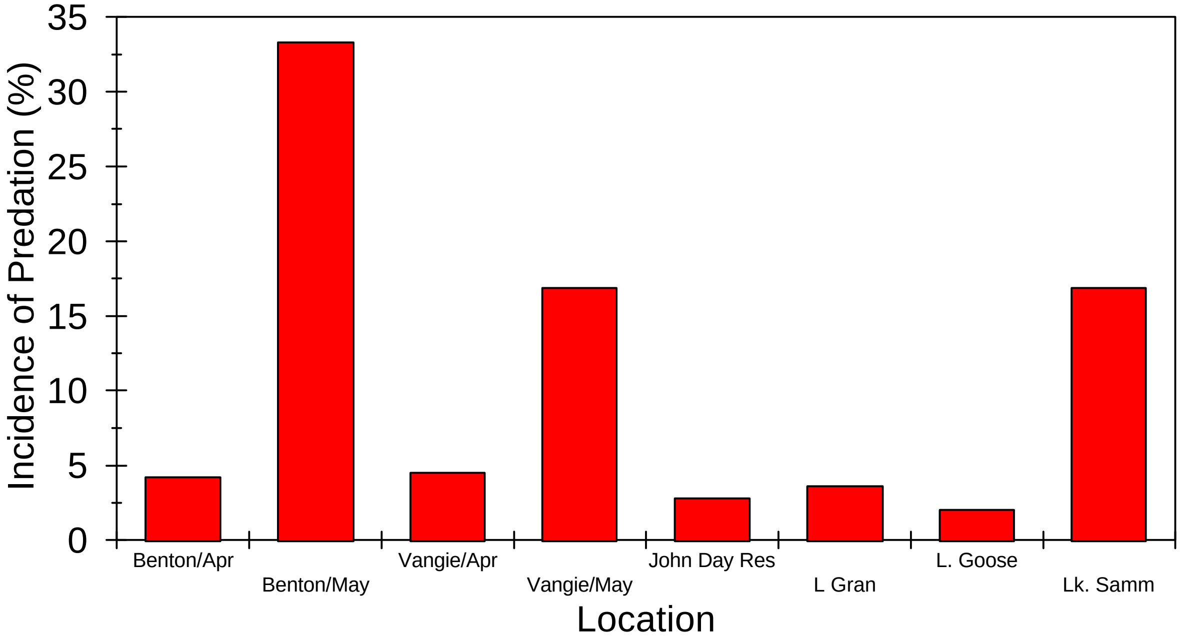

Figure 13. Incidence of predation (% of sampled predators containing at least one salmonid) by smallmouth bass in two sections of the lower Yakima River during two time periods in 1998 as well as spring data from four other sites in the northwest (data from Bennett et al. 1991; John Day Res = John Day Reservoir on the Columbia River, L Gran = Lower Granite Reservoir on the Snake River, L Goose = Little Goose Reservoir on the Snake River, Lk. Samm = Lake Sammamish, Washington).

Table 15. Management actions intended to reduce losses of salmonids to predation in the lower Yakima River. Each action listed is qualitatively rated by its potential to result in the desired effect as well as its potential to produce undesired ecological effects.

Management Action	Desired effect	Undesired effects (risks)
Trapping migrants/removal	Low	Low-Moderate
Electrofishing/removal	Moderate	Moderate
Capture/relocation	Moderate	Low-moderate
Removal of Angling regs.	Low	Low
Bounty Program	Low-Moderate	Low
Decrease water temp. 2 C	High	Low

Each of the actions listed in Table 15 has some potential to decrease losses of juvenile salmonids to fish predators within the time frame that the action is applied. Long term effects of these actions are uncertain, but unlikely to produce much of the desired effect over time, unless the action is maintained at a high level of effort. Trapping predatory fish migrating into the Yakima River from the Columbia River could remove some of the larger adult smallmouth bass and channel catfish. The benefits of this are that within a given year, many fish could be removed, thereby reducing predation within that year. Drawbacks of trapping migrants are that it only reduces the migratory portion of the populations, which could be compensated for by resident populations. Also, it targets only the larger/reproducing individuals which do not appear to be as selective for salmonid smolts as prey items (i.e., they eat larger prey, e.g., chiselmouth). Further, any potential benefits, in terms of reduced predation, will accrue only upstream of the trap and the trapping would have to be conducted every year to produce the survival benefits for smolts, unless spawning by predators was impacted, in which case future reductions in predation could result. Finally, disposal of the fish that were removed could be difficult if they are found to be contaminated. Mountain whitefish and bridgelip suckers collected by the USGS in the lower Yakima River between 1989 and 1991 were found to be highly contaminated with DDT (Washington State Department of Health 1995). Smallmouth bass and channel catfish samples have been provided to the EPA and the data should be released in mid-1999.

Using electrofishing to remove predators could be effective at reducing the number of predators within the area that is covered by the electrofishing crews. Repeated passes would have to be done to achieve appreciable depletions in the predator population due to the generally low capture efficiency of this gear (2-4% per day per boat for smallmouth bass; a lower, but unknown effectiveness would be expected for northern pikeminnow; and an extremely low effectiveness would be expected for channel catfish). Electrofishing has the added benefit of being selective, in that it can be applied to areas and size ranges that appear most critical. Electrofishing also has moderate potential for producing undesired effects such as injuring or impairing the reproductive capacities of returning adult salmonids (Snyder 1995). In addition, electrofishing injuries to emigrating smolts may reduce their long-term fitness and survival (McMichael et al. 1998). Finally, electrofishing would only affect the area where it was conducted, and it would have to be applied multiple times annually to be effective. Similar to the trapping/removal effort, fish would have to be disposed of, which may be problematic if they are found to be contaminated.

Capture and relocation of fish could reduce the number of predators within the areas sampled if a host of gear types were employed to capture predatory fishes. This would only be viable if the fish are found to be fit for human consumption (see previous paragraph). Undesired effects on other species would depend on the types of methods used to capture the fish and the level of effort (e.g., the number of electrofishing trips) to capture the fish. Again, the effects of this approach would generally only be apparent in the reaches sampled and during the year of sampling unless future reproduction of predatory fishes were reduced.

Removal of the angling regulations would not be likely to produce any appreciable effect on the predator populations. There are currently no restrictions on gear or harvest for channel catfish and northern pikeminnow in the Yakima or Columbia rivers. Tagged smallmouth bass were captured by anglers at a mean rate of 3.15%, which if we assume a non-reporting rate of 50%, translates into an exploitation rate of about 6.3%/year. However, anglers released 42% of the bass they captured, yielding a harvest estimate of about 3.7%. It appears unlikely that eliminating the 5 fish limit on smallmouth bass would have any substantial effect on the density of predators.

A bounty program for predatory fishes, if it achieved harvest rates similar to those reported by Beamesderfer et al. (1996), could be effective in decreasing predation loss to fishes during the years that the bounty program operated. The annual removal of 9-16% (the range reported by Beamesderfer et al. (1996)) of the predatory fishes in the lower Yakima River could potentially increase adult returns by that amount. Undesirable impacts to salmonids would likely be fairly low, as the adult salmonids are not present in large numbers when most of the angling for predatory fishes would occur. However, most of the angling for predatory fishes would probably occur after the spring emigrating smolts were out of the Yakima River, thereby reducing the potential to positively influence survival rates within the year the predatory fish were removed. Disposal of predatory fish may be complicated by the issues of contamination mentioned above.

Decreasing the river temperature during the spring could substantially reduce the loss of salmonids to predation by fish. The effect of water temperature on the metabolic rates and subsequent meal turnover times in fishes is large. A 2 C drop (from 13.2 to 11.2 C) in water temperature would decrease the losses of salmonids to smallmouth bass by 23% in the Benton reach during the May sample period. Digestion rates of northern pikeminnow and channel catfish would be similarly affected. This could possibly be achieved by changes in management or configuration of the irrigation system in the Yakima basin. Vaccaro (1986) projected a 2 to 3 C decrease in water temperature in April and May, 1981, for unregulated flow conditions (102 to 181 m^3/s) versus regulated flow (42 to 57 m^3/s). It may also be possible to restructure irrigation returns to pass water through the ground to clean and cool it prior to entering the river channel via groundwater. Reducing water temperature could potentially affect the entire reach of the Yakima River where predation by fish is most prevalent. Also, it could potentially reduce the influx of predators from the Columbia River if the temperature of the Yakima River was reduced to the point where it was cooler than the Columbia River. Cooler water would potentially benefit returning adult spring chinook salmon and steelhead as well as decreasing the chances for smolts and adults to be affected by pathogens. There are some drawbacks/potential roadblocks to this action. To decrease the temperature in some years would be difficult due to the distance between storage reservoirs and the river reach where most predation occurs, as well as natural variability of the hydrograph (low flow and high flow years) and weather (hot weather) patterns. It would also be expensive and possibly politically difficult to modify system operations and/or structure to accomplish this task.

It is possible that the loss of salmonids to predaceous fishes in the lower Yakima River could be reduced by a combination of the aforementioned management actions. If, for example, the river were cooled 2 C during smolt emigration, predatory fishes were removed on four electrofishing runs early in the season (before smolt emigration), and a bounty program were instituted that reduced predator populations to a level similar to the reductions reported for the sport reward program for northern pikeminnow (Beamesderfer et al. 1996), then the cumulative survival advantage (reductions in losses to predation) of these actions might be close to 40% (23% + 4% + 12.5%; for smallmouth bass). A multiple-method approach such as this would have the largest cumulative benefits for salmonid survival but would also carry the highest risks to non-target species and highest economic costs. Ultimately, it will be a public policy decision to determine what, if any, management approach will be taken to reduce unnaturally high predator impacts on anadromous salmonids in the lower Yakima River.

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Interactions between Coho Salmon and Warmwater Fish in Western Washington Lakes

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Study Rationale and Objectives

Warmwater fish are exotic to the Pacific Northwest, and can prey on and compete with native fish and wildlife (Wydoski and Whitney 1979; Pflug and Pauley 1984; Poe *et al.* 1991; Kane *et al.* 1992; Tabor *et al.* 1993; Curet 1993; Fayram 1996; McMahon and Bennett 1996). Perhaps the interactions currently of most concern in Washington are those with wild salmonids. Some once-abundant salmon runs have declined to such low levels that they are eligible for listing under the Federal Endangered Species Act. Many factors have been blamed for these declines including overfishing, hydropower, urbanization, logging practices, hatchery practices and interactions with exotic species.

To meet these growing concerns, the Washington Department of Fish and Wildlife developed a Wild Salmonid Policy to guide agency efforts in salmon restoration. A part of this policy states that specific steps will be taken to limit the impacts of exotic species on native salmonids. Additionally, an important part of recent warmwater surcharge legislation designed to enhance fishing opportunities for warmwater species is that warmwater fish cannot be enhanced where there may be significant impact to wild salmonids. Knowledge of where and to what extent warmwater fish may be impacting salmonids is vital to the management of both warmwater fish and salmon.

The purpose of our study is to determine the extent and nature of interaction between common warmwater fishes and native anadromous salmon. We have two goals for our study, depending on available funding. They are to (1) estimate the degree of overlap in distribution among various warmwater and salmon species, and (2) estimate the impact of warmwater fish predation and competition on coho salmon migrating through and rearing in Western Washington lakes. We are currently in the first year of our study, so the following provides a brief overview of our goals and methodologies.

Goal 1. Identify the degree of overlap between the distribution of warmwater fish and selected salmon species.

The extent of spatial overlap among various warmwater fish and salmon is important to evaluate the degree of interaction in watersheds statewide. We are investigating the degree of overlap in distribution using geographic information systems (GIS) technology. Gradient and elevation ranges for warmwater species is being obtained from preexisting data and will be truth checked with information from field surveys. This information will be used to develop a GIS overlay of potential warmwater fish distribution by major species in Washington state. Warmwater species overlays will be placed over existing maps of salmon distribution (WDFW, Unpublished Data) to identify areas where overlap may occur.

The products from this work will be: (1) maps of Washington showing areas where the potential exists for various warmwater fish and salmon species to interact; (2) a determination of the extent of this overlap for various salmon stocks; and (3) a prioritization of watersheds on the basis of potential for interaction.

Goal 2. Investigate the extent of warmwater fish predation and competition on coho salmon in three Western Washington lakes.

Within overlap areas, warmwater fish have the potential to affect salmonid populations through competition and predation. The effects of warmwater predators on salmon populations in the Columbia, Yakima and Snake River systems and two large Western Washington lakes have been studied by several researchers (Pflug and Pauley 1984; Poe *et al.* 1991; Shively *et al.* 1991; Curet 1993; Tabor *et al.* 1993; Burley and Poe 1994; Fayram 1996; McMichael, WDFW Unpublished Data). However, little is known about potential interactions which may occur in the hundreds of smaller lowland lakes in western Washington. Many of these lakes contain warmwater species and provide important juvenile salmon rearing habitat and migration corridors.

We are investigating the extent of predation and competition by warmwater species on coho salmon migrating through and rearing in three Western Washington lakes (William Symington, 32 ha; Wildcat, 44 ha; and Long, 130 ha). Coho salmon smolts pass through these lakes on their migration to the sea, and also use these lakes for rearing areas as fry. These three lakes all have traps on the outlet which are being monitored to enumerate the number of salmon smolts leaving each lake.

The Wisconsin bioenergetics model (Hanson 1997) is being used to estimate the total number of smolt equivalents consumed by piscivores in each lake. This estimate will be then compared to the total number of smolts leaving the lake to estimate degree of smolt loss to both warmwater and coldwater piscivores. Required model inputs are the predator abundance, thermal histories of the waters where predation is taking place, stomach content data, and energy densities of both predators and prey. We are estimating the total number of piscivores (both warmwater and coolwater fishes) in each lake using standard electroshocking, netting, and mark-recapture techniques (Ricker 1975). Feeding habits of the piscivores are being evaluated throughout the year at two week intervals during smolt migration and at monthly intervals throughout the remainder of the year using stomach-flushing techniques and stomach content analysis. All salmon recorded from stomachs are being converted to smolt equivalents. Thermal histories of predators are being obtained from hydrolab data collected in areas where fish were captured. In upcoming seasons, we will investigate food competition between warmwater panfish populations and juvenile salmon.

Products from this study will be (1) an estimate of the number of coho salmon smolts passing through three lakes which are eaten by both warmwater and coldwater piscivores; (2) an estimate of the number of coho salmon smolt equivalents rearing in the lake which are eaten by picivores; (3) that component of fry and smolt picivory which is due to warmwater fish; (4) a comparison of the number of coho salmon removed by predators to the size of the overall run leaving the lake; and (5) a preliminary evaluation as to whether or not food availability is limiting coho salmon rearing in these three lakes.

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Competition and predation between rainbow trout and largemouth bass in Crane Prairie Reservoir.

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Introduction

Faced with increasing angler pressure and recognizing opportunities presented by development of multiple use reservoirs, fishery managers developed the concept of a "two-story" fishery to increase utilization of available lentic habitat. With bass and other centrarchids inhabiting the shallow, warm littoral areas of a lake or reservoir and trout or walleye utilizing the cooler, deeper limnetic regions, managers could theoretically increase the production of gamefish from lentic habitats (Eddy and Underhill 1974).

Although there are many examples of the creation of successful "two-story" fisheries, biological and social issues often affect the outcome. The level of biological interactions, e.g., competition and predation, can determine the success of such a fishery, while the social acceptance of the program is often influenced by the preferences, biases and perceptions of the user groups. Crane Prairie Reservoir is a case in point. The historic capacity of this reservoir to produce large rainbow trout, *Oncorhynchus mykiss*, in excess of 10 pounds, from releases of hatchery-reared fingerling has been its claim to fame. Following the appearance of largemouth bass *Micropterus salmoides* in this blue-ribbon trout lake in the early 1980's, the production of trophy bass (in excess of 4 pounds) has been unmatched by any Eastern Oregon reservoir. However their presence has caused concern among management biologists and trout anglers. Predation of bass on stocked trout and possible decreases in trout growth and survival as a result of competitive interactions were identified as possible conflicts arising from an expanding bass population.

Social perception and unanswered biological questions led the Department to investigate this interaction in 1989 and 1990. That study provided information about some biological and social aspects of the fish community and fishery, but did not investigate the interactions throughout the entire growing season. The present study was designed to complement the previous study with several objectives:

1. Determine the extent to which various sizes oflargemouth bass consume stocked hatchery trout;
2. Investigate diet overlap between fingerling hatchery trout and largemouth bass; and
3. Assess whether competitive interactions with largemouth bass could be limiting the growth of stocked hatchery trout.

Study Site

Crane Prairie was a natural prairie located at the convergence of the upper Deschutes River, Cultus River, Quinn River, Rock Creek, Cultus Creek, and several other minor tributaries. The first Crane Prairie dam was constructed in 1922 by the Bureau of Reclamation. The present 36-foot high dam was constructed for irrigation storage in 1940. At full pool, the reservoir covers 4,167 acres, impounds 55,330 acre-feet of water, and has an average depth of 11 feet and a maximum depth of just over 20 feet (Johnson et al. 1985).

Timber was not cleared from the meadow and the adjacent lodgepole pine forest when the reservoir was impounded. These trees, now partially or totally submerged, provide excellent cover for fish as well as a tremendous amount of substrate for production of aquatic insects (King 1968). In addition, they provide perches for avian predators which may influence fish abundance and species composition in the reservoir (Lind 1976, Anderson 1985). Exposure and weathering of ordinarily submerged trees by low pool levels in recent years has accelerated the decay and loss of standing timber in the reservoir.

Tui chub *Gila bicolor* first appeared in the reservoir in 1953 and flourished in the shallow, productive water. By the early 1980s, they comprised over 80%, by number, of the reservoir fish community (personal communication, Ted Fies, Oregon Department of Fish and Wildlife, Bend District

Fish Biologist, Bend). Tui chub were the primary prey for largemouth bass, rainbow trout, and avian predators. Conditions associated with the recent drought - (reduced access to suitable spawning sites and increased predation due to decreased water volumes) - have caused the collapse of the chub population (personal communication, Ted Fies, Oregon Department of Fish and Wildlife, Bend District Fish Biologist, Bend). When they were abundant, tui chub were the predominant food item of largemouth bass greater than 200 mm (Shrader 1993). This has increased concerns of trout anglers regarding the quality of the trout fishery if bass switch their primary prey from the dwindling tui chub to stocked hatchery rainbow trout.

Methods and Materials

Fish were collected at approximately 2-week intervals between June and October, 1994 with an electrofishing boat. Bass > 200 mm collected early in the season were marked with a caudal punch. Subsequent recaptures allowed calculation of short-term, area-specific population estimates.

Hatchery rainbow trout released in Crane Prairie Reservoir were marked with an adipose fin clip and with oxytetracycline (OTC). The fish were fed TM-100, a veterinary grade of OTC, with their food for 2 weeks to achieve a cumulative dosage of 0.5 grams of OTC per kilogram of fish. OTC is deposited in the bone of actively growing fish and is discernible under ultraviolet light as a fluorescent band in vertebral sections (Weber and Ridgeway 1962, 1967). Thus hatchery trout that had been consumed by bass and were too badly decomposed to identify the adipose fin clip were identifiable using this technique.

Stomach contents of largemouth bass > 200 mm were recovered through gastric lavage followed by an inspection of the mouth and esophagus for large items not flushed clear. Stomach contents were rinsed through a sieve (1-mm opening) and preserved in 10% formalin. A sample of bass < 200 mm and rainbow trout were sacrificed and their digestive tracts were removed and preserved.

Food items were examined using a variable power (7-30X) binocular dissecting microscope and were identified to the lowest practical taxonomic level (most often to order, but in some cases, sub-order or family), and counted. In most cases separate tallies were kept for adult insects and their larval stages; dipterans, other than chironomid larvae, were the primary exception. Identification of partially digested fish remains to family was accomplished from diagnostic bones (Hansel et al. 1988)or vertebral columns (H. Hansel, U.S. Fish and Wildlife Service, unpublished data). Hatchery trout were distinguished from other salmonids by tetracycline marks in sections of vertebrae.

Percentage contribution to the diet (by volume) of each category of food item was calculated on the basis of the entire volume of food eaten by a category of gamefish (e.g., hatchery rainbow, 200-249 mm largemouth bass, etc.) sampled on a particular date. Volume of other specific food items consumed was calculated by multiplying the number of individuals by the average volume per individual. Average displacement (volume) per individual was measured by placing 10 to 20 representative individuals in a graduated centrifuge tube partially filled with water.

Estimates of Losses to Bass Predation

Loss of hatchery rainbow trout through largemouth bass predation was estimated by applying rates of consumption to the estimated population of each size class of bass (200-299 mm, 300-399 mm, and 400 mm and larger; APPENDIX A). Previous work (Shrader 1993) indicated that bass less than 200 mm did not prey on hatchery trout to an appreciable degree. Gastric evacuation rates (time to 90% digestion) were estimated from Markus (1932) and Cochran and Adelman (1982). The period of active predation on stocked trout was estimated from the presence of hatchery rainbow in bass stomachs collected during electrofishing samples. For purposes of estimation of bass predation on stocked trout, it was assumed that trout were preyed on for only the period when they were observed in bass stomachs. Calculation of digestion rates was based on average water temperatures of 16, 20, and 22°C for successive two week periods beginning on the date of first stocking.

Assessment of Competitive Interaction

Investigation of possible competitive interaction between stocked rainbow trout fingerlings and largemouth bass requires identification of significant diet overlap for prey items which are limited in abundance. This simplistic definition assumes no niche segregation has occurred between bass and trout to minimize competitive pressure.

Trout diet composition was described through collection of trout stomachs during routine electrofishing. Contents were analyzed in the same manner as previously discussed for bass stomachs. Diet overlap will be quantified using the Schoener index (Wallace 1981), which is calculated as follows:

$$\alpha = \overset{n}{\underset{i=1}{1}} - 0.5(\Sigma \left| p_{xi} - p_{yi} \right|),$$

where

n = number of food categories,

p_{xi} = proportion, by volume, of food category i in the diet of the length category of largemouth bass, and

p_{yi} = proportion, by volume, of food category i in the diet of stocked fingerling rainbow trout.

The resultant index ranges from a value of 0.0 to 1.0 and is considered to be biologically significant when the index exceeds 0.60 (Zaret and Rand 1971; Mathur 1977). The index for the rainbow trout/largemouth bass interaction will be calculated twice - with and without exclusion of rainbow trout in the bass diet.

Prey availability or abundance was assessed indirectly using bioenergetic simulations of the patterns of trout growth. The index output by the model, a P-value, is a proportionate measure of how a species' observed consumption approaches its theoretical consumption (as limited by the ambient thermal regime). In the absence of physical limiting factors, if the P-value of a species is substantially below 1.0, then there is the possibility that growth is being limited by competition. Parameters for the chinook salmon bioenergetic model of Hewett and Johnson (1987) were modified for rainbow trout (Rand et al. 1993). Values for caloric densities of prey species were obtained from Richman (1958), Davis and Warren (1971), and Hewitt and Johnson (1992).

Water temperatures used for bioenergetic modeling were a combination of recorded and estimated values. Estimated temperatures were checked against onsite water temperatures recorded during sampling.

Results

Rainbow Trout and Largemouth Bass Diet Composition

Stocked rainbow trout consumed a variety of prey items (Table 1), reflecting their categorization as generalists or opportunistic feeders (Calhoun 1966, Scott and Crossman 1973). Amphipods, damselflies, snails, zooplankton, caddisflies, or chironomids were important prey items of stocked rainbow trout at one time or another during the year (Table 1). The importance of different taxa of prey to largemouth bass varied with the size of the fish and the month (Table 2). Diet summaries of bass > 400 mm are based on inadequate samples and are not presented. Largemouth bass less than 200 mm did not consume hatchery rainbow trout (Table 2). Invertebrates, primarily amphipods, mayflies, dragonflies, damselflies, and chironomids, were the major prey of these small bass, although stickleback were occasionally an important prey item of bass greater than or equal 200 mm (Table 2).

Hatchery rainbow trout were an important component of the diet of bass > 200 mm in June and July, composing up to 67% of the diet of 300-399 mm bass in June (Table 2). Higher water temperatures in the littoral areas during August forced rainbow trout to abandon that habitat, as evidenced by their absence in electrofishing samples. In August and September, amphipods and three-spined stickleback became the prevalent prey of 200-299 mm bass. Large prey items, crayfish and salmonids other than hatchery rainbow trout (hatchery kokanee, hatchery and wild brook trout, and wild rainbow trout and whitefish) comprised the bulk of the diet of 300-399 mm bass from July through September. The percentage of empty stomachs increased significantly in October sampling, suggesting that bass were not feeding actively as water temperatures dropped below 10°C.

Loss of Hatchery Rainbow Trout to Bass Predation

Based on the 1994 length frequency distribution (Figure 1), the estimated 11,000 largemouth bass would be distributed as follows: 9,706 bass between 200 and 299 mm, 1,114 bass between 300 and 399 mm, and 179 bass greater than or equal to 400 mm.

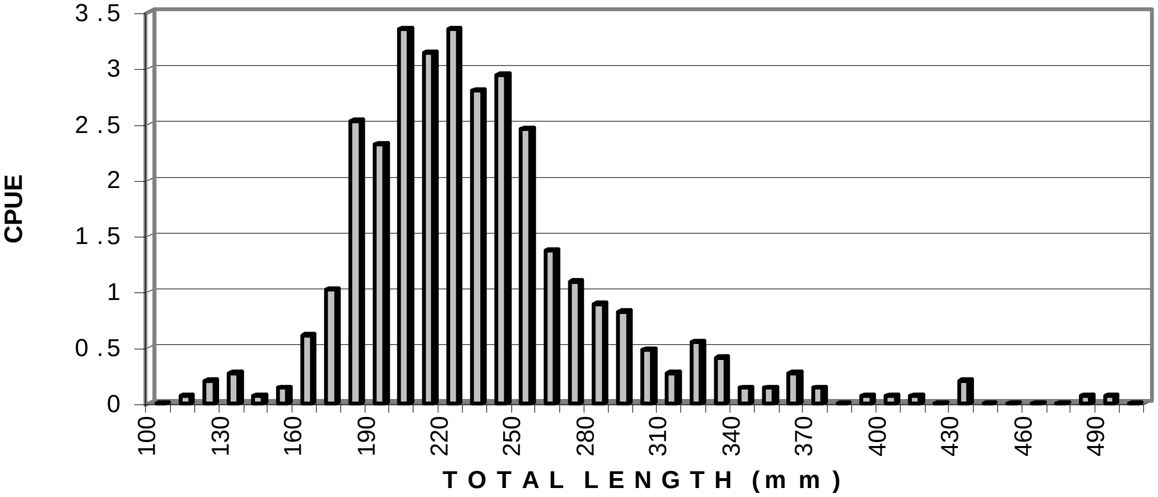

Figure 1. Length frequency distribution of largemouth bass captured by electrofishing from Crane Prairie Reservoir in 1994. Catch-per-unit-effort (CPUE) expressed as number of bass captured for every 1000 seconds of electrofisher time.

The rate of bass predation on stocked trout was not consistent across the reservoir. Bass in the area of Crane Prairie Resort preyed more heavily on hatchery trout immediately following stocking (1.0 trout per 200-299 mm bass and 2.0 trout per 300-399 mm bass) than did bass in the rest of the reservoir (0.026 trout per 200-299 mm bass and 0.045 trout per 300-399 mm bass). Predation on hatchery trout immediately following stocking at other stocking sites (Rock Creek and Quinn River ramps) was not different from rates seen after trout had dispersed. As a result, predation loss was calculated separately for the "Resort" subpopulation immediately following stocking and the entire Crane Prairie bass population for the remainder of the year.

The "Resort" subpopulation of bass was estimated at 2,134 fish based on mark-recapture results (Appendix A). Allowing four days for hatchery trout to disperse following stocking at the Resort ramp (personal communication, Ted Fies, Oregon Department of Fish and Wildlife, Bend District Fish Biologist, Bend; Wurtsbaugh and Tabor 1989), an estimated 4,784 trout were eaten by "Resort" bass

(APPENDIX A). Stocking at the resort ramp was terminated after this high loss at that site was initially exposed.

The rate of bass predation on hatchery trout varied with the peak rate seen in June (which coincided with stocking of hatchery trout on June 7, 14, 23, and 24). Hatchery trout were found in bass stomachs on July 7 and not on the next sample occasion (August 4). The estimated number of hatchery trout consumed by bass (including those from the single plant at the Resort ramp) was 13,954 fish, or 6.8% of the hatchery fish stocked (Appendix A).

Bass consumption of salmonids other than hatchery rainbow was examined using the same methodology discussed above. The inability to identify partially-digested stomach contents beyond family did not allow segregation and calculation of species-specific predation losses. An estimated 15,284 wild rainbow and mountain whitefish, wild and hatchery brook trout, and hatchery kokanee Oncorhynchus nerka, were eaten by largemouth bass from May through October.

Bioenergetic Modeling of Trout Growth

The P-values obtained for rainbow trout stocked on June 7 ranged from 0.53 to 0.84 (Table 3). These values should be considered as minimum P-values as trout stocked after June 7 were probably included in the endweight calculations. In addition, anglers began to harvest some of the larger hatchery trout by the end of September. This harvest could have reduced the observed P-value for the period August 4 to October 4 by reducing the average size of fish available for our sample.

Estimation of Diet Overlap

Schoener overlap indices varied monthly and with the size category of bass (Table 4). Diet overlap between stocked rainbow trout and largemouth bass never exceeded 0.60 for those months when adequate fish were collected.

Discussion

The idealized concept for a two-story fishery assumes a lake's production is optimized by partitioning of habitat between trout and bass. In reality the littoral and pelagic zones are not compartmentalized - water, nutrients, and fish can and do move dynamically throughout the entire lake (Johannes and Larkin 1961). Competition and predation are direct interactions that may occur between trout and bass during periods of spatial overlap. Conditions in 1994 - low water levels and the disappearance of the tui chub - were almost optimal for estimating the maximum effect of bass on hatchery trout.

Table 1. Diet composition, by percentage of total volume consumed, for rainbow trout in Crane Prairie Reservoir, 1994. Sample size (n) reflects actual number of stomachs examined that contained food.

Month	n	Amphipods	Damselfly	Dragonfly	Snails	Zooplankton	Mayfly	Caddisfly	Other
June	7	11.3	37.4	0.0	0.0	13.3	0.0	16.1	21.9[a]
July	11	44.2	4.8	0.0	0.0	5.8	6.0	2.2	37.0[b]
August	13	24.9	0.4	0.0	54.4	0.0	0.6	3.2	16.5[c]
September	14	19.5	0.3	0.0	4.1	29.4	0.5	31.6	14.6[d]
October	9	12.7	8.1	4.4	55.5	17.1	0.0	0.0	2.2

[a] Miscellaneous insects (7.7%), stoneflies (9.9%), and water striders (4.3%).
[b] Miscellaneous insects (33.6%), stoneflies (1.9%), and water striders (1.5%).
[c] Miscellaneous insects (16.0%), and leeches (0.5%).
[d] Miscellaneous insects (14.6%).

Table 2. Diet composition, by percentage of total volume consumed, for largemouth bass in Crane Prairie Reservoir, 1994. Sample size (n) reflects actual number of stomachs examined that contained food.

Month	n	Hatchery Rainbow	Other Salmonids	Stickle back	Zooplankton	Amphipod	Caddis fly	May fly	Damsel fly	Dragon fly	Cray Fish	Other
0-99 mm largemouth bass[a]												
July	5	0.0	0.0	0.0	0.0	7.3	3.1	72.1	17.3	0.0	0.0	0.2
August	4	0.0	0.0	0.0	0.0	38.2	0.0	0.0	60.6	0.0	0.0	1.2
100-199 mm largemouth bass												
June	1	0.0	0.0	57.4	0.0	0.0	0.0	42.6	0.0	0.0	0.0	0.0
July	4	0.0	0.0	0.0	0.0	42.4	0.0	5.1	10.0	29.6	0.0	12.9[b]
August	16	0.0	0.0	6.0	0.0	28.0	0.0	15.8	9.4	0.0	0.0	40.8[c]
September	20	0.0	0.0	60.0	0.0	9.4	0.0	0.4	23.2	0.0	0.0	7.0
October	2	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
200-299 mm largemouth bass												
June	27	41.0	4.0	14.7	0.0	1.5	0.0	0.2	21.2	3.6	11.0	2.8
July	10	36.0	0.0	0.7	0.0	2.3	0.0	8.1	6.2	30.7	0.0	16.0[d]
August	44	0.0	0.0	25.9	0.0	45.3	0.0	1.3	0.6	7.4	7.4	12.1[e]
September	26	0.0	2.5	70.7	0.0	2.0	0.0	0.0	1.5	8.9	0.0	14.4[f]
October	17	0.0	0.0	11.0	0.0	20.2	0.0	0.7	3.2	7.1	5.4	2.4
300-399 mm largemouth bass												
May	26	0.0	4.8	16.3	0.0	9.0	0.0	1.3	33.8	26.7	0.0	8.1
June	13	67.8	10.1	2.1	0.0	0.3	0.0	0.0	15.5	2.4	0.9	0.9
July	7	10.7	87.5	0.0	0.0	0.1	0.0	0.4	0.4	0.0	0.0	0.9
August	16	0.0	0.0	5.3	0.0	0.8	0.0	0.0	0.2	0.0	92.1	1.6
October[g]	4	0.0	73.8	2.0	0.0	0.8	0.0	0.0	0.0	4.1	0.0	19.3[h]

[a] No 1-99 mm largemouth bass were collected in June, September, and October.
[b] Miscellaneous insects (10.3%), and snails (2.6%).
[c] Miscellaneous insects (21.8%), snails (11.8%), and unidentified fish (7.2%).
[d] Leeches (11.2%), and miscellaneous insects (5.0%).
[e] Snails (5.2%), miscellaneous insects (4.3%), and leeches (2.3%).
[f] Snails (6.2%), miscellaneous insects (5.9%), and unidentified fish (2.2%).
[g] Includes 1 fish collected in September.
[h] Unidentified fish (19.1%), and miscellaneous insects (0.2%).

Table 3. P-values generated from bioenergetic modeling of growth of hatchery rainbow trout from June 7 to October 4, 1994 in Crane Prairie Reservoir.

	Deschutes Channel	Littoral Area
June 7 – August 4	0.53	0.53
August 5 – October 4	0.79	0.84

Table 4. Monthly Schoener diet overlap indices for rainbow trout and different size categories of largemouth bass from Crane Prairie Reservoir, 1994. Monthly index was not calculated if 2 or fewer fish were collected.

Size of bass (mm)	June	July	August	September	October
1-99	--	0.29	0.38	--	--
100-199	--	0.40	0.55	0.34	--
200-299	0.47	0.17	0.43	0.16	0.30
300-399	0.43	0.35	0.27	--	0.05

Stress related to handling during transport and stocking has been shown to create behavioral changes in trout which can decrease their ability to reach cover (Sigismondi and Weber 1988) and increase their vulnerability to predation (Ayles et al. 1976; Barton et al. 1980, 1986). Over a third of the trout fingerlings lost to predation were consumed by largemouth bass immediately following stocking at the resort ramp. However, our sampling was not able to detect any difference between the level of predation occuring in the vicinity of the Rock Creek and Quinn River stocking sites immediately before and after stocking of trout. In contrast to the area around the Resort ramp, these areas possessed high structural complexity - abundant woody debris and large rocky substrate - which probably provided trout refugia from predation (Glass 1971; Crowder and Cooper 1982; Savino and Stein 1982).

Hatchery trout were not a dominant food item in the diet of largemouth bass following the initially high levels seen following stocking. This is in spite of trout and largemouth bass being often found in the same habitat during our sampling. Night electroshocking probably secured a good representation of bass consumption of trout as bass feeding peaks during crepuscular periods (Reynolds and Casterlin 1976; Helfman 1981) and calculated gastric evacuation times were greater than 24 hours. Even though hatchery trout are extremely naive with respect to predation and bass are successful in 90% of their attacks (Nyberg 1971), trout quickly learn to incorporate predation risk into their behavioral strategies (Tabor and Wurtsbaugh 1989). Tabor and Wurtsbauch (1989) demonstrated that the addition of predators (brown trout) to a pond caused juvenile rainbow trout to stop actively foraging and seek cover in inshore areas. Once they adjusted to their new environment, trout undoubtedly used the abundant cover in Crane Prairie (woody debris, vegetation, and rocky substrate) to reduce their exposure to bass predation.

Definitive proof of competition for food between largemouth bass and hatchery trout must show a shared utilization of a limited resource. P-values generated through modeling of rainbow trout growth suggest some factor(s) is limiting trout from reaching their potential during the period from June 7 to August 4. Diet overlap indices suggest that the levels of overlap occuring are not biologically significant. So given these results, are largemouth bass and rainbow trout competing for food?

Identification of the nature and extent of competition between bass and trout is an important, albeit, difficult interaction to quantify. Niche segregation by species can confound in situ investigations of competition for food based on diet overlap (Abrahams 1996) - our study did not estimate fingerling trout preferences or diet in the absence of bass. What we saw was the diet as a result of any interaction or segregation developed to reduce competitive pressure. Ideally the diet of both species would have been investigated with and without the other species present and then compared. Stocked rainbow trout consumed a variety of prey items, reflecting their categorization as generalists or opportunistic feeders (Calhoun 1966, Scott and Crossman 1973). This plasticity probably reduces the negative effects of any competitive interaction with bass, but the question remains to what extent are fingerling trout consuming what they prefer or what they are being "forced" to eat as a result of interaction with bass. Our use of bioenergetics and diet overlap is a powerful method in confirming the lack of competition, i.e., P-value close to 1, but is substantially less effective in confirming its presence. If the P-value is less than 1, then competition is just one possible explanation. Given the limitations of our study, there is no way to evaluate this.

Another possibility for the lower initial P-value of stocked trout could be due to a reduction in feeding efficiency due to a novel environment. Condition of hatchery rainbow decreased substantially through July before increasing in August. This could have reflected a period of adaptation to to foraging in a natural environment.

One provocative explanation for the results of the bioenergetic modeling was that trout behavior to reduce the risk of predation affected their ability to consume food. The difference in the rate of predation losses between the resort site (little or no cover) and the other two sites (abundant cover) suggests that rainbow trout are taking advantage of the cover in the reservoir to reduce the predation risk. Juvenile salmonids are considered energy maximizers (Dill et al. 1981; Bachman 1984), which means they only have a fixed amount of time to feed and to obtain as much energy as possible (Pyke et al. 1977). Predator avoidance behavior by juvenile trout could reduce the time available for feeding and result in the inability to consume as much as their metabolic rate will allow. Wilzbach (1985) demonstrated that in the presence of predators, stream-dwelling adult cutthroat trout *Oncorhynchus clarki* were more apt to stay associated with cover when food abundance was high than low. This scenario could explain the reduced P-value despite the lack of biologically significant levels of diet overlap.

Growth of hatchery rainbow trout in Crane Prairie Reservoir, therefore, may be limited not by food or competition, but by a shift in the foraging strategies of trout in response to predation risk from largemouth bass and/or birds. Prey species will frequently alter their foraging behavior or strategy, often at a energetic loss, to balance a perceived predation risk (Dill 1983; Dill and Fraser 1984; Gotceitas and Colgen 1987). Predator avoidance by *Campostoma anomalum*, an algal-grazing minnow, constrained their feeding efficiency and allowed algal abundances to increase in stream pools (Powers et al. 1985). Werner et al. (1983) found that bluegill *Lepomis macrochirus* limited their habitat use to areas of low foraging profitability when a predator, largemouth bass, was present and, as a result, grew more slowly than when no predators were present.

The increase in the P-value during the latter period examined (August 4 - October 4) coincides with the elimination of predation risk for most of the trout. By mid-August, the influence of predation on the distribution of stocked trout was diminished or eliminated as most of the hatchery trout had grown too large to be consumed by the bass present in the reservoir. Thermal segregation of the two species may have also contributed to the increased P-value, but this separation was only apparent for a short amount of time. Decreased predation risk allowed greater optimization of foraging, negating the benefits associated with cover. Mittlebach (1981) shows that small bluegill chose to stay in the less rewarding vegetation to reduce predation risk, while larger bluegill, too big to be preyed upon, foraged in the pelagic area with impunity. Decreased predation risk could have allowed Crane Prairie trout to consume closer to the metabolic capability during the latter part of the summer.

Bioenergetic modeling offered a bridge for addressing the question of competition through collection of basic biological and physical information. However, there are some problems associated with this kind of modeling. When using the model, it is easier to determine when competition is not occuring, i.e., the P-value is close to one. As we have seen, when the resultant P-value is less than one, competitive limitation is only one possible explanation. Also, parameters used in modeling are subject to errors and biases which can affect the results. Lewis and Helms (1964) demonstrated that vulnerability to bass predation within a species varied due to size of bass and prey. Size-selective predation of smaller rainbow trout could positively bias estimates of growth in this study. Gear selectively for larger fish could have also positively bias estimated growth. Conversely, inclusion in samples of rainbow trout stocked after June 9 could negatively bias growth estimates and resultant P-values. Angler harvest of faster-growing (larger) fish in September and October could have also negatively biased growth estimates and resultant P-values by shifting the average size of trout left in the reservoir downward. Higher water temperatures during the latter period examined could have increased the activity of trout and/or prey items, thus making them more vulnerable and accessible to predation. Errors in temperature could have affected results but P-values were fairly robust in trials where possible differences were modeled. Despite all these problems, bioenergetic modeling was the most feasible methodology to make a qualitative assessment of competition given the constraints this study was conducted under.

The dynamics of the hatchery trout program have undoubtedly changed in response to the reduction in tui chub. Abundant tui chub populations in other waters, Diamond Lake for instance, have negatively affected trout programs and often resulted in chemical rehabilitation of the lakes. Bass predation was probably a factor in the demise of the chub population, but it is unlikely that it was solely responsible given the relative dispersal rates of both species (Crowley 1981). Reduced access to good spawning habitat due to drought-related low water levels undoubtedly contributed to the disappearance of tui chub in the reservoir.

Management Implications

Interactions between largemouth bass and rainbow trout in Crane Prairie Reservoir do not negate co-management of both species under present conditions. Information gained from this study, primarily predation rates, can be used to estimate the direct effects of changes in largemouth bass population structure on predation losses of rainbow trout. The 1989-90 study suggested that there is about a 8.5% return to the creel on hatchery rainbow trout stocked in Crane Prairie. The 9,172 trout consumed by "non-Resort" bass in 1994 translates to about 778 trout lost to the angler creel or a 6% reduction in trout harvest. This is in exchange for the recreation associated with catching over 29,000 largemouth bass. Future trout losses due to predation can be estimated using bass predation rates generated from this study. Higher water levels and/or increases in the tui chub or largemouth bass population sizes would undoubtedly affect the accuracy of these estimates, but they could be used as estimates of maximum rates of consumption.

The theory that a perceived largemouth bass predation risk has reduced the foraging efficiency of rainbow trout is one of several explanations of the study results. If this hypothesis is valid, it should result in reduced growth and survival, but District sampling has not noted any appreciable change in the success of the hatchery program. It is questionable, however, given the sensitivity of the sampling program, whether it could detect a small change attributable to competitive interaction with bass. It is possible that the altered foraging behavior occurs for such a short time (two months) that it results in no measurable change in trout survival and, ultimately, the fishery.

Competition is an important interaction to consider when discussing bass management at Crane Prairie. The productivity and diversity of prey in Crane Prairie Reservoir may reduce competition for food between hatchery trout and largemouth bass, but results of our study were inconclusive. The variable we were unable to investigate was the effects of an abundant tui chub population on this system. The fish community in Crane Prairie is dynamic and effects at one level can cause cascading changes throughout the system. Given the importance of tui chub in the diet of Crane Prairie largemouth bass (Shrader 1993), a decrease in chub numbers has probably lead to increased consumption of trout by bass. This loss to the trout fishery may be offset by decreased competition with a reduced tui chub population (due, in part, to bass predation), but complicated by the reduced availability of chub for large trout. In addition to the possibility of direct competitive interactions with chub, trout may alter their behavior in the presence of an abundant tui chub and accept more of a predation risk while feeding. Dill and Fraser (1984) have shown that in the presence of competitors, juvenile coho salmon decreased their response to predation risks while feeding. This suggests that if bass had not reduced chub numbers, trout might have been more active and, therefore, more vulnerable to bass predation. How this myriad of indirect interactions balance out is beyond our ability to predict. As a result, we must restrict our estimation of management effects to a very gross level.

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APPENDIX A

Estimation of Stocked Hatchery Rainbow Trout Lost Through Predation by Largemouth Bass at Crane Prairie Reservoir

Hatchery trout consumed by "Resort" bass:

Estimated population = 2,134 bass, which equates to
1,876 200-299 mm bass,
232 300-399 mm bass, and
25 bass > 400 mm.
Consumption rates =
1 stocked trout / 200-299mm bass, and
2 stocked trout / bass > 300.

Digestion rate of 1 trout for a 250 mm bass =
approximately 24 hours @ 18°C.

NOTE: Although comparable information for largemouth bass is not available, a 250 mm smallmouth bass digests 1 trout at the same rate that a 350 mm smallmouth digests 2 similar sized trout.

Assuming that it takes stocked trout 4 days to disperse from the stocking site and that predation loss decreases linearly from a maximum on the day of stocking to zero 4 days later, then trout mortality due to predation is:

Day 1 2,392 trout;
Day 2 1,594 trout;
Day 3 796 trout; and
Day 4 0 trout
TOTAL 4,782 trout consumed by "Resort" bass.

Hatchery trout consumed by remainder of reservoir bass:

Estimated 1994 Crane Prairie Reservoir largemouth bass population = 11,000 fish > 200 mm.

This is based on a proportional relationship between the 1989 electrofishing CPUE (25.46) and average population estimate (10,530) and the 1994 electrofishing CPUE (26.6).

Based on an estimated 11,000 bass greater than or equal to 200 mm and the 1994 electrofishing CPUEs, the 1994 population (minus the "Resort" subpopulation) consists of:
7,830 200-299 mm bass,
882 300-399 mm bass, and
154 bass > 400 mm.

Consumption rates =
0.026 stocked trout per 200-299 mm bass = 206 trout/meal,
0.045 stocked trout per 300-399 mm bass = 40 trout/meal; and
0.333 stocked trout per bass > 400 mm = 77 trout/meal.

Average digestion time @ 16°C = 49.5 hours;
@ 20°C = 34.0 hours; and
@ 22°C = 28.5 hours.

Size of Bass	Number of	Trout per	Trout consumed over a 14 day period

(mm)	bass	meal	16^{o}C	20^{o}C	22^{o}C
200-299	7,830	206	1,398	2,030	2,423
300-399	882	40	271	394	470
>400	154	77	522	759	905
			2,191	3,183	3,798

Therefore, total loss of hatchery trout to non-Resort bass = 9,172 fish.

Estimate of total loss of hatchery rainbow trout to largemouth predation:

Total loss of hatchery trout to non-Resort bass = 9,172
Total loss of hatchery trout to Resort bass = 4,782
Total loss of hatchery trout to bass predation = 13,954 or 6.8% of stocked rainbow trout

Using the same methodology an estimated 15,284 wild salmonids were consumed by bass.

Dietary Overlap Between Introduced Fishes and Juvenile Salmonids In Lower Granite Reservoir, Idaho-Washington

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Abstract- *Dietary analysis was conducted on five introduced and two juvenile salmonid species collected in Lower Granite Reservoir during spring 1995 to quantify dietary overlap occurring during smolt rearing and out migration. We found that the diets of both introduced fishes and juvenile salmonids sampled were diverse, presumably as a result of unusually high spring flows that increased prey diversity in the reservoir. Results from this study suggest that similar food items of juvenile chinook salmon (Oncorhynchus tshawytscha) and steelhead (O. mykiss) are being found in introduced fishes, particularly chironomid larvae and pupae, and Ephemeroptera nymphs. Our Schoener Index analysis comparing the dietary biomass for all fishes considered in this study reflected these similarities, as values near or exceeding the critical level of overlap (>0.60) were found. However, based on the unlimited food resources and the relatively low abundance of selected introduced fishes in the reservoir, the biological significance of this dietary overlap for juveniles salmonids is likely not contributing to higher mortality in juvenile salmonids.*

Introduction

The Snake River watershed historically supported large runs of anadromous salmon *Oncorhynchus spp.* and steelhead *O. mykiss*. Currently, stocks of Snake River salmon have been listed as endangered under the Endangered Species Act (Menke 1993). The depressed status of these stocks has lead to a large number of scientific studies to identify key factors that have contributed to their decline. Although overfishing has substantially depleted some salmonid stocks, direct and indirect losses due to environmental modifications have had the greatest permanent effect on their viability (Williams 1989). Tributary dams, unscreeened irrigation diversions, habitat degradation and in-stream siltation from logging, mining, and grazing activities have eliminated or severely degraded many of the valuable spawning and rearing areas used by these fishes. Despite the severity of these deleterious effects on salmonid habitat, construction and operation of instream hydroelectric dams along the Columbia and Snake River systems may be the largest contributors to the declining salmon and steelhead runs in the inland northwest (Raymond 1988).

Extensive research has been conducted on effects of hydroelectric dams and resulting reservoirs on juvenile salmonid survival (Holmes 1958; Raymond 1969, 1979, 1988; Bell and Delacy 1972; Bell 1981; Curet 1994). Research has been directed primarily towards smolt mortality as a result of passage through turbine in-take and prolonged exposure to lethal concentrations of nitrogen gas (Raymond 1979, 1988). Recovery efforts have been made to alleviate the severity of these factors by developing transportation, collection, and by-pass facilities for juvenile salmonids, and modifying spillways to reduce gas supersaturation (Williams 1989). Raymond (1968) found that juvenile chinook salmon *O. tshawytscha* moved only one-third as fast through reservoirs as through free-flowing stretches of river. Prolonged migration time of smolts through the reservoir increases the probability of predation (Raymond 1979; Curet 1994), and may disrupt timing for optimal entry into seawater (Mahanken et al. 1982). However, understanding the deleterious effects of hydroelectric dams on juvenile salmonids is not complete and other contributing factors may exist.

Dietary overlap has been speculated as being a factor contributing to juvenile salmonid mortality in Lower Granite Reservoir (Poe 1992). Curet (1994) found that sub-yearling chinook salmon were feeding at about 27% of maximum during their brief rearing and migratory period in Lower Granite Reservoir. These results were consistent with other research conducted by Poe (1992) and Muir (1996) who found that smolts collected at Lower Granite Reservoir had high percentages of empty stomachs in contrast to migrants collected at other dams. Reduced consumption by juvenile salmonids in the Lower

Snake River reservoirs could be the result of changes in the benthic community that occurred as a result of the impoundment, specifically a decrease in diversity, availability, and abundance (Bennett and Shrier 1986). These changes in the prey base, combined with an established population of introduced fishes have elevated the concern of smolt mortality as a result of competitive interactions. In a preliminary study that investigated the possibility of dietary overlap in Lower Granite Reservoir, Bennett et al. (1997a) found that diets of several species of introduced fishes were similar to those of chinook salmon and steelhead in 1994 and 1995, suggesting that similar food items were being proportionally consumed by both introduced fishes and juvenile anadromous fishes in Lower Granite Reservoir. These results suggest the need for a more thorough evaluation of food habits between introduced fishes and anadromous salmonids in the lower Snake River reservoirs.

Dietary overlap among introduced fishes and juvenile salmonids needs to be determined to provide managers with adequate information for making decisions regarding the potential for restoration of Snake River salmonids. As a result, we evaluated the food items of juvenile salmonids and introduced fishes collected in Lower Granite Reservoir to assess the degree of dietary overlap.

Study Area

Lower Granite Dam, completed in 1975, impounds 53 km of the Snake River extending from the dam at Rkm 173.1 (Rm 107.5) in Washington into the Snake and Clearwater rivers in Idaho (Figure 1). The total surface area of the reservoir is 3,602 ha, with a mean depth of 16.6 m and maximum of 42.1 m (Curet 1994). Electrical power generation, navigation and recreational activities are the major uses of the dam and resulting reservoir (Bennett and Shrier 1986). The annual temperature ranges from 2 to 23 ^{o}C with no thermal stratification. Riparian vegetation along the shoreline is sparse as a result of the 1.52 m water level fluctuation from reservoir operations (Curet 1994). Lower Granite Reservoir is the uppermost impoundment on the lower Snake River that is encountered first by outmigrating Snake and Clearwater River chinook salmon and steelhead juveniles.

Lower Granite Reservoir was divided into three strata (stratum 1 Rkm 211 – 225.1 (Rm 131.0 - 139.75); stratum 2 Rkm 193.2 - 211 (Rm 120.0 - 131.0); and stratum 3 Rkm 173.1 - 193.2 (Rm 1075.5 - 120.0)) for sampling juvenile salmonids and introduced fishes (Figure 1). The shoreline was separated into 0.4-km sections of similar habitat types and each section represented one sample site, thus yielding 258 possible sites. The number of sites sampled within each stratum and habitat type was determined by the proportional allocation formula (Scheaffer et al. 1990). In 1995, 60 sites were randomly sampled semimonthly from May through July and monthly in April and August through November.

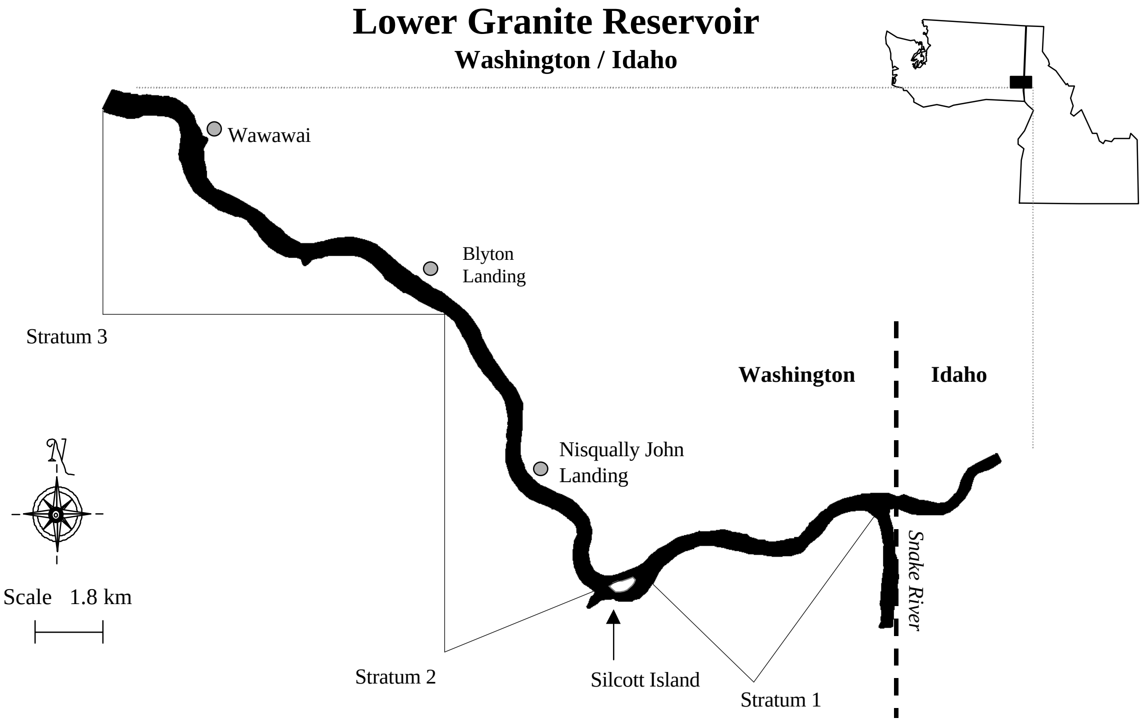

Figure 1. Map of Lower Granite Reservoir, Washington / Idaho.

Methods

Collection Procedures

Electrofishing and beach seining were used for shoreline collections of introduced and salmonid fishes. Electrofishing was conducted using a Smith-Root electroshocking boat for daytime and nighttime collections. The boat was operated parallel to the shoreline with current turned on and off through the length (0.4 km) of the site. A constant electrical output of 400 volts at 3 to 5 amps was used to stun fish without causing mortality. Beach seining was conducted using a 30.5-m x 2.4-m beach seine with a 2.4-m x 2.4-m x 2.4-m bag constructed of 0.6-cm knotless nylon mesh. The seine was placed parallel with, and approximately 5-25 m from the shoreline. The seine was pulled toward the shore, sampling an area from 366 m^2 to 1,830 m^2, respectively. Beach seining was conducted over cobble, talus, and sand/silt habitats. One to three hauls were conducted at each location depending on shoreline habitat.

All fishes sampled were placed in live wells immediately upon capture. Each fish was weighed (g) and measured for length (mm). Introduced fishes were measured to total length and juvenile salmonids were measured to fork length. Stomach contents were evacuated from fish anaesthetized with MS 222 using a modified lavage technique (Seaberg 1957), flushed into a mesh filter, and transferred to a sample container where they were preserved in 10% formalin. Fish were allowed to fully recover prior to release. A maximum of 5 to 10 stomachs of juvenile salmonids was sampled per location within each of the three strata. Juvenile salmonids longer than 100 mm were sampled for stomach contents, while yellow perch *Perca flavescens*, crappie *Pomoxis spp.* and sunfish *Lepomis spp.* longer than 70 mm were sampled for stomach contents.

Lab Analysis

Stomach contents of introduced fishes and juvenile salmonids were identified to the lowest practical taxonomic level in the laboratory using dissecting microscopes. Prey items were identified using several taxonomic keys: Borror et al. (1981), Merrit & Cummins (1984), Pennak (1989) and Wiggins (1996). Prey items were separated into taxonomic groups and enumerated. When possible, parts of insects were combined with similar prey items and the total number for each group was estimated. Digested weights were obtained by blotting prey items dry and weighing to the nearest 0.001 milligram. When prey items were not intact, head capsules were counted, and body parts were combined for weighing. Partially digested, unidentifiable foods were weighed as a group.

When fish were found in a stomach sample, fork length (nearest mm) was measured and weights were obtained to the nearest 0.001 milligram. When prey fish were too digested to be properly identify, diagnostic bones from cleitherum, opercle, dentary, hypural bones, and vertebrae were used to distinguish between salmonid and non-salmonid prey (Hansel et al. 1988). Species identification was further determined using a bone manual to aid in specific bone morphological traits.

Data Analysis

Stomach contents were analyzed for dietary overlap from five introduced fishes and two juvenile salmonids captured during April – June (spring) 1995. Stomach contents of fishes collected in strata 1-3 were pooled, and analyzed on a reservoir wide basis. Dietary analysis of introduced fishes and juvenile salmonids was divided according to fish species.

Differences in the diets of juvenile salmonids and introduced fishes were determined using the average of the weight percentage of each prey item consumed. Prey items were consolidated into 28 categories based on taxonomic distinction. Total biomass (g) of all food categories in each fish species was then calculated. The percent of each prey category based on total biomass was averaged to derive the percent composition by weight of each prey category for each fish species.

Comparisons of each prey category consumed were made between introduced fishes and juvenile salmonids based on the mean percent biomass (g). A measure of biomass is the most appropriate when calculating dietary overlap (Wallace 1981). Percent biomass of dietary items was based on identifiable prey items, non-food items and unidentified prey were omitted in the comparison. To test for dietary overlap between introduced fishes and juvenile salmonids, we employed the Schoener Index (Wallace 1981). Values for the Schoener Index vary from 0 when the samples are completely distinct (containing no food categories in common) to 1 when the samples are identical with respect to proportional food category composition. Dietary overlap is considered to be biologically significant when the value exceeds 0.6 (Zaret and Rand 1971). The Schoener Index is calculated as:

$$\alpha = 1 - 0.5 \left(\sum_{i=1}^{n} \left| p_{xi} - p_{yi} \right| \right)$$

where, p_{xi} and p_{yi} are the proportions of food resources (i) used by species x and y, and n is the total number of resource categories used by each species. The Schoener Index values for each comparison were used to determine which species exhibited dietary overlap.

Results

Ninety-two different prey items were identified from the stomachs of 302 introduced fishes and 583 juvenile salmonids sampled during spring 1995 in Lower Granite Reservoir. Lengths of introduced fishes and juvenile salmonids were similar (Table 1.). The biomass of prey items consumed by juvenile salmonids was about three times lower than in introduced fishes, except for white crappie that were similar.

Dipteran larvae and pupae (mainly chironomidae) accounted for the highest mean biomass of identifiable prey items found in all fishes, except in juvenile chinook salmon where Ephemeroptera nymphs comprised the highest percentage (27.0%; Table 2.). Ephemeroptera nymphs contributed the second highest mean dietary biomass in the stomachs of pumpkinseed (21.5%), white crappie (24.1%), black crappie (21.4%), and yellow perch (21.9%). Combined, these prey items accounted for greater than 50% of the mean biomass in the diets of pumkinseed (58.4%), white crappie (66.5%), black crappie (53.2%), yellow perch (53.3%) and juvenile chinook salmon (51.7%). Terrestrial based insects, predominately Coleoptera, Hymenoptera, and adult Diptera, accounted for a higher percent of the mean biomass in bluegill (25.2%) and juvenile chinook salmon (31.3%) and steelhead (32.5%) than in other fishes. Evidence of piscivory existed predominately in the diets of white and black crappie (20.3% / 23.7% mean biomass, respectively), and yellow perch (25.1% mean biomass). Fish in the diets of these species consisted primarily of larval fishes. Fish accounted for a small proportion of the dietary mean biomass found in pumkinseed (4.2%), juvenile chinnok salmon (0.8%) and steelhead (0.3%). Crustaceans were found in the diets of all fishes sampled, and consisted primarily Amphipoda. Zooplankton comprised greater than 10% of the mean biomass in the diets of bluegill (16.7%) and juvenile steelhead (11.4%).

Schoener Index values were high between all introduced fishes and juvenile salmonids, however a value of significant dietary overlap (0.60) was exceeded only between bluegill and juvenile chinook salmon (0.61) and steelhead (0.69) (Table 3.). Schoener index values comparing pumkinseed, white and black crappie, and yellow perch with juvenile chinook salmon were higher than 0.57, whereas values comparing these introduced fishes with juvenile steelhead were comparably lower.

Table 1. Total length, total weight of all food items, and weight of food items per fish for the five introduced and two anadromous fishes used in the diet overlap analysis. Values indicate the mean and standard error. Ranges are presented in paraentheses.

Fish Species	Total number of fish	Total Length (mm)	Total biomass (g) food items	Biomass food items/fish
Pumpkinseed	67	140.4+/-2.5 (80 - 181)	22.46	0.34+/-0.07 (0.00-3.00)
Bluegill	16	151.4+/-5.6 (111 - 188)	4.61	0.29+/-0.08 (0.01-1.20)
White crappie	106	120.8+/-4.3 (65 - 239)	15.74	0.15+/-0.05 (0.00-4.97)
Black crappie	79	165.6+/-6.0 (55 - 296)	36.56	0.46+/-0.12 (0.00-7.14)
Yellow perch	37	194.1+/-7.6 (96 - 282)	8.34	0.23+\-0.05 (0.00-1.42)
Chinook salmon	379	122.5+/-1.0 (81 - 229)	32.2	0.08+/-0.01 (0.00-0.71)
Steelhead	204	172.9+/-3.3 (86 - 295)	27.27	0.13+/-0.02 (0.00-2.19)

Table 2. Percent of identifiable prey catagories found in the stomachs of five introduced fishes and two juvenile salmonids from Lower Granite Reservoir, Washington/Idaho. "T" indicates items in diet were terresterial invertebrates, "A" indicates aquatic invertebrates, "C" indicates crustacean, "F" indicates fish, and "O" indicates other.

Prey Category	Pumpkinseed (N = 65)	Bluegill (N = 16)	White crappie (N = 106)	Black crappie (N = 79)	Yellow perch (N = 36)	Chinook salmon (N = 379)	Steelhead (N = 204)
O Plant	0.02	0.7			4.8	0.4	0.02
A Misc. aquatic insects	3.9	9.19	2.1	3	0.6	0.9	1.8
T Misc. terrestrial insects	0.02	1.3			0.01	1	2.7
O Annellida	16.2	10		0.15	0.1	0.2	2.7
C Amphipoda	7.3	12.7	5.1	7.9		2.7	7.9
C Cladocera	0.02		1.9	0.3	0.01	0.01	0.02
C Copopoda	0.4	3.8	0.6	1.6	3.4	0.3	0.3
C Decapoda	1.3	0.01	0.1			0.01	
C Isopoda	0.5	0.1	0.02	0.02		0.01	3
C Ostracoda	0.02	0.2	0.02	0.01		0.01	0.3
T Ephemeroptera (adults)			0.2			0.8	1.8
A Ephemeroptera (nymphs)	21.5	9	24.1	21.4	21.9	27	10.2
T Plecoptera (adults)		2.2	0.2	1.4	2.6	0.6	0.4
A Plecoptera (nymphs)			0.03	2.4		0.6	2.2
T Hemioptera		0.6		0.01		1	1.4
T Trichoptera (adults)	0.8	0.3	0.03	0.9		2.6	1.3
A Trichoptera (larvae)	1.9	3.7	1.3	2.3	1.4	3.4	1.8
T Coleoptera	1.5	6.1				1.6	7
A Diptera (larvae/pupae)	36.9	24.9	42.4	31.8	31.4	24.7	23.7
T Diptera (adults)	1.2	5.8	0.3	1.5	1.1	11.8	9.1
O Mollsca	1.1			0.01			0.9
T Homoptera	0.2	0.3		0.3	0.9	2.7	2.5
T Hymenoptera	0.1	8.6		0.6	0.01	9.1	6.4
O Insect exuviae	1	0.5	1.3	0.7	6.6	7.8	12.3
F Fish UID / larval	4.1		8.9	18.1	15.8	0.4	0.3
F Salmonid fishes			2.7	4	5		
F Non-salmonid fishes	0.02		8.7	1.6	4.4	0.4	
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 3. Schoener Index values comparing diet-overlap between introduced fishes and juvenile salmonids collected in Lower Granite Reservoir during spring (April-June) 1995. Asterisks (* *) indicate significant dietary overlap.

Spring (April-June) 1995	Chinook salmon (N=397)	Steelhead trout (N=204)
Pumpkinseed (N=65)	0.57	0.54
Bluegill (N=16)	*0.61*	*0.69*
White crappie (N=106)	0.57	0.45
Black crappie (N=79)	0.58	0.53
Yellow perch (N=36)	0.59	0.46

Discussion

Our results support speculations of other researchers (Poe 1992; Muir 1996) that dietary overlap is occurring during downstream migration of juvenile salmonids in Lower Granite Reservoir. Diptera (Chironomid) larvae and pupae, and Ephemeropteran nymphs were found consistently in diets of all fishes sampled, and appeared to be the most selected prey item in spring 1995. Our Schoener analysis reflected these consistencies, as values near to or exceeding the critical level of overlap (0.60) were found. However, the effects of this diet overlap may not be highly significant to the survival of juvenile chinook salmon and steelhead in Lower Granite Reservoir.

During periods of smolt rearing and out migration, food resources in Lower Granite Reservoir are likely not limiting. Lower Granite is unique among the four Lower Snake River reservoirs as free flowing tributaries (Clearwater and upper Snake Rivers) feed its headwaters. Davis (preliminary data, University of Idaho) in his evaluation of invertebrate drift in Lower Granite Reservoir found that during spring high flows, drift from these riverine tributaries increased aquatic insect diversity and abundance in the reservoir. This source of invertebrate recruitment likely increases the prey base in the reservoir during smolt migration. Concern for dietary competition may be warranted during periods or years of low flow when invertebrate recruitment is minimal; as was indicated by Davis' (unpublished data, University of Idaho) results. Under this condition, dietary overlap may become more critical if the aquatic invertebrate community in the reservoir were unable to support the food demands of juvenile salmonids. Measurements of benthic invertebrate standing crop recorded during periods of smolt migration indicated no correlation between fluctuations in benthic invertebrate densities and peak juvenile salmonid abundance in the reservoir (Bennett et al. 1997b). Together, these factors suggest that food resources are unlimited in Lower Granite Reservoir during juvenile salmonid migration. Thus, the effects of dietary overlap on the survival of juvenile salmonids are likely minimal.

Effects of food resource competition may be further minimized for juvenile salmonids as a result of the relatively low abundance of the five introduced fishes we examined in Lower Granite Reservoir. Bennett et al. (1997c) examined persistence and stability of the resident fish assemblage in Lower Granite using fish abundance data collected during 1985 through 1993. Although results from this 8-year study indicated a reservoir wide increase in Centrarchid fishes numerically, by 1993 abundances of bluegill, pumkinseed, black and white crappie, and yellow perch accounted for less than 7% of the resident fish assemblage. If under the worse-case scenario food resources were to become limiting in the reservoir, based on these relatively low abundance estimates, it is unlikely dietary overlap among these fishes would seriously affect juvenile salmonid survival.

The importance of Diptera (Chironomid) larvae and pupae, and Ephemeroptera nymphs in the diets of all fishes sampled may partially be explained by the availability concept in fish feeding dynamics, in which seasonal diet changes are related to seasonal changes in abundance and availability of various food items (Dauble et al. 1980; Becker 1970; Carlander 1969). Several studies (Dorband 1980; Bennett and Shrier 1986; Bennett et al. 1990; Bennett et al. 1993; Bennett et al. 1997b; Davis, unpublished data, University of Idaho) have reported that Dipteran (most prominently Chirnomid) and Ephemeropteran species are dominant components of the reservoir's aquatic invertebrate fauna in spring. Presence of these prey items in the diets is likely related to their high abundance.

Although we found the diet contents of selected introduced fishes with respect to aquatic based insects were similar to those of juvenile salmonids, we did observe differences in the consumption of terrestrial based insects (mainly adult Dipterans, Coleopterans and Hymenopterans) and fish. This degree of variability slightly decreased dietary overlap for juvenile salmonids, particularly with white and black crappie and yellow perch. It is possible during migration through the reservoir, juvenile salmonids are more surface oriented in response to increased buoyancy from smoltification (Pinder and Eales 1969). This behavior possibly promoted the increase in feeding of juvenile salmonids on prey items floating at or near the water surface, which may account for the relatively high biomass of terrestrial based insects in their diet. In contrast, selected introduced fishes probably fed more frequently along littoral areas of the reservoir where Bennett and Shrier (1986) found the abundance of small fish were highest.

In this study, we sought to determine the degree of dietary overlap among two juvenile salmonid and five introduced fishes in Lower Granite Reservoir. While our analysis was limited to data collected during a single sampling period (April-June, 1995), our results suggest that, at least during some portions of their migration through the reservoir, juvenile salmonids are consuming similar prey items as selected introduced fishes, and thus dietary overlap occurs. However, other biological factors that exist in the reservoir related to invertebrate availability and relative fish abundance, no doubt lessen the effects of dietary overlap for juvenile salmonids.

Care must be taken when evaluating our results of dietary overlap among selected introduced fishes and juvenile salmonids. Our analysis was intended to assess dietary overlap that exists on a reservoir wide basis. Therefore, spatial comparisons between upper, middle and lower reservoir areas were not thoroughly evaluated and should be examined, as prey abundance throughout the reservoir is probably not uniform. Our results, while accurately portraying dietary overlap for yearling chinook salmon, did not evaluate it among sub-yearling chinook salmon. Because of their extended rearing period in the reservoir, diet overlap with introduced fishes may be more extensive with subyearling chinook salmon and should be further examined.

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Strategies for Today

Session Chair:

Ray Temple
Oregon Department of Fish and Wildlife

Bringing Back the Natives in Arizona

Joe Janisch*
Arizona Game and Fish Department

Abstract- *Since 1930 almost 70 million fish representing 17 nonnative species have been stocked in eastern part of Arizona. These fish were stocked to create or improve sport fishing opportunity. This area of the state had native Apache trout, spine dace and two species of native sucker. Fish management efforts in recent years have been directed at the removal of brown, rainbow and brook trout in the attempt to re-establish Apache trout.*

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* Joe chose to have only the abstract of his talk published in the Proceedings.

Population assessment and experimental control of lake trout in Upper Priest Lake, Idaho

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Abstract- *Upper Priest Lake is a 567 ha natural lake located in northern Idaho. The lake is connected to a much larger lake, Priest Lake, by a 3 km low gradient river channel. Lake trout were never intentionally introduced into Upper Priest Lake, and they are thought to have immigrated from Priest Lake, where they were intentionally stocked in 1925. Lake trout were first documented in Upper Priest Lake in 1985. We used gill-nets, sonic-tagging, and conventional angling methods to 1) assess lake trout and bull trout populations in 1997 and 2) to determine if recreational angling could be used to help control lake trout. We captured 152 lake trout, ranging in size from 190 to 980 mm. A mark-recapture estimate indicated a population of around 877 fish, assuming immigration approximated emigration. Lake trout were captured in all areas and at all depths of the lake, and were frequently netted in the same areas as bull trout. Anglers were unable to effectively capture lake trout while minimizing bull trout by-catch. The ratio of bull trout to lake trout in the angler catch was about twice that of the gill-net catch, suggesting that anglers unable to avoid catching bull trout using conventional fishing. We documented movement of sonic-tagged lake trout between Upper Priest and Priest lakes in at least two of 9 monitored fish. In addition, anglers returned three spaghetti-tags from fish caught in Priest Lake that had been tagged in Upper Priest Lake.*

Based on the information collected in 1997, an experimental lake trout removal project was initiated in 1998. From June through October, we used gill-nets to remove 776 lake trout from Upper Priest Lake. Depletion estimates indicated the population was between 480 and 1,000 fish at the beginning of the effort. Declining catch rates and progressive increase in the ratio of bull trout to lake trout suggest that our efforts to reduce the lake trout population were successful. Furthermore, we were largely successful in avoiding negative impacts to bull trout, with only three mortalities in the netting effort. The poor recapture rate of lake trout tagged in 1997, sonic telemetry monitoring, and angler tag returns from Priest Lake, all indicate that lake trout migration between Upper Priest and Priest lakes is common. Because of the apparent invasion of untagged fish from Priest Lake between 1997 and 1998, we do not believe lake trout population control efforts will be effective unless we are able to control immigration.

Introduction

Upper Priest Lake is a 567 ha natural lake located in northern Idaho (Figure 1). The lake has a mean depth of ≈13 m and a maximum depth of 32 m. Upper Priest Lake is connected to Priest Lake by a 3 km low gradient river channel known as the Thorofare. Due to the construction of a small dam at the outlet of Priest Lake, both lakes are at the same elevation (743 m).

Both lakes historically supported healthy populations of bull trout *Salvelinus confluentus* (Bjornn 1957). The Priest Lake population is believed to be functionally nonexistent, and the Upper Priest Lake population is considered depressed and at risk. Lake trout *S. namaycush* were originally introduced into Priest Lake in 1925 (Bjornn 1957). There are no records of lake trout being introduced into Upper Priest Lake, and they are thought to have immigrated from Priest Lake through the Thorofare. Lake trout were absent from the lake in 1956 when an extensive fisheries survey was conducted on Upper Priest Lake (Bjornn 1957), and were still apparently not established in the lake as late as 1979 (Rieman et al. 1979). Mauser (1986) reported lake trout were occasionally caught in the upper lake in 1985. Detailed angler diaries kept by two avid Upper Priest Lake anglers indicate lake trout were common by 1993, and their catch records show an increasing relative abundance in the following years (Unpublished data).

Evidence suggests that lake trout and adfluvial bull trout did not naturally develop sympatric populations (Donald and Alger 1993). Bull trout populations in many lakes outside of the Priest Lake drainage, where lake trout have been introduced, are in decline (Donald and Alger 1993). In Priest Lake, the bull trout population collapsed in a period of only a few years in the early 1980's. From 1956 to 1978, anglers harvested between 1,200 and 2,300 fish annually (Mauser and Ellis 1985). In 1983, total catch and harvest were estimated at 159 and 92 fish, repectively, and by 1986, no bull trout were reportedly caught during an April-November creel survey (Mauser et al. 1988). Concurrent with the declining bull trout population, the lake trout population increased rapidly. Annual lake trout harvest was estimated to be less than 300 fish from 1956 to 1970. In 1978, harvest was estimated at 5,700 fish, and by 1994, harvest was estimated at around 14,000 fish. The increase in lake trout abundance is thought to be largely due to the introduction of mysis shrimp *Mysis relicta* in 1965 and a subsequent increase in survival of juvenile lake trout (Mauser 1985). Deteriorating tributary habitat, overharvest, and predation and/or competition with lake trout may all have contributed to the collapse of the bull trout population.

Indications of an expanding lake trout population and the potential threat of lake trout to native bull trout and cutthroat trout prompted an evaluation of the lake trout and bull trout populations in 1997. Based on information collected during that assessment, an experimental lake trout removal project was initiated in 1998. This paper describes the activities and results of our 1997 survey, and describes the progress to date of the 1998 lake trout population control project.

Methods

1997 Assessment

Netting-We collected lake and bull trout from Upper Priest Lake during four sampling periods from early June through mid-October in 1997. Sampling dates were June 2-4, July 14-16, August 14-15, and October 15. We used experimental monofilament sinking gill-nets (45.7 x 1.8 m with six panels ranging from 1.8 to 6.4 cm bar measure mesh). Nets were set throughout the lake perpendicular to shore at depths ranging from 3 to 32 m. The bathometry of Upper Priest Lake is U-shaped, with depth increasing rapidly from shore. For this reason, most gill-nets were set on a slope and covered a range of depths. At each set, we recorded the depth, time, type of net used and location. For analysis we categorized median net depth into three zones: 1) shallow (<10m), 2) middle (10-20m) and 3) deep (>20 m). To minimize injury to fish, we set five to six gill-nets at a time which usually allowed enough time to check the nets every 45-60 minutes. Nets were set during daylight hours only.

Netted lake trout and bull trout were measured to the nearest cm (total length; TL), weighed and allowed to recover in a live well. Lake trout greater than 320 mm were tagged with an individually numbered Floy spaghetti tag. Tags were inserted through the fish about 5-10 mm beneath the third (anterior) dorsal fin ray and secured with an overhand loop knot. Lake trout less than 320 mm were considered too small to effectively spaghetti tag and were sacrificed. Fish were taken 200-300 meters from the gill-netting site and released.

Angling-To determine if conventional fishing methods would be an effective means of collecting lake trout without causing unacceptable risk to bull trout, we recruited several anglers to participate in a two-day sampling effort August 14-15, 1997. We specifically invited anglers with the equipment and knowledge to be effective on Upper Priest Lake. Although most participants had not fished the upper lake prior to the effort, the majority had extensive lake trout fishing experience on Priest Lake (e.g. two participants were lake trout fishing guides, and another is a volunteer lake trout tagger who has caught over 300 lake trout in Priest Lake since 1995). To maximize catch rates, we allowed the use of bait (normally prohibited in Upper Priest Lake) and multiple rods per angler. We required all hooks be barbless to prevent injury to bull trout. We issued spaghetti tagging equipment to each boat and instructed them on the tagging procedure. Anglers were instructed to tag only lake trout, to minimize stress and possible mortality to bull trout. Participants recorded time fished, equipment used, and for all fish caught, the species, length, depth, and location of catch.

In addition to the two-day organized intensive fishing effort, we collected extensive angling data from May to November from two anglers who avidly fished Upper Priest Lake and maintained detailed catch records throughout the 1997 season. In addition to the 1997 season, these anglers supplied catch records maintained since 1993, when they first began fishing Upper Priest Lake.

Combined Mark and Recapture-Throughout the gill-netting and angling efforts we maintained records of the numbers of fish captured, tagged, released, recaptured and any mortalities. This data was then used in a mark-recapture population estimate. We used Peterson's Mark-Recapture method (Ricker 1975) using the June/July efforts as the marking run, and the August/October efforts as the recapture. Confidence intervals were approximated with a Poisson distribution (Ricker 1975). For the purposes of this estimate, we acknowledged that the population may not have been closed, but assumed that immigration approximated emmigration during the period of analysis. Because we only tagged fish 320 mm and larger, the population estimate does not include any fish <320 mm. We therefore corrected the population estimate by using length frequency of the catch to estimate the proportion of fish less than 320 mm. Because we used experimental nets, we don't believe the catch was biased to larger fish. We then added this percentage to the mark-recapture estimate for a total lake trout population.

Experimental Lake Trout Control

In 1998, a netting crew of two people used gill-nets to capture and remove lake trout from June through October. We ceased netting from mid-July through mid-September because of the high surface water temperatures (>20°C) and the associated stress to incidentally captured bull trout. As in 1997, we used experimental, monofilament, sinking gill-nets. Nets were pulled every 45-50 minutes. We initially used 4-5 small nets per set (45.7 x 1.8 m with six panels ranging from 1.8 to 6.4 cm bar measure mesh). Beginning July 13 we switched to larger nets (91.4 x 2.4 m experimental nets with 3 panels of 2.5, 3.8, and 5.1 cm mesh), but fished only 2-3 per set. Because we switched to larger nets in the later sampling weeks, we standardized catch to a unit of sampling effort (fish/hr/100m^2 gill-net). At each set, we recorded the depth, time, and net location. Gill-nets were set throughout the entire lake and were moved based on catch rates at a particular site and the discretion of the netting crew. A concerted effort was made to avoid incidental bull trout captures. When two to three bull trout were caught in a particular set, we relocated the nets in a different area of the lake. Nets were set during daylight hours only.

Captured lake trout were measured and weighed, and processed for delivery to an area food bank. Stomach and otolith samples were collected from subsamples of representative size groups. Bull trout were measured, weighed, and marked with a visual implant (VI) tag.

Lake Trout Movement

We implanted coded sonic tags in 10 lake trout to provide additional information on the movements of lake trout in Upper Priest Lake. Fish were collected with gill-nets during the August, 1997 sampling effort. We attempted to utilize only mature fish that were likely to spawn during the fall of 1997. Based on length at maturity information from lake trout in Priest Lake, only lake trout of at least 500 mm (TL) were sonic tagged. Fish of this length were well in excess of the minimum weight suggested to accommodate the sonic tags (tag weight < 2% body weight; Winter 1983). We monitored the fish on a weekly basis from August through November, 1997. Telemetry was on a more intermittent schedule in 1998.

We also collected movement information from anglers who caught lake trout in lower Priest Lake that had been spaghetti-tagged in Upper Priest Lake. Although we did not use reward-tags in this study, they were clearly numbered and identified as Idaho Fish and Game tags.

Results

1997 Assessment

Netting-We netted a total of 121 lake trout (including recaptures) during the four sampling efforts, ranging in size from 190 to 980 mm. Lake trout were captured in several locations around the lake in depths ranging from around 8 to 30 m. Most lake trout were captured in depths greater than 10 m (Table 1). Bull trout were also collected in several locations around the lake and in all three depth zones, with no single zone exhibiting significantly higher catch rate than the others (Table 1; Chi-square test, alpha = 0.05). Bull trout catch rates were much lower than for lake trout, and were highly variable due to the low number of fish collected. There was a clear overlap in distributions of the two species based on gill-net catch and several sets contained lake trout and bull trout in the same net.

Angling-A total of 11 anglers (in six boats) participated in the two-day effort and logged a total of 100 rod hours. Twenty-five lake trout and 6 bull trout were caught, for catch rates of 4 and 16.7 h/fish, respectively, or a combined catch rate of 3.2 h/fish. Depth of catch overlapped between the two species with lake trout and bull trout both being caught at depths ranging from 17 to 31 m (Table 1). Bull trout and lake trout were caught using the same equipment and methods. With the exception of one bull trout which was caught by vertical jigging, all fish were caught by trolling with downriggers. Anglers collected an additional 42 lake trout and nine bull trout during the extensive angling efforts from May to November. An additional six lake trout were tagged during the extensive angling efforts.

The ratio of lake trout to bull trout varied between gill-netting and angling. From June through October, we captured 121 lake trout and 12 bull trout for a ratio of 10:1. The two day fishing effort in August resulted in a catch of 25 lake trout and six bull trout for a ratio of 4.2:1. Although this doesn't represent a significant difference in the ratios (Chi-square test, $p>0.1$), the inclusion of the catch from the extensive angling effort (42 additional lake trout and nine bull trout) does indicate that bull trout are caught at a significantly ($p<0.05$) higher rate by angling (4.5:1) than by gill-netting (10:1).

Combined Mark and Recapture-The total number of lake trout collected by gill-netting and angling was 152. One-hundred and twelve of these fish were tagged, and five were subsequently recaptured. Based on the mark-recapture estimate, the total population of lake trout greater than 320 mm TL at the time of the October sampling effort was 701 fish (95% confidence range of 346 to 1,417). Using the length frequency of all gill-netted lake trout, we estimated the portion of the lake trout <320 mm to be approximately 25%. We therefore added 25% to the mark-recapture estimate for a total population estimate of 878 fish (95% CI of 466 to 1,913 fish).

The total number of bull trout collected by gill-netting and angling was 20, with only one recapture. This was insufficient to conduct a mark-recapture population estimate for bull trout. Bull trout ranged in size from 190 to 730 mm. As with lake trout, on average, bull trout caught by angling were larger than those gill netted. We collected few juvenile bull trout, and comparison with gill-net data from 1956 indicates a much smaller proportion of juvenile bull trout in the population than in the previous survey (Figure 2). Gill-net effort was similar in these two studies with regard to time, location, and depth of sets. Although we don't have sufficient data to compare the current and historical estimates of population size, the marked shift in size frequency between the 1957 and 1997 efforts may indicate a lack of recruitment.

Experimental Lake Trout Control

We removed a total of 776 lake trout from Upper Priest Lake prior to November, 1998. Lake trout ranged in size from 150 to 1000 mm (TL), with a median size of 400 mm (Figure 3). Total weekly catch of lake trout was fairly constant (Table 2), although we did observe a decline in standardized catch rates throughout the season. The switch to larger nets in week 6 led to an immediate increase in catch rates, even after standardizing to 100 m^2 of net. Some of this may be the result of the improved efficiency of the larger nets which were used from week 6 through week 10, resulting from fish being less likely to swim around or over these nets than the smaller nets.

We used the standardized gill-net catch to standardize the total weekly catch (fish/hr/100m^2 gill-net * 72 net hours). We then conducted a depletion population estimate using the total number of fish removed to form a depletion trendline. Because of the apparent improved efficiency of the larger nets, we conducted separate depletion estimates for weeks 1-5 and weeks 6-10. As perceived in the field, the depletion trendlines indicate that the nets fished with different efficiencies. The increased slope of the line in the later weeks depict the improved efficiency and greater rate of depletion than the small nets (Figure 4). The total estimated population using depletion with the smaller nets was 743 ± 260 (95% CI). The depletion estimate using the larger nets was596 ± 120 (95% CI). Addition of the 321 fish depleted prior to week 6 raises this estimate to 917 fish, and indicates both types of nets yield similar estimates.

Throughout the 1998 effort, we collected 37 bull trout. As with the 1997 netting efforts, we saw a broad overlap in the habitats utilized by bull trout and lake trout. Of 35 nets which caught bull trout, 24 (69%) also contained lake trout. We were able to minimize bull trout mortality by netting only when surface water temperatures were <17°C, however, we did have three mortalities during the effort. We observed an increase in the ratio of bull trout to lake trout throughout the sampling weeks (Figure 5). Initially, we captured over 80 lake trout per bull trout, but by October, the ratio had declined to less than 20 lake trout per bull trout. These ratios are not unbiased, and likely overestimate the number of lake trout per bull trout, as we did attempt to minimize our catch of bull trout.

Lake Trout Movement

Nine of the 10 sonic tags implanted into lake trout transmitted signals that we were able to locate (the tenth tag was likely malfunctioning when it was implanted). Of the remaining nine tagged fish, we had no apparent mortalities following surgery. In the period from August, 1997 through October, 1998, at least two of the nine tagged fish have emigrated from Upper Priest Lake to Priest Lake. One of these fish was located in Priest Lake on October 2, 1997 nearly 16 km from where it had last been located in the upper lake, and by November 26, it had returned to Upper Priest Lake. The other fish remained in Upper Priest Lake through the 1997 telemetry effort, but was found in southern Priest Lake in June of 1998, where it has remained. An additional sonic tagged fish disappeared from Upper Priest Lake, and has not been located. Because of the size of Priest Lake, telemetry is logistically difficult and time consuming. The missing fish could very possibly be in the lower lake despite our inability to locate the signal. The remaining lake trout have moved throughout Upper Priest Lake since being tagged. Most of these fish exhibited no strong affinity to a particular area, but seem to travel widely throughout the lake. We saw no strong evidence of movement to, and congregation around a particular spawning site of sonic-tagged fish. However, we did not track fish during the night, when spawning aggregations may have formed.

Anglers reported three spaghetti-tagged fish in Priest Lake that had been tagged in Upper Priest Lake. Although three of 112 fish may not seem to be a meaningful percentage, it is important to realize that these are only the fish *caught and reported* in lower Priest Lake (no reward was indicated on spaghetti tags). Therefore, the three fish reported most likely represent a much larger percentage of lake trout that emigrated from Upper Priest Lake and were not caught (or were caught and not reported).

Discussion

The 1997 gill-netting and angling efforts confirmed the presence of a well established lake trout population in Upper Priest Lake. The size distribution of lake trout depicts a relatively young and expanding population. Many of the fish collected were currently, or soon would be, of reproductive age. The collection of numerous juvenile fish <300 mm suggests lake trout have reproduced successfully in Upper Priest Lake. The effects on the bull trout population are, thus far, largely speculative; however, the historical collapse of the bull trout population in Priest Lake, may portend a similar situation in Upper Priest Lake. Although we have insufficient estimates of current and historical population size to draw meaningful conclusions, the marked shift in size frequency between the 1957 and 1997 efforts suggests a lack of juveniles. For these reasons, we believe the expanding lake trout population is an immediate threat to the persistence of the bull trout population in Upper Priest Lake. Aside from no-action, the two available alternatives for 1998 were 1) to open an unrestricted fishery for lake trout in Upper Priest Lake, and 2) begin a gill-netting removal program.

Use of a Sport Fishery

Since 1994, Upper Priest Lake has been managed as a catch-and-release fishery. The harvest restriction was implemented to protect fragile cutthroat and bull trout populations. No significant lake trout fishery existed and very few were harvested in the upper lake prior to 1994. Currently, few serious anglers fish Upper Priest Lake. The lake is primarily used by boaters, hikers, and canoeists. Initially, the current regulations prohibiting lake trout harvest on Upper Priest Lake combined with their apparent threat to bull trout advanced the notion that anglers could contribute to lake trout control measures. The angler catch composition represented in this assessment, however, suggests angling is not an ideal means to reduce the lake trout population without creating an additional threat to bull trout. Inasmuch as the ratio of bull trout to lake trout was higher with angling than with gill nets, there was little evidence that a recreational fishery can be used to selectively harvest lake trout. Instead the evidence suggests the opposite, that bull trout have a relatively higher capture rate than do lake trout. Because anglers were unable to specifically target lake trout over bull trout, limiting angling related mortality of bull trout is a concern, particularly because it appears the largest, most fecund bull trout have the greatest probability of capture. The potential for hooking mortality and misidentification led us to conclude that the risks of utilizing recreational anglers to reduce the lake trout population would outweigh the benefits.

Use of Gill-Nets

The progressively declining catch rates and the concurrent improvement in the lake trout:bull trout ratio, demonstrate that the 1998 gill-netting was successful in removing a significant portion of the lake trout population in Upper Priest Lake, while minimizing negative impacts to the bull trout population. Unfortunately, using recovery of the spaghetti-tagged fish as a measure of our success, depicts a less successful effect. The 1997 population of 466-1,913 fish (estimated with mark-recapture), and the 1998 population of 483-1,002 fish (based on removal) both indicate that removal of 776 lake trout should have represented a very sizeable reduction in the population. In fact, we would have removed between 41 and 100% of the population, and should have recovered 45 to 112 of the spaghetti-tagged fish. To date, we have recovered only 13. Similarly, we have recaptured only 3 of the 10 sonic-tagged fish.

Several possibilities may explain the poor recovery rate of tagged fish. First, the tagged fish may have had a much higher mortality. We do not believe this is the case, however, because of the high survival (90-100%) of sonic tagged fish, which were also spaghetti-tagged. Second, the tags may be tearing or falling out. Again, we believe this is unlikely. We have examined lake trout for scars or sores, and we have seen no evidence of tag loss. Furthermore, the two sonic tagged fish that were recovered both had retained the spaghetti tags. We believe the most plausible explanation is movement of lake trout between Upper Priest and Priest lakes. Emigration of tagged fish combined immigration of untagged fish could greatly skew the tag recovery rates, as well as explain the apparent increase in population from 1997 to 1998.

Movement of sonic and spaghetti tagged lake trout demonstrates that lake trout migration between Upper Priest Lake and Priest Lake is common. Emigration of two to three of the nine sonic tagged fish indicates that a significant portion of the fish marked in Upper Priest Lake in 1997 are now in the lower lake. This is somewhat confirmed by angler spaghetti-tag returns. We consider the documented number of fish traveling between the lakes to be a minimum estimate. Because of the irregularity of telemetry in 1998, additional sonic tagged fish may have traveled between the lakes at times when no monitoring was being conducted.

The efficacy of a lake trout reduction program in Upper Priest Lake is largely based on the assumption of a relatively closed population. The slow growth and late age-at-maturity of lake trout make them easily over-exploited (Healey 1978), and imply that removal of mature fish could precipitate meaningful population reduction. Prior to the 1998 effort, however, we were well aware that recruitment to the population of mature Priest Lake immigrants could easily offset gains made by removal of Upper Priest Lake fish. Unfortunately, the results of the 1998 netting effort and the movements of tagged fish indicate that the Upper Priest Lake and Priest Lake represent a single, open population.

Options for eliminating or minimizing recruitment from the lower lake are limited, complex, and controversial. The most ambitious (and most controversial) alternative would be to attempt to collapse the lake trout population in Priest Lake as well as Upper Priest Lake. Aside from social implications, the feasibility of such a project is questionable. Priest Lake is nearly 9,500 ha, or roughly 17 times the size of Upper Priest Lake. Although commercial methods used in the Great Lakes have been proven to be very efficient and capable of severely depressing lake trout populations (Healey 1978), such a project may be cost prohibitive. The second alternative is to utilize a weir or other fish passage barrier in the Thorofare to prevent immigration to Upper Priest Lake. Although this may seem simple, there are many social and biological implications to this alternative as well. Upper Priest Lake is a very popular boating site. Canoeists, kayakers, and hikers, have unsuccessfully lobbied to restrict motor boats from Upper Priest Lake in the past. Any structure preventing boat passage may be very unpopular with many recreationists as well as local governing officials. Furthermore, the Thorofare is likely a passage corridor for westslope cutthroat trout, bull trout, mountain whitefish, and other native fish, and the potential for negative impacts of a migration barrier to these populations will need to be considered.

Table 1. Depth of catch of lake trout and bull trout collected by gill-netting and angling from June through October, 1997 in Upper Priest Lake, Idaho.

	Lake trout		Bull trout	
Depth Zone	Gill-nets	Angling	Gill-nets	Angling
1 (<10 m)	12	3	6	4
2 (10-20 m)	67	17	4	0
3 (>20 m)	40	6	4	2

Table 2. Gill-net effort, standardized effort (to 100 m^2 of gillnet), fish caught and standardized catch rates of lake trout and bull trout from Upper Priest Lake, Idaho in 1998.

			Lake trout		Bull trout	
Week	Set hours	Standardized	number	fish/100 m^2/hr	number	fish/100 m^2/hr
Jun 8-10	79.8	66.7	83	1.24	1	0.01
Jun 15-17	71.9	60.1	60	0.98	1	0.02
Jun 22-24	82.7	69.1	90	1.30	3	0.04
Jun 30-Jul 1	61.1	51.1	35	0.69	1	0.02
Jul 7-9	76.5	64.0	53	0.83	2	0.03
Jul 13-15	53.2	116.7	132	1.13	5	0.04
Sep 21-24	37.2	81.6	163	2.00	11	0.13
Sep 28-30	32.1	70.4	62	0.88	10	0.14
Oct 13-15	32.1	70.4	56	0.80	3	0.04
Oct 19-21	31.2	68.5	42	0.61	2	0.03

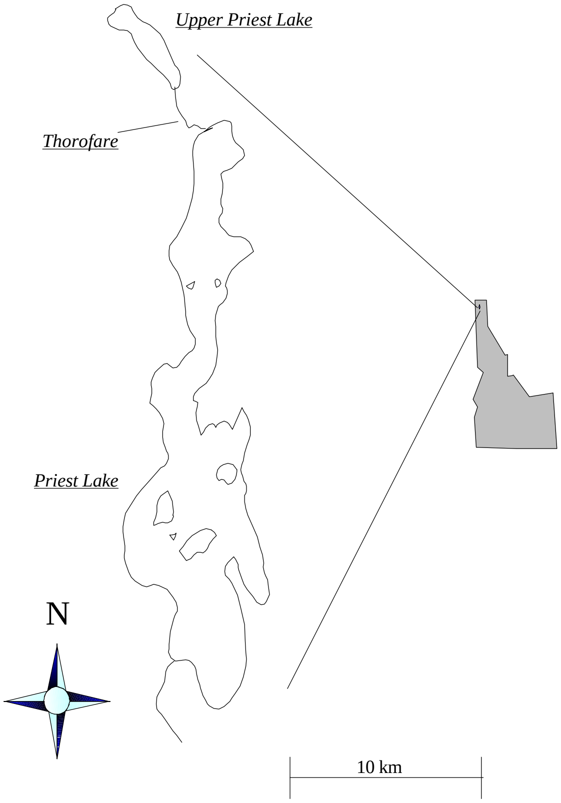

Figure 1. Location of Upper Priest Lake, the Thorofare, and Priest Lake, Idaho.

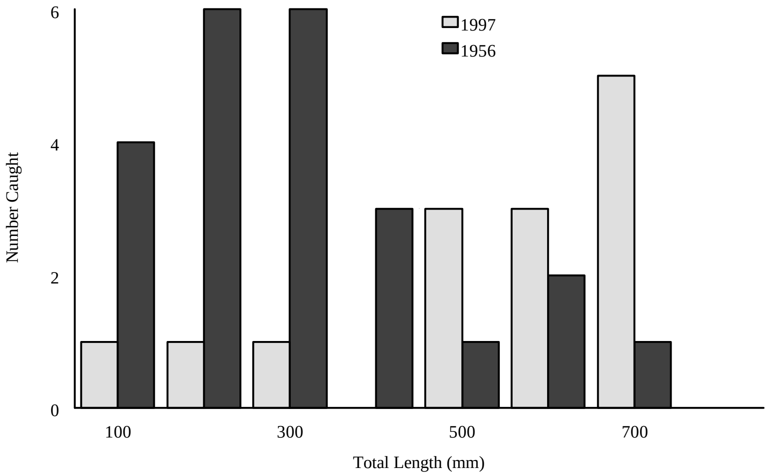

Figure 2. A comparison of the length frequency distribution of bull trout collected by gillnetting in Upper Priest Lake, Idaho, in 1956 (Bjornn 1957) and 1997.

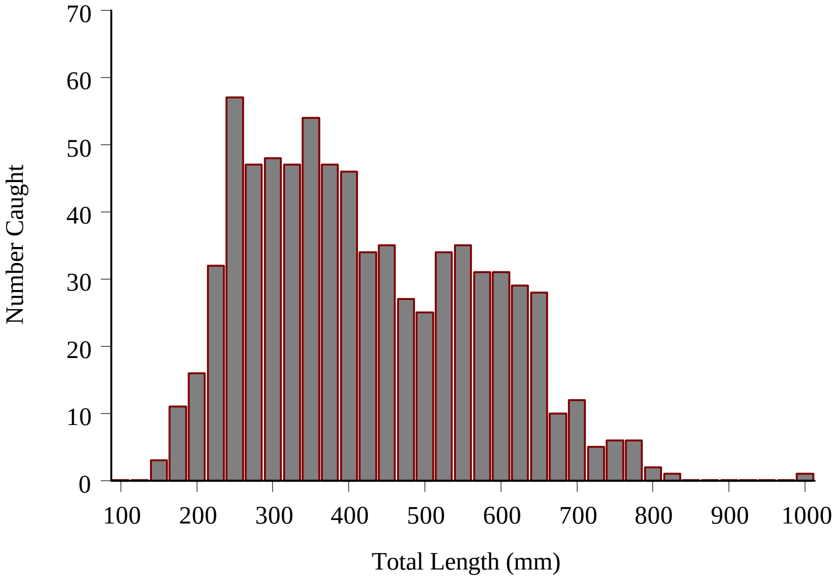

Figure 3. Length frequency distribution of lake trout collected by gillnetting in Upper Priest Lake, Idaho, from June through October. 1998.

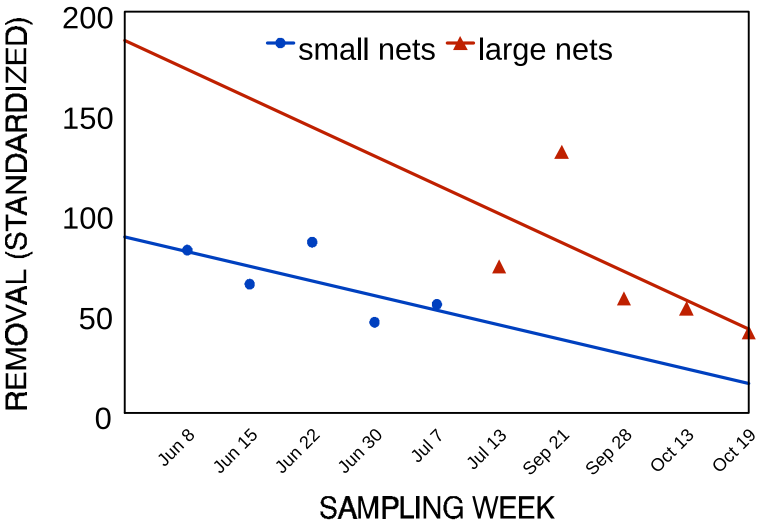

Figure 4. **Standardized weekly catch of lake trout from Upper Priest Lake, Idaho and depletion trendlines fit to small gill-nets (June 8-July7) and larger gill-nets (July 13-October 19).**

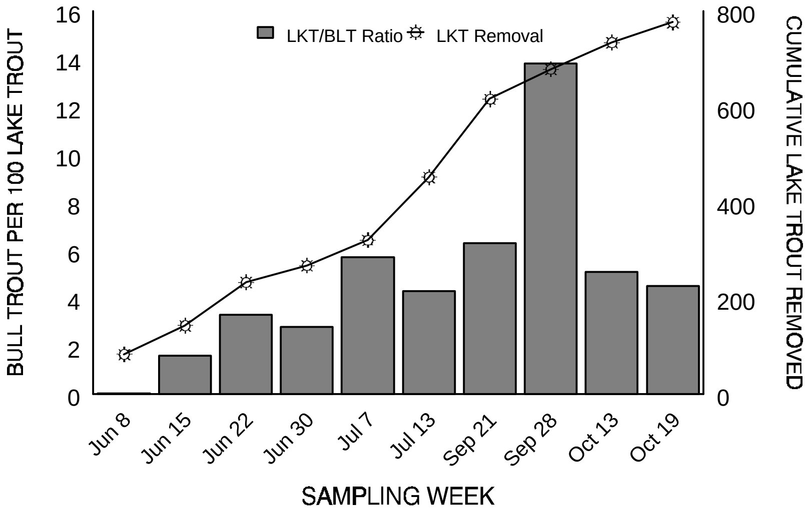

Figure 5. **The ratio of lake trout to bull trout captured in gill-nets (Y1 axis), and the cumulative number of lake trout removed (Y2 axis) from Upper Priest Lake, Idaho in 1998.**

Acknowledgements

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Biological and Social Impacts of the Illegal Introduction of Northern Pike into Northern Idaho

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Northern pike: deadly predator or trophy sport fish? The illegal introduction of northern pike into northern Idaho created a no win situation for fishery managers. It was feared that northern pike would be the final blow for the severely depressed cutthroat population in Coeur d'Alene Lake. The ease at which anglers established new populations posed a threat to waters throughout Idaho, but the ability to control or eliminate pike populations was marginal at best. On the other hand, northern pike created a new sport fishery for large, easy to catch fish that were good to eat. This paper briefly discusses the biological and social considerations that were used to shape management direction for northern pike in Idaho.

Exotic fish species have played a major role in shaping sport fishing opportunities in the lowland lakes of northern Idaho. Historically, the only game fish species present were westslope cutthroat trout, bull trout and mountain whitefish. Many smaller lowland lakes were probably barren or populated with native nongame species before exotic game fish were introduced. Stocking by the former U.S. Fish Commission at the turn of the century established largemouth bass, black crappie, yellow perch, pumpkinseed sunfish, brown and black bullhead, tench, lake trout, brook trout, rainbow trout and lake whitefish. Idaho Fish and Game added to the mix with rainbow and brown trout, kokanee and chinook salmon, splake (lake trout/brook trout hybrid), bluegill, tiger muskie (northern pike/muskellunge hybrid), smallmouth bass and channel catfish. One species that was not intentionally introduced, however, was the northern pike. The illegal introduction of northern pike and establishment of viable populations in the panhandle of northern Idaho resulted in significant changes to existing fish populations and sport fisheries.

Northern pike were first discovered in northern Idaho in 1974 at two locations. A single fish was collected by Idaho Fish and Game personnel in the Clark Fork River below Cabinet Gorge Dam near the Idaho/Montana border and an angler reported catching a northern pike in Cave Lake, Coeur d'Alene Lake system. The Cave Lake population came from a reported illegal release of 12 fish hauled over from Lone Pine Reservoir, lower Flathead River drainage, Montana in 1972. Lone Pine Reservoir was the original site for the illegal establishment of northern pike in Montana in 1953 (personal communication, Jim Vashro, Montana Fish Wildlife and Parks). Cave Lake is one of eight "Lateral" lakes directly connected to the Coeur d'Alene River and to Coeur d'Alene Lake (31,500 surface acres). Colonization of the entire Coeur d'Alene/ Lateral Lake system occurred relatively rapidly and was no doubt aided by anglers transporting fish in boat livewells. By the mid 1980's, northern pike were firmly established throughout the entire Coeur d'Alene system, and they were beginning to show up in other disjunct lowland lakes.

Once established, northern pike created a highly desirable sport fishery unique in Idaho. Anglers formerly from Midwestern states had something familiar to fish for and many native Idaho anglers were experiencing northern pike fisheries for the first time. The aggressive feeding behavior of northern pike provided anglers with a fish that was relatively easy to catch at virtually all times of the year. The white flaky meat of northern pike was also considered prime eating, despite their numerous Y bones. Northern pike were harvested primarily by bait anglers during the spring and through the ice in the winter, and by lure anglers during the summer and fall. Most northern pike anglers were harvest oriented and anything over about 16 inches was considered fair game. Other pike anglers fished strictly for trophy fish and they became a very vocal special interest group. An angler effort estimate in Cougar Bay (Coeur d'Alene Lake) during a three week period during the spring fishery was 14,685 hours in 1991 (Nelson et. Al. 1996). The prespawn bait and bobber fishery allowed both boat and bank anglers of all skill levels the opportunity to catch trophy sized pike (typically unspawned females over 20 pounds) and new state record fish were being caught each spring. The existing 38 lb. 9 oz., 49 inch fish was caught in April of 1992; an 8 year old unspawned female.

The Coeur d'Alene Lake northern pike fishery was being compared to catch-and-release fisheries in the Northwest Territories in terms of the trophy fish being caught. Trophy pike anglers demanded seasons to end the "slaughter" occurring during the prespawn bait and bobber fishery and winter meat fishery. They also pushed for a one or two fish bag limit and high minimum size limit in hopes of maintaining this unique trophy fishery.

Trout anglers, on the other hand, demanded the game fish status of pike be removed and mandatory kill regulations be implemented. They were concerned about the predatory impact of northern pike on trout fisheries and the continued spread of pike to other waters from illegal introductions. Cutthroat trout in Coeur d'Alene Lake had already been compromised by the significant loss of spawning and rearing habitat in tributary streams and the establishment of non-native salmonids and warmwater species. Northern pike created an additional threat to cutthroat from predation. Adult cutthroat migrate through weedy bays on their way to and from spawning streams from April through June. Juvenile cutthroat are vulnerable in these same areas during early June when their stream rearing is completed at age 1 to 3 and they migrate to the lake.

Northern pike created a “no win” situation for fishery managers. Idaho state management direction gives priority to native species; adfluvial westslope cutthroat trout being the primary species of concern in the Coeur d'Alene Lake system. There was no biological data quantifying the predatory impact on cutthroat or the potential benefit to cutthroat from northern pike suppression efforts. Elimination of northern pike from the Coeur d'Alene Lake system was also not possible due to their high reproductive potential and complete distribution throughout a very large area.

It was also not possible to sustain a trophy northern pike fishery. The phenomenal fishery that existed in the late 1980's and early 1990's was the result of a fish invading a vacant niche and relatively low angler exploitation. Trophy pike management in other states typically involves eliminating nearly all harvest opportunity to allow some fish to reach an old age. Protecting pike from harvest would increase pike numbers, resulting in slower pike growth and putting other game fish populations at risk as predation increased.

Management direction for northern pike at that time called for maximum harvest opportunity to maintain pike populations at low densities. It was reasoned that impacts on other fish species would be reduced and northern pike growth rates would remain high. Trophy fish would still be available, but in far fewer numbers, due to the large size of Coeur d'Alene Lake and the ability of some fish to escape harvest long enough to reach trophy size.

Threats were being made by some pike anglers to spread northern pike to all lowland lakes in the region due to the Departments bias against pike. Fishing regulations on northern pike were hotly debated during the 1988-89 regulation setting process. Minimum size limits and seasons were not considered, but a three fish bag limit was proposed based on angler opinion surveys and the experience of other states. Angler opinions continued to influence the process and the Fish and Game Commission ultimately approved a five fish northern pike bag limit and a five pole (tip-up) limit while ice fishing were implemented in 1988.

The five fish limit had no biological effect because most anglers rarely caught five fish. Socially, however, pike anglers felt that some limit was better than no limit and demands for trophy pike management and the vocal threat to illegally spread northern pike to other waters diminished. The five rod (tip-up) limit for ice anglers was, however, an important management tool in allocating limited ice fishing space. Historically, some anglers would set out as many as 50 tip-ups per angler excluding most other anglers from the most productive fishing areas.

Management changes were also made in 1988 to improve adfluvial cutthroat populations. Harvest opportunity was significantly reduced by the seasonal closure of several “hot spot” fisheries where cutthroat were concentrated and vulnerable. A drainage wide 1 over 14 inch harvest rule was implemented to reduce angler exploitation. Catch-and-release fisheries were established in headwater areas.

A comprehensive two year study was finally funded in 1989 and 1990 to evaluate the population dynamics, food habits, movement and habitat use of northern pike in the Coeur d'Alene Lake system (Rich 1992). Adult northern pike densities were some of the lowest reported in the literature, whereas somatic growth rates and condition factors were some of the highest. Angler exploitation was high and directly proportional to accessibility of the water fished. High growth rates of pike were directly related to low densities. Low densities were initially the result of northern pike colonizing a vacant niche, but high angler exploitation also played an important role.

Radio tagged northern pike indicated a strong preference for habitat associated with the aquatic macrophyte beds of *Potamogeton* and very limited movements through deep, unvegetated lacustrine habitats. Prey selection varied seasonally and with local availability of prey. Yellow perch were the most important prey item numerically, but salmonids and catostomids were the most important by weight. Adfluvial westslope cutthroat trout were selected for by northern pike. Estimates for cutthroat trout consumption in Cougar Bay of Coeur d'Alene Lake ranged from 2,500 to 4,200 trout for a population of northern pike ranging from 600 to 1,000 fish.

It appeared that concerns about predation on native cutthroat trout were justified. Harvest estimates of cutthroat trout in the mouth of the Spokane River just around the corner from Cougar Bay were in the

2,500 to 4,000 fish range before this fishery was closed in 1988. All the gains made by reducing angler harvest were essentially eaten up by northern pike. Cutthroat trout did not respond to the protective regulations, but they continue to persist at low levels.

Poor habitat conditions in tributary streams appear to be far more important than northern pike predation in regulating overall cutthroat trout abundance, however. Cutthroat populations in tributaries to Wolf Lodge Creek on the north end of Coeur d'Alene Lake range from poor to good depending on the quality of rearing habitat present. Cutthroat spawners and juvenile migrants from all the various tributaries are subject to the same level of northern pike predation in Wolf Lodge Bay. Habitat condition is the primary limiting factor, but northern pike play an important role in suppressing an already depressed cutthroat population.

Illegal introductions of northern pike in other panhandle region lakes continued. Northern pike travel well in boat livewells and their high fecundity (9,000 eggs per pound of female) and good spawning success with few individuals make them easy to establish. The establishment of northern pike in Hayden Lake, a popular quality trout and bass fishery, in 1994 caused a public furor and renewed demands for the eradication of northern pike from all panhandle waters. The five fish limit on northern pike was removed on Hayden Lake in 1996 and harvest was encouraged. Creel checks still indicated that most anglers were catching fewer than five pike daily. A "no limit" rule may not be biologically effective, but it does seem to have important social implications. Promoting pike harvest has focused an intense winter ice fishery on Hayden Lake that may be helping to keep the pike population from becoming overabundant.

Northern pike recruitment appears to be controlled by natural factors, rather than angler harvest. High natural mortality of eggs and newly hatched larvae is primarily related to water level and temperature fluctuations during the spring spawning season. Predation by other warmwater species on pike eggs and larvae may also play a role in some lakes. Elimination of northern pike is therefore not a realistic management option and the best we can hope for is maintaining pike populations at low densities by encouraging angler harvest.

Realistically then, the most effective management tool for northern pike in northern Idaho is essentially been no management. The five fish bag limit on northern pike is not regulating harvest and therefore has no biological effect. The social impact of a five fish bag limit is unquantifiable, but it appears to have created a tolerable situation for both trout and pike anglers. Going back to no bag limit on northern pike would likely renew the concerns of pike anglers about their fishery resource being mismanaged and possibly encourage a new round of illegal introductions, without having any positive effect on trout populations. For better or worse, northern pike are here to stay in northern Idaho, and their presence will be factored into native species management decisions.

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Regulations: A Tool in Native Fish Management

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Abstract- *The future of fish management may be directed at deciding how we undo forty years of good intentions. I say good intentions because at the time the decisions were made based on the rules and values of the times. Today the Endangered Species Act and public involvement are on the top of our list of fish management tools. This presents today's manager the opportunity to think out of the "box". We need to use regulations that will not protect species but help illuminate them or at least reduce their numbers.*

* Joe chose to have only the abstract of his talk published in the Proceedings.

The effect of striped bass predation on recovery of the endangered Sacramento River winter chinook: A Bayesian population viability analysis

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Abstract- *Enhancing the Sacramento River striped bass population poses a potential threat to the endangered winter chinook salmon. In order to assess the risk of a striped bass stocking program, a Bayesian population dynamics model for winter chinook was developed that includes the effect of predation by striped bass. A prior distribution for striped bass predation rate was developed by applying a Bayesian hierarchical model to published stomach contents data. After fitting the population dynamics model to winter chinook spawning escapement data, the model was used to examine the influence of striped bass population size on the probability of winter chinook extinction and recovery. The model suggests a striped bass population stabilization program would increase winter chinook extinction risk only slightly, but increasing the population of adult striped bass from 700,000 to 3 million would more than double extinction risk.*

Background

The Sacramento River system is home to a variety of native and non-native fishes, including the endangered winter chinook salmon (*Oncorhynchus tshawytscha*) and the introduced striped bass (*Morone saxatalis*). Winter chinook were fairly abundant as recently as the late 1960s, but have declined dramatically since then (Fig. 1). Many causes for decline have been identified, including habitat loss, high water temperatures, inadequately screened water diversions, and predation (NMFS, 1997). Winter chinook were listed as an endangered species under the federal Endangered Species Act in 1994. The listing requires state and federal agencies to consult with the National Marine Fisheries Service (NMFS) if their actions might result in take of winter chinook.

Striped bass were introduced to the San Francisco Bay/Delta in the late 1800s. The population grew to support a commercial and recreational fishery in the early part of this century. Since the mid 1960s, both winter chinook and striped bass populations have declined (Fig. 2), in part, due to the operation of the State and Federal water projects. In 1986, the California Department of Water Resources and California Department of Fish and Game (CDFG) agreed on the mitigation requirements for expansion of the State's pumping capacity at the Harvey O. Banks Pumping Plant. Pursuant to this agreement the State is encumbered with an obligation to mitigate the effect of the pumps on fishery resources including striped bass. The CDFG would like to direct this mitigation program to ensure continued sport fishing opportunities by net-pen rearing striped bass salvaged at the State and Federal water pumping facilities. These fish would be released back to the river at age 1 or 2, when they are less vulnerable to water diversions. Because striped bass prey on chinook salmon, CDFG needs an incidental take permit from NMFS to implement any striped bass augmentation program. NMFS must determine that the proposed project does not jeopardize the continued existence of winter chinook before issuing the incidental take permit. This paper describes an analytical approach for determining the impact of striped bass stocking on winter chinook extinction risk and recovery probability.

Methods

Addressing the jeopardy question requires an assessment of how a proposed action will alter the probability that the endangered species will persist. Population viability analysis (PVA) is commonly used to quantify the impact of changes in survival rates on the probability of population persistence (Beissinger and Westphal, 1998). At the heart of a PVA is a population dynamics model. In this case, we used an age-structured process-error stock-recruitment model for predicting winter chinook spawning escapement to assess how changes in striped bass abundance alter extinction and recovery probabilities.

Assessing the impact of striped bass stocking on winter chinook requires answering two questions: (1) how many salmon do striped bass eat; and (2) how do changes in striped bass abundance change the probability of winter chinook extinction or recovery. We used Bayesian statistical methods to address these questions, because they allow us to incorporate disparate data sets into the analysis and express predictions about future population changes in terms of probability distributions that include uncertainty arising from limited data.

Relevant data include published striped bass food habits studies performed in the Sacramento River system, estimates of striped bass abundance, estimates of chinook abundance and survival, and estimates of winter chinook spawning escapement. Food habits data were modeled hierarchically (Gelman et al. 1995) to estimate the number of juvenile salmon that each striped bass consumes per day. Chinook abundance and survival information was used to estimate the number of juvenile chinook that could be vulnerable to striped bass predation. Together, these estimates were used to generate a probability distribution for the per-bass predation rate. This distribution was used as an informative prior distribution in the population dynamics model. Winter chinook population data were used to fit a population dynamics model that includes striped bass predation; striped bass abundance was a covariate.

The winter chinook population dynamics model has a form similar to that used by Botsford and Brittnacher (1998), except that the natural log of the growth rate parameter is the sum of several components. These include an underlying population growth rate in the absence of striped bass predation, a striped bass predation effect that is a linear function of striped bass abundance, a density-dependent term, a process error term representing environmental variation, and an effect of major protective actions that were taken to protect winter chinook starting in 1989. Uninformative prior distributions were used for all parameters except the striped bass predation rate parameter.

The model was fit to the winter chinook escapement data using the Sample-Importance Resampling algorithm, producing a joint posterior probability distribution for the model parameters. The posterior distribution was then used with the population dynamics model to simulate the behavior of the winter chinook population under varying levels of striped bass predation.

Analysis of the striped bass stocking plan

CDFG put forward three plans for consideration: a no-action plan, where the adult striped bass population is expected to decline to around 512,000; a stabilization plan, where the adult striped bass population is kept at 700,000 adults; and a more ambitious augmentation plan, where the adult striped bass population is increased to 3,000,000 adults. The likely impact of these plans was evaluated by using the winter chinook population model with the posterior parameter distributions and the various levels of adult striped bass. For each plan, the probability of reaching the quasi-extinction threshold (defined as less than 50 spawners in three consecutive years) and the recovery threshold (defined as more than 20,000 spawners) was computed over a 100-year time horizon. Results are shown in Figure 3.

If no striped bass stocking were to occur, the model predicts that winter-run chinook have a 20% chance of quasi-extinction within 50 years, and a 46% of recovering to 20,000 adults. While most conservation biologists would view a quasi-extinction probability of 20% as uncomfortably high, it is much lower than the certain extinction predicted by a model assuming constant intrinsic growth rate (Botsford and Brittnacher, 1998). The more optimistic prediction is due mostly to the substantial probability that mean population growth rate has increased since winter chinook were listed under the ESA. The decline of the adult striped bass population to 512,000 from 700,000 contributes only a small effect to increased survival probability.

If a striped bass stocking program were conducted such that the striped bass population was stabilized at 700,000 adults, the probability of quasi-extinction in 50 years would rise from 20% to 21%, and the probability of recovery would decline from 46% to 44%. An adult striped bass population of 3,000,000 would have a 52% chance of causing winter-run chinook quasi-extinction and an associated recovery probability of 19% over the 50 year time horizon. If, on the other hand, striped bass predation could be completely eliminated, the probability of quasi-extinction would decline to 16% and the probability of recovery would rise to 52% at the 50-year time horizon. These analyses indicate that while striped bass predation contributes significantly to extinction risk, winter chinook would still be at risk even in the absence of striped bass.

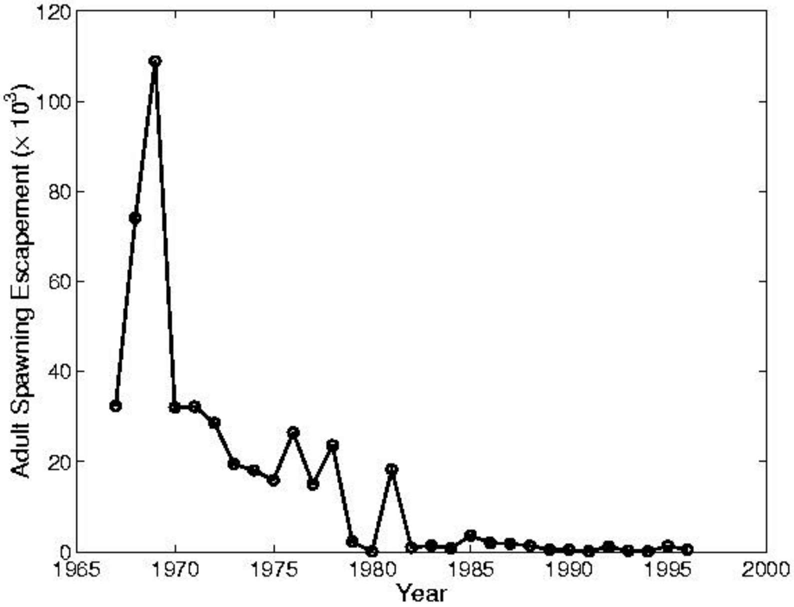

Figure 1. Winter chinook adult spawning escapement (age 3 and 4).

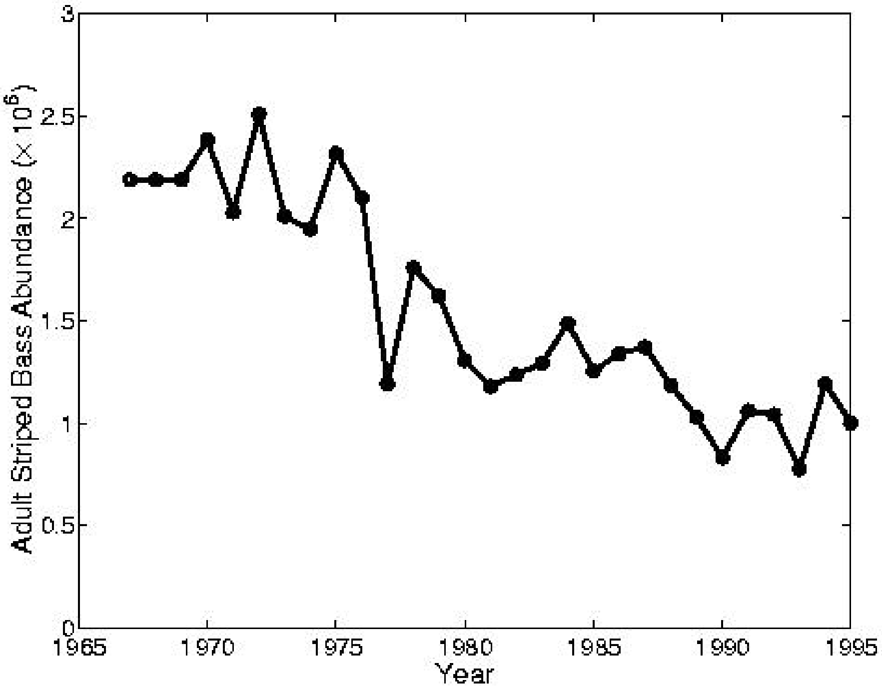

Figure 2. Adult striped bass abundance in the Sacramento-San Joaquin rivers and estuary (age 3+).

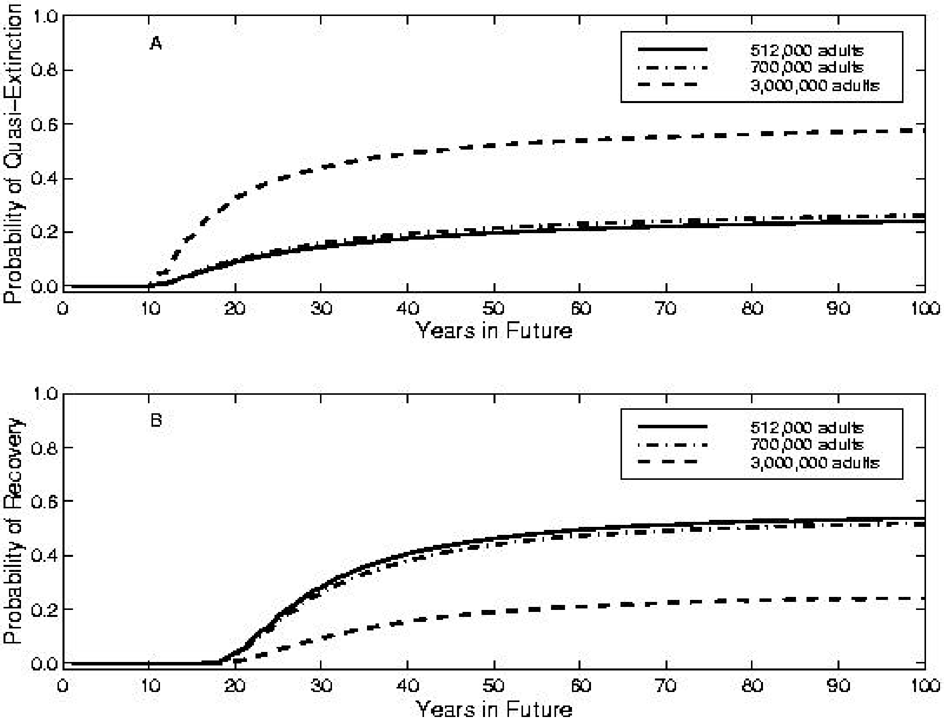

Figure 3. Probilities of winter-run chinook quasi-extinction (A) and recovery (B) under different adult striped bass population sizes.

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Management of Aquatic Plants in Washington State Using Triploid Grass Carp

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Introduction

Triploid grass carp *Ctenopharyngodon idella* were legalized for aquatic macrophyte control in Washington state in 1990. Since then, numerous lakes and ponds have been stocked with these fish to control nuisance aquatic vegetation. Although intensive studies have examined a few individual lakes and ponds (Bonar 1990, Pauley and Bonar 1995, Scherer et al. 1995), little work has been done to assess their efficacy statewide since their legalization.

Several questions regarding the use of grass carp for management of aquatic macrophytes in the Pacific Northwest remain unanswered. These include their ability to control, but not eliminate all submersed macrophytes when used under routine management conditions; the suitability of the current grass carp stocking rates used in Washington; effects of grass carp on water quality parameters statewide; and public satisfaction associated with grass carp introductions. To investigate some of these questions, we conducted a statewide survey of the effects of tripod grass carp on public satisfaction, aquatic macrophyte communities and water quality of 98 Washington lakes and ponds stocked between 1990-1995.

Methods

Aquatic plant coverage maps, and interviews with biologists and landowners provided pre-stocking data on the abundance of aquatic plants in each lake. For post-stocking effects, we conducted a rapid assessment of current macrophyte community status and selected water quality parameters during the peak of the aquatic macrophyte growing season between July 19 and August 22, 1995. We visually estimated current surface macrophyte coverage in the same manner as was done for the permit maps before stocking. We also used recording fathometers to assess submergent plant volume (Thomas et al. 1990). Lakes were separated into three categories based on the degree of macrophyte control: those where macrophytes were completely eliminated 2-5 years following stocking; those where macrophytes were controlled to an intermediate level 2-5 years following stocking, and those where little or no macrophyte control was observed. We measured chlorophyll α, total turbidity, secchi depth, alkalinity and water color to assess differences in water quality between lakes which experienced the three levels of aquatic plant control. We also interviewed landowners to evaluate their overall satisfaction with the grass carp treatments.

Results and Discussion

Noticeable effects of grass carp on macrophyte communities did not take place in most waters until two years following stocking. After two years, submersed macrophytes were either completely eradicated (39% of the lakes) or not controlled (42% of the lakes) in most lakes. Control of submersed macrophytes to intermediate levels occurred in 18% of lakes at a median stocking rate of 24 fish per vegetated surface acre. Most of the landowners interviewed (83%) were satisfied with the results of introducing grass carp. Average turbidity of sites where all submersed macrophytes were eradicated was higher (11 nephelometric turbidity units [NTU's]) than at sites where macrophytes were controlled to intermediate levels (4 NTU's) or unaffected by grass carp grazing (5 NTU's). Most of this turbidity was abiotic and not algal. Chlorophyll α was not significantly different between levels of macrophyte control.

Triploid grass carp were a popular aquatic plant control option, and effectively grazed most submersed macrophyte species found in Washington state. However, calculating stocking rates based on landowner estimates of aquatic plant coverage rarely resulted in intermediate levels of aquatic plant control, even when that was the objective. Most stockings resulted in either eradication or little control of aquatic plants. Additionally, the effects of particular stocking rates varied considerably. We recommend grass carp not be used in waters where complete submersed plant eradication or elevated turbidity cannot be tolerated. However, in those sites where aquatic plant eradication is acceptable, grass carp can be effective and popular.

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Effects of Grass Carp on Warmwater Fish and Coho Salmon in Devils Lake, Oregon

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Introduction

Devils Lake is a 678 acre natural lake on the north-central Oregon Coast. It has a drainage area of 24 square miles and an average depth of 10 feet (maximum depth 22 feet). The lake is highly eutrophic and is situated in a maritime climate immediately adjacent to the ocean.

Fish resources within the lake and the associated drainage basin include native populations of coho salmon, cutthroat and steelhead trout. In addition, warmwater gamefish including largemouth bass, bluegill, black crappie, yellow perch and brown bullhead have been present since their introduction early in the century. Warmwater gamefish were eradicated from the lake in 1959 when the lake was treated with rotenone to remove European Carp. The treatment resulted in elimination of European carp, but warmwater gamefish that were present before treatment were soon re-introduced. The lake has been stocked with catchable size rainbow trout for many years and currently receives 24,000 rainbow trout each spring at a size of 3 fish per pound.

Sterile triploid grass carp were introduced into the lake in 1986 (10,000 stocked) and 1987 (17,000 stocked) as part of a program initiated by area residents to restore water-based recreation. Recreational use of the lake had been severely curtailed by an invasion of exotic aquatic macrophytes that covered most of the lake's surface area.

Effects of grass carp during the six years following initial introduction in 1986 were evaluated in two studies (Thomas et. al., 1989 and CH2M Hill, 1994.). These studies looked at response of aquatic vegetation, water quality and fish assemblages to the grass carp introduction. They determined that:

1. Aquatic macrophytes remained abundant during this time frame.
2. Water quality was variable with no clear effect from grass carp.
3. Fish populations were variable with no clear effect from grass carp.

In response to the still abundant aquatic macrophytes, an additional 5,000 grass carp were stocked in 1993. By 1994, essentially all aquatic macrophytes disappeared from the lake (Systma, 1996) and have not re-established as yet.

This report summarizes and discusses recent trends in the fish resources of Devils Lake since grass carp introduction, with emphasis on the years following macrophyte elimination. Information on Devils Lake fish resources during recent years has been collected primarily by ODFW and includes:

1. Annual electrofishing of the lake during the spring and fall.
2. Gillnet sampling at irregular intervals.
3. Catch information from bass fishing tournaments.
4. Annual adult coho salmon spawner counts in Rock Creek.

Results

Warmwater gamefish have declined sharply since aquatic macrophytes were eliminated from Devils Lake in 1994. This decline appears to have occurred in all introduced warmwater gamefish including largemouth bass, bluegill, yellow perch, black crappie and brown bullhead.

Largemouth bass

The largemouth bass population in Devils Lake is currently characterized by a moderate abundance of large fish in combination with seasonally abundant young of the year bass (Tables 1 and 2, Figures 1 and 2). Fish within the 7 to 14 inch size range are present in very low abundance. Young of the year bass observed in fall electrofishing are essentially gone by the following spring. The mechanism causing the poor over winter survival of small bass is not known. It is hypothesized that in the absence of aquatic macrophytes, the small largemouth bass are vulnerable to heavy predation by avian predators (diving ducks, cormorants, etc.) and larger fish (adult bass, etc.). Bass tournaments at Devils Lake corroborate the interpretation from electrofishing (Table 3, Figure 3). Average fish weight in bass tournaments has steadily increased in Devils Lake and is now the highest in the state. This is presumably due to lack of recruitment of small bass into intermediate size ranges. This absence of recruitment, if it continues, will lead to very low largemouth bass abundance as older fish are harvested or die.

Table 1. Length frequency of largemouth bass electrofished in Devils Lake during annual ODFW Fall sampling.

	YEAR							
Length (inches)	1992	1993	1994	1995	1996	1997	1998	Total
1	1	1					1	3
2	26	44	14	39	29	9	12	173
3	65	106	74	181	141	24	51	542
4	21	24	79	164	126	18	63	495
5	3	20	54	17	126	12	41	273
6	11	5	28		26	1	11	82
7	7	1	9	1		2		20
8	5							5
9				2	1			3
10	4			1	1			6
11	3							3
12	1							1
13						1		1
14	1							1
15								0
16			1					1
17	1		1	2	1	1		6
18	2	2		2				6
19		1	1			1	1	4
20			1	1				2
>20					1			1

Table 2. Length frequency of largemouth bass electrofished in Devils Lake during annual ODFW Spring sampling.

	YEAR						
Length (inches)	1993	1994	1995	1996	1997	1998	Total
1							0
2	1			1		1	3
3		1		2			3
4				1		1	2
5						1	1
6							0
7	1						1
8							0
9							0
10				1			1
11							0
12							0
13		1					1
14		1					1
15	3	3					6
16		2	3				5
17	3	1		1	1	1	7
18	2		1	4	3		10
19	2		1			1	4
20	1	1					2
>20							0

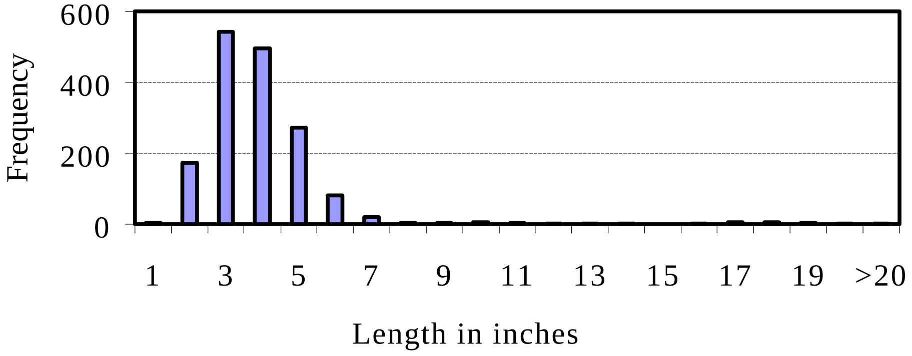

Figure 1. Devils Lake largemouth bass length frequencies for 1992-1998 fall sampling.

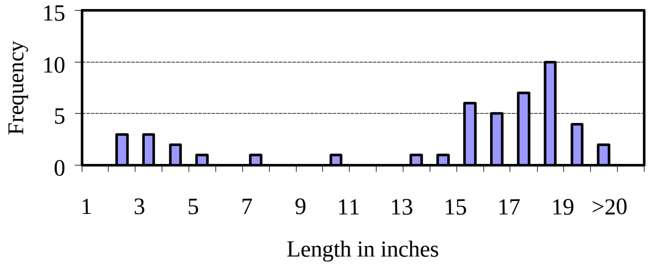

Figure 2. Devils Lake largemouth bass length frequencies for 1993-1998 spring sampling.

Table 3. Devils Lake bass tournament results for 1984-1997.

YEAR	MIN LENGTH	# EVENTS	ANG DAYS	# BASS	BASS PER ANG-HR	AVG WT
1984	12	4	81	101	0.13	2.00
1985	12	5	95	142	0.17	2.10
1986	12	1	8		0.14	1.90
1988	12	1	21	13	0.08	2.37
1989	12	5	56	63	0.12	2.66
1990	12	2	24	23	0.11	2.77
1991	12	2	16	29	0.22	2.93
1992	12	1	11	9	0.10	3.28
1993	12	6	71	69	0.11	3.42
1994	12	5	93	97	0.10	4.19
1995	12	4	41	26	0.06	4.19
1996	12	1	13	9	0.08	4.22
1997	12	1	15	15	0.14	4.67

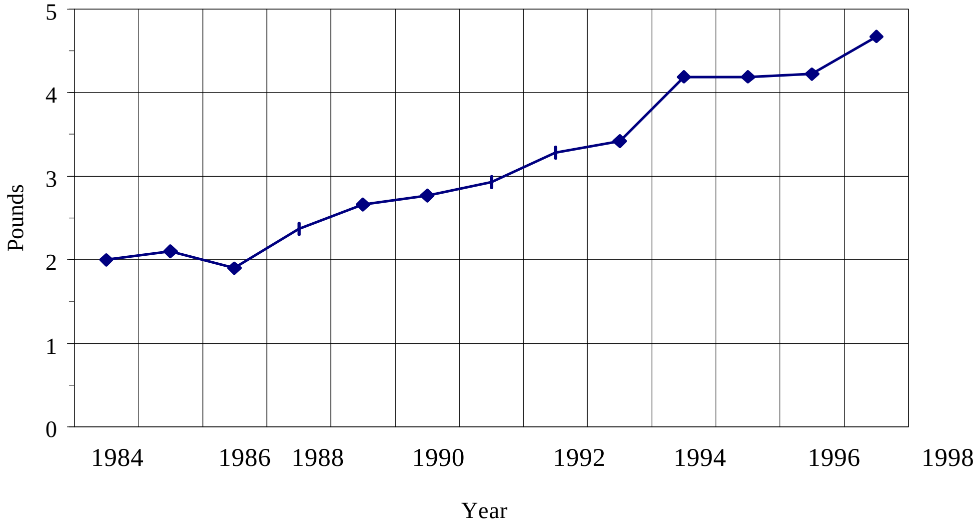

Figure 3. Devils Lake largemouth bass: average weight of tournament fish.

Bluegill, black crappie, yellow perch and brown bullhead

All species of warmwater gamefish commonly referred to as panfish appear to have declined to very low levels since aquatic macrophytes were eliminated from Devils Lake. This decline is evident from annual fall electrofishing and miscellaneous net samples from the lake (Tables 4 and 5, Figures 4 and 5). Anglers fishing Devils Lake for panfish report results consistent with the various inventory data. The mechanism explaining the major decline in Devils Lake panfish is unknown. It is hypothesized that in the absence of macrophytes, panfish are excessively vulnerable to predation.

Table 4. Warmwater gamefish captured in Fall electrofishing at Devils lake, excluding largemouth bass.

	CPUE (Fish per 1000 Sec)		
YEAR	BLUEGILL	PERCH	CRAPPIE
1985	39.8	26.4	3.7
1986	40.7	32.5	19.9
1992	113	19.6	8.8
1993	20.8	136.6	7.5
1994	0	5	0
1995	0.6	9	0
1996	0.7	0	0
1997	1.4	1.4	0
1998	1.4	0	0

Table 5. Gillnet and trapnet results from Devils Lake.

DATE	BLUEGILL	PERCH	CRAPPIE	BULLHEADS
5/81	0	593	35	135
3/84	2	35	5	19
10/92	44	64	55	139
5/93	23	6	2	22
7/94	4	2	0	2
9/94	1	11	0	16
5/9/96	0	0	0	3
10/96	1	5	0	0
4/25/97	0	0	0	0

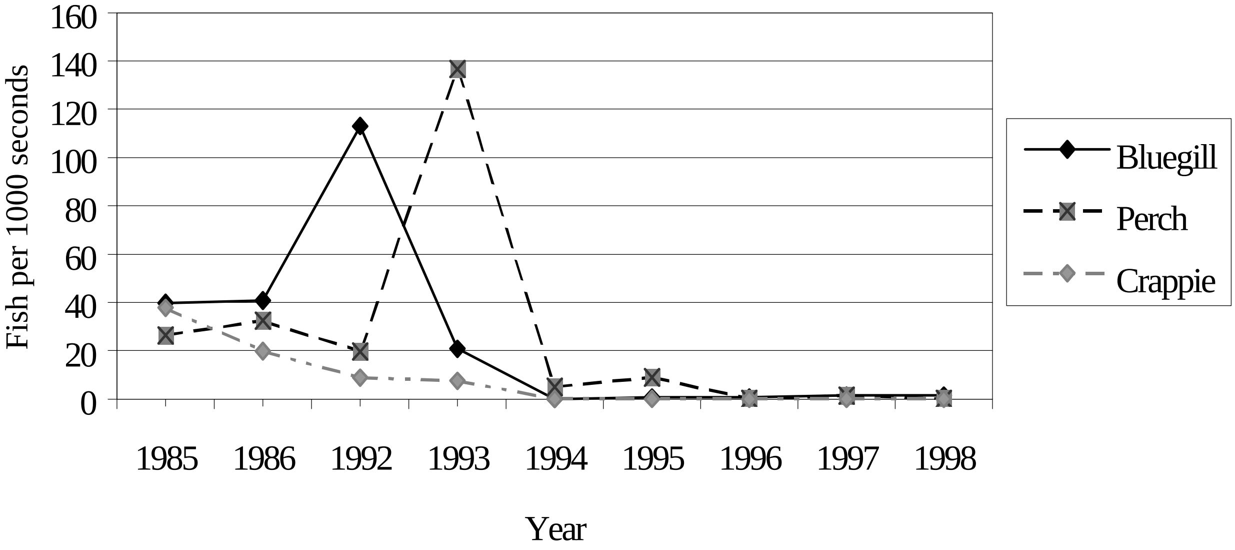

Figure 4. Fall electrofishing samples of panfish from Devils Lake.

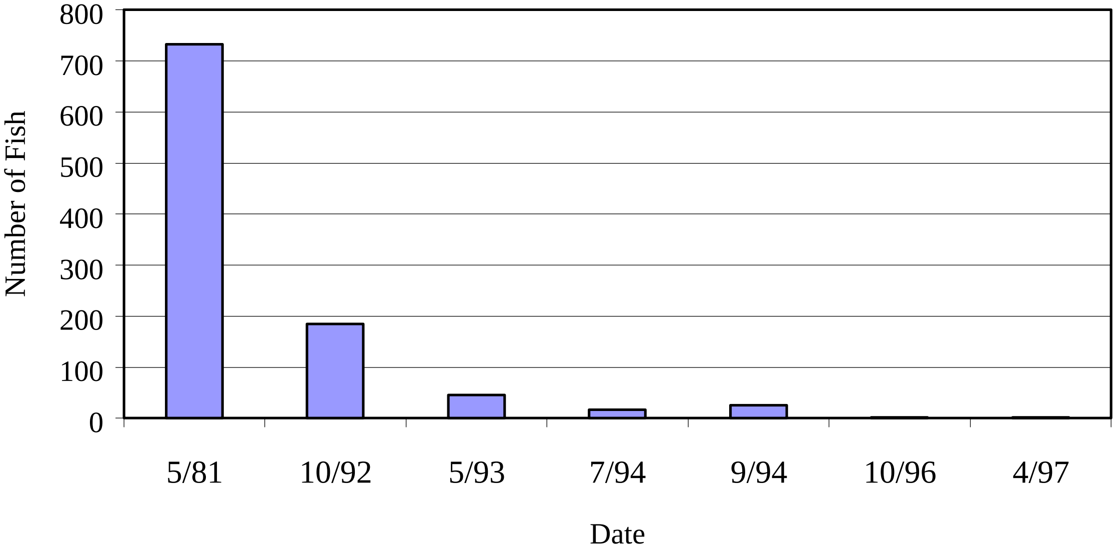

Figure 5. Catchable size panfish caught in net samples from Devils Lake.

Coho salmon

Coho salmon abundance in the Devils Lake Drainage Basin is indexed annually based on spawning fish surveys in Rock Creek, the primary tributary feeding into the lake. Adult coho abundance in these surveys has been highly variable between years with no clear declining or increasing trend evident (Table 6, Figure 6). The adult coho returns in 1996 would be the first age class where the juvenile life history stage was subjected to a macrophyte-free lake. Since 1996, adult coho returns are within the range of previous years. However, during this time frame, coho salmon in other north-central Oregon coast streams have been at record low levels. Factors thought to contribute to the low wild coho returns in this area are El Niño ocean conditions and severe flooding in February, 1996. It is currently not possible to associate changes in the Devils Lake environment with adult coho returns.

Table 6. Adult coho salmon peak count in the two Rock Creek (Devils Lake) spawning surveys. Both surveys are one mile in length.

YEAR	Lower Survey	Upper Survey
1980	11	
1981	7	
1982	8	
1983	2	
1984	12	
1985	16	29
1986	12	26
1987	7	4
1988	5	4
1989	6	17
1990	2	10
1991	11	20
1992	0	2
1993	6	17
1994	13	31
1995	3	16
1996	1	11
1997	3	13
1998	7	26

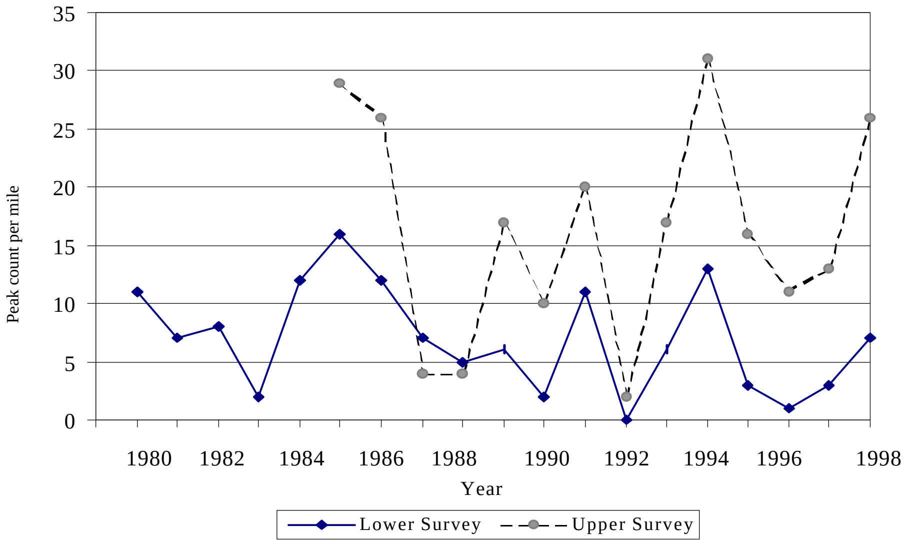

Figure 6. Devils Lake, Rock Creek adult coho spawner survey.

Net sampling of Devils Lake suggests increased abundance of both juvenile coho salmon and hatchery rainbow trout (Table 7). However, net sampling has been intermittent and at different dates which could also effect results. Size of juvenile coho captured during gillnet samples indicates that they are able to reach large sizes in the lake (Figure 7).

Table 7. Juvenile coho salmon and rainbow trout captured in net sampling of Devils Lake.

Date	Coho	Trout
5/81		4
3/84	2	5
10/92	0	2
5/93	5	8
7/94	4	41
9/94	0	31
5/9/96	26	44
10/96	0	17
4/25/97	27	114

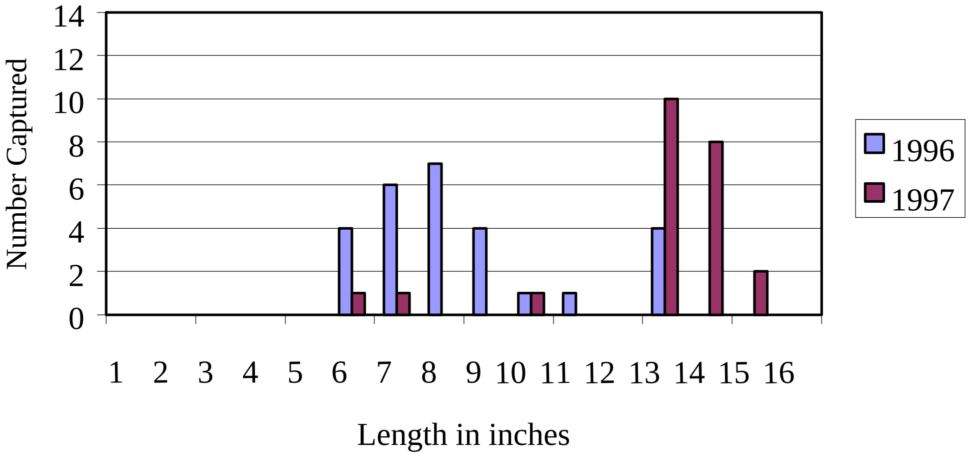

Figure 7. Devils Lake coho 1996-97 Spring gillnet samples.

Discussion

It appears that grass carp are a powerful tool capable of altering fish populations in eutrophic coastal lakes with abundant aquatic macrophytes and warmwater gamefish. In Devils Lake, following macrophyte elimination, panfish quickly declined to very low levels, while largemouth bass are declining at a slower rate due to lack of recruitment.

Warmwater gamefish are thought to be detrimental to native coho salmon through both competition for food and space and direct predation. In Devils Lake, wild coho returns have been variable since warmwater gamefish declines have been occurring. The time frame is short however at only 3 years, and occurred when other environmental factors resulted in record low coho returns to adjacent streams. Additional years of monitoring are necessary to more definitively understand effects of macrophyte and warmwater gamefish reductions on native coho salmon.

Wild coho population trends in other Oregon coastal lakes suggest potential benefits to native coho. Coho salmon returns to Tenmile Lake declined following bluegill and largemouth bass introductions in the early 1970's and have not recovered (Figure 8). Nearby coastal lakes (Siltcoos and Takhenitch) have had a full assemblage of warmwater gamefish and stable coho returns throughout this time frame suggesting the Tenmile declines were caused by the bluegill and/or bass introductions.

Devils Lake represents an opportunity to better understand the effects of warmwater gamefish on native coho. Monitoring of fish populations must continue, or may need to be expanded for more definitive results.

Future decisions are also needed on grass carp re-stocking of Devils Lake. It is uncertain how long the existing grass carp population will hold macrophytes down. Resurgence of macrophytes will almost certainly lead to increased populations of exotic warmwater fish. Options currently available include removal of grass carp to stimulate macrophytes and warmwater fish recovery, supplemental stocking of grass carp to assure macrophytes do not come back, or let the current situation play out until attrition in the grass carp population allows macrophyte recovery. Under this third option it is very uncertain when sufficient grass carp would die out to allow recovery of aquatic plants.

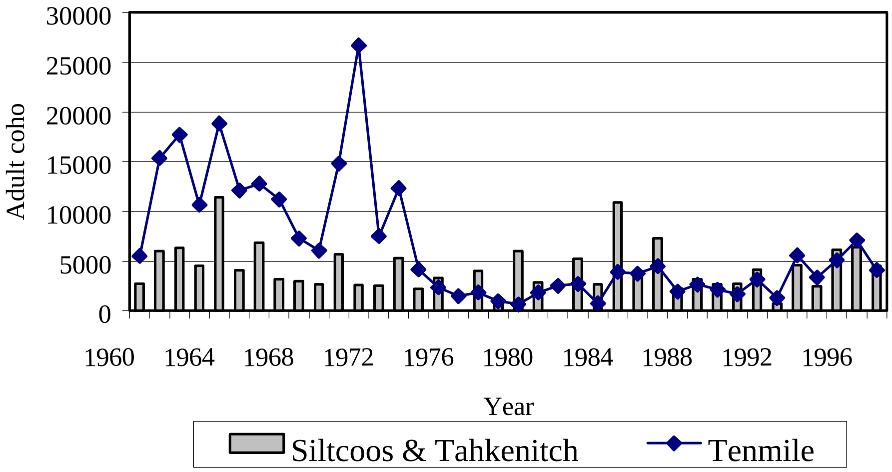

Figure 8. Adult coho spawners.

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Tools for Tomorrow

Session Chair:

Ray Beamesderfer
Oregon Department of Fish and Wildlife

So Many Predatory Resident Fishes-What Needs to be Done?

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Abstract- *Construction of reservoirs on the Lower Snake River provided more favorable habitat for certain species of introduced fishes. More than 50% of the fishes residing in the Lower Snake River reservoirs are introduced. Many of these are game fishes, like smallmouth bass, largemouth bass, yellow perch, both black and white crappies, channel catfish, and several species of bullheads, but some are also potential predators on downstream migrating juvenile salmonids. Our studies indicate many of these fishes can consume up to 8-10% of the run of certain stocks of downstream migrating juvenile salmon. Dietary analysis has shown that smallmouth bass in Lower Granite Reservoir and possibly other Lower Snake River reservoirs are the most intense juvenile salmonid predators although stomachs of channel catfish, crappies and yellow perch were found to contain salmonid fishes. The significance of this predation by some introduced fishes is muted because of specific habitat requirements and resulting low population abundance. Our studies indicate that anadromous salmonid survival can be enhanced by creating habitat conditions favorable for rearing and migration of downstream migrating juvenile salmonids that in turn, are less favorable for many of the introduced fishes. Also, slow growth combined with high annual mortality suggests strong potential for population regulation of larger sized potential predators by the sports fisheries in the Lower Snake River reservoirs.*

Introduction

The advent of introduced fishes in the Columbia Basin was from the late 1800s to early 1900s (Lampman 1949). Completion of east-west railroads facilitated transportation of these fishes from their native ranges. Many introductions were successful and stocks of catchable fishes developed although angler interest was generally low. However, many of these introductions were only marginally successful because of limited suitable habitat. Construction of dams and the resulting change in physical habitat, however, provided an opportunity for the abundance of these fishes to increase. Some species like smallmouth bass *Micropterus dolomieu* can be successful in both lotic and lacustrine systems (Coble 1975), whereas other species like crappies *Pomoxis* spp. and yellow perch *Perca flavescens* are found in low abundance in all but lacustrine systems (Carlander 1977).

The literature is replete with studies demonstrating the predatory habits of many of these introduced species in their native range (Carlander 1977, 1997; Scott and Crossman 1973) although their role as a salmonid predator has been sporadically reported. Bennett et al. (1983) provided some early findings on the role of several introduced fishes in the Snake River. They reported that several of these fishes in Little Goose Reservoir contained salmonid fish parts. Their work on the Snake and that of Hjort et al. (1981) in John Day Reservoir indicated that predation could be a significant source of mortality to downstream migrating salmonids. These preliminary results supported an extensive analysis of predation in John Day Reservoir that showed an estimated 2.7 million (95% CI=1.9-3.3 x10^6) smolts were being consumed by resident fishes. Northern pikeminnow *Ptychocheilus oregonensis* accounted for approximately 78% of the smolt losses although walleye *Stizostedion vitreum* (13%), and smallmouth bass (9%) accounted for the remaining 22% (Rieman et al. 1991). Other predator assessments followed the John Day Reservoir study and most showed predation was highest in tailwaters (Ward et al. 1995) or predator abundance varied between the Columbia and Snake rivers (Zimmerman and Parker 1995). Most of these studies focused on northern pikeminnow, smallmouth bass, and channel catfish *Ictalurus punctatus.*

The role of predators in the Snake River reservoirs has received less attention. Chandler (1994) first completed an assessment of predation by northern pikeminnow. He showed that consumption of juvenile salmonids within Lower Granite Reservoir was similar to that throughout John Day Reservoir although total salmonid losses could not be calculated because a direct estimate of pikeminnow abundance was not made. Predation by introduced fishes has been one part of an overall aquatic assessment in Lower Granite Reservoir (Bennett et al. 1988, 1990). The purpose of this paper is to examine incidence and magnitude of predation by introduced fishes on juvenile salmonids in some of the Lower Snake River reservoirs.

Study Area

Lower Granite (LGR) and Little Goose (LGO) reservoirs are the first and second reservoirs on the lower Snake River reservoirs. Both reservoirs are similar in size (LGO-4,057 ha; LGR-3602 ha) although overall habitat characteristics differ as Little Goose Reservoir has numerous backwaters compared to Lower Granite Reservoir (Bennett et al. 1983). These backwaters provide more shallow water habitat and denser growths of aquatic macrophytes than occur in LGR. These shallow, well-vegetated, backwaters provide more suitable habitat for several resident fishes such as yellow perch *Perca flavescens* and black *Pomoxis nigromaculatus* and white *P. annularis* crappies. For a more thorough analysis of habitats in LGR see Curet (1994) and Dresser (1996).

Methods

Stomach samples of most potential predators were collected primarily by electrofishing although some fishes were collected by gill netting (See Bennett et al. 1988, 1990). Fishes were collected primarily at night although some were sampled at 6-hour intervals (Curet 1994). Once collected, fishes were identified, measured for total length and stomach contents obtained by lavage for all centrarchids and yellow perch. Channel catfish had to be sacrificed and stomach contents were obtained by dissection (Gray et al. 1984). All contents were preserved and later identified to the lowest practical taxonomic level. We used diagnostic bone keys (Hansel 1988) to identify the species of unknown bony parts. Food items were identified into 93 food categories and then generally lumped into insects, salmonid and non-salmonid fishes, crayfish, and microcrustaceans (see Karchesky and Bennett this volume).

Results and Discussion

We have found that smallmouth bass are the most significant predator of the introduced fishes in Lower Granite Reservoir. Frequent consumption of salmonid fishes and their high abundance makes them a significant predator on especially subyearling chinook salmon and wild steelhead. Curet (1994) showed that an estimated 4% of the juvenile fall chinook salmon that migrated through Lower Granite Reservoir during 1992 were consumed by smallmouth bass. Anglea (1997) showed that the smallmouth bass population was underestimated by Curet (1994) and predation was probably closer to 6%. Some managers believed that Curet's results may have been inflated because his study was conducted during 1992, a year of extremely low flows and unusually high water temperatures and it followed the early spring experimental drawdown of LGR. Anglea (1997) examined smallmouth bass predation on downstream migrating juvenile salmonids and found that predation differed substantially between 1994, a low flow year, and 1995, an average flow year. He estimated that the predatory loss of juvenile salmonids by smallmouth bass in LGR was about 82,500 in 1994 and 64,000 in 1995. Anglea's (1997) estimate of approximately 7% of the potential fall chinook run demonstrated that smallmouth bass were a significant predator in LGR. More recent studies suggest the influence of predation by smallmouth bass on juvenile salmonids can vary substantially among years. Naughton (1998) recently found that smallmouth bass in the forebay, tailwater and in the Snake and Clearwater arms of LGR consumed about 14,000 juvenile salmonids during both 1996 and 1997 combined. This estimate was about 17 % of that of Anglea's. Consumption of juvenile fall chinook was approximately 30% of the salmonid estimate and could have been approximately 4% of the fall chinook run. These studies demonstrate that smallmouth bass can be a significant predator in Lower Granite Reservoir and possibly other Lower Snake River reservoirs although annual variation also can be significant.

Channel catfish seem to be another potentially significant predator in the Lower Snake River reservoirs. Bennett et al. (1983) reported that 99.6 % of the food items in channel catfish were fishes from the tailwater of Lower Granite Dam during spring 1979 and 1980. Juvenile steelhead and chinook salmon were the most common fishes present. In 1987, Bennett et al. (1990) showed similar abundance of juvenile salmonids in the diet of channel catfish collected from Lower Granite Reservoir. Because of their low population abundance, I do not consider channel catfish to be a significant predator in Lower Granite Reservoir although their abundance appears to increase downstream in the Lower Snake River reservoirs (Zimmerman and Parker 1995; Bennett et al. 1983; Normandeau 1998). Thus, the predatory impact of channel catfish may be substantially higher in other Lower Snake River reservoirs.

Other introduced fishes also have been found to have high incidence of salmonids in their diet. White and black crappies contained smolts during the period from 1994 through 1997 (Bennett Unpublished data). The incidence of predation was higher in white than black crappies and annual variation was substantial. During some years, insects constitute a substantial part of their diet but the presence of salmonids has comprised up to 25% (weight) of their diet. However, crappies are low in abundance in Lower Granite Reservoir but may be more significant predators in other reservoirs like Little Goose Reservoir where they attain higher abundance (Bennett et al. 1983; Normandeau 1998).

We found up to 20% of the diet of yellow perch consisted of juvenile salmonids in LGR. Yellow perch consumed primarily insects although consumption of juvenile salmonids was observed during several years. No juvenile salmonids were found in the diet of bullheads from Lower Granite Reservoir. Aquatic insects were their principal dietary item.

Significance of Juvenile Salmonids in the Diets of Introduced Fishes

The presence of juvenile salmonids in the diet of smallmouth bass, channel catfish, white and black crappies, and yellow perch has to be carefully examined. The intensity of predation by smallmouth bass on juvenile salmonids, demonstrated by Curet (1994) and Anglea (1997), is considered significant, especially on subyearling chinook salmon. Estimates of abundance of smallmouth bass are known (N= 65,401 >70 mm; Anglea 1997) so the actual proportion of predation is significant. I believe these studies have demonstrated a significant level of predation by smallmouth bass, especially on fall chinook salmon. The small body size and rearing of fall chinook salmon in shallow waters in Lower Granite Reservoir (Bennett et al. 1998) result in significant habitat overlap with especially smallmouth bass. Predation by smallmouth bass appears the highest in Lower Granite of all Lower Snake River reservoirs probably because they attain highest abundance of all the Snake River reservoirs (Zimmerman and Parker 1995).

Other introduced predators in the Lower Snake River reservoirs do not have the potential to impact juvenile salmonids as great as smallmouth bass. Probably the main reason is that these other fishes are probably much less abundant. Bennett et al. (1983) found crappies to comprise approximately 21% of the fish community in LGO although their relative abundance was inflated by extensive sampling in a backwater (Deadman Bay). In LGR, crappies attain lower abundance than in LGO (Bennett and Shrier 1986; Bennett et al. 1990).

One of the largest unknowns is the absolute abundance of channel catfish in the Lower Snake River reservoirs. In Little Goose Reservoir, channel catfish were estimated to constitute about 3 % of the fish community. In LGR they attain lowest abundance of all the four Lower Snake River reservoirs but are more abundant in the other Lower Snake River reservoirs (Bennett et al. 1983; Zimmerman and Parker 1995; Normandeau 1998). The incidence of juvenile salmonids in the stomachs of channel catfish was significant in LGO (Bennett et al. 1983) and LGR (Bennett et al. 1990) but without an absolute estimate of abundance, I can infer that salmonid consumption may be significant throughout the Lower Snake River reservoirs. Absolute abundance estimates should be made to assess their impact to the survival of juvenile salmonid fishes.

Potential Management Actions

The question remains, if this predation were deemed significant, can anything be done to enhance juvenile salmonid survival. Anglea (1997) demonstrated that the consumption of salmonids was significantly higher in larger smallmouth bass (>250 mm) although bass from 70 mm (total length) contained salmonids. Therefore, I believe that any action that reduces larger smallmouth bass can have a beneficial effect on survival of downstream migrating or rearing salmonids. Because of the low abundance of larger smallmouth bass in the Lower Snake River reservoirs (LGR-estimated N=307 >390 mm), maintaining non-protective regulations has merit. Regulations such as minimum size limits or slot limits that would enhance the number of larger smallmouth bass should be avoided. Smallmouth bass in the lower Snake River system grow slowly, requiring over 10 years to attain the size of highest level of predation. Annual survival is approximately 47%; therefore, 53% of these smallmouth bass die annually that further reduces the number of larger smallmouth bass. Maintaining catch and keep regulations would greatly reduce the number of these larger smallmouth bass and keep the number of larger fish low.

Our data also suggest that management actions that enhance habitat conditions in the migration/rearing corridor of the lower Snake River for juvenile salmonid survival should have deleterious effects on introduced fishes. One such action that has been successfully used to enhance survival of fall chinook salmon is flow augmentation (Connor et al. 1998). Connor et al. (1998) recently demonstrated that flow augmentation from Dworshak and Hells Canyon reservoirs increased PIT tagged fall chinook salmon detection rates and, presumably survival, by approximately 500%. In 1995, the highest detection rates of PIT tagged fall chinook salmon at LGR coincided with the lowest consumption rates by smallmouth bass (Anglea 1997) and possibly other introduced species. Decreasing water temperatures in LGR from upstream flow augmentation appears related to decreased mortality, presumably from less fish predation on fall chinook salmon. Higher inflows in LGR increase turbidity and decrease water temperatures (Connor et al. 1998). Smallmouth bass and other centrarchid fish are sight feeders, and being from warmwater systems, are generally considered to have optimum temperatures near 30° C (Coble 1975). Therefore, enhanced detection of PIT tagged fall chinook salmon at Lower Granite Dam may be, in part, related to decreased predation by smallmouth bass and possibly other introduced fishes. Proper timing of upstream flows appears to have survival benefits to juvenile salmonids in LGR, probably in part, by decreasing predation rates.

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Modeling Food Web Interactions: A Conceptual Framework and Applications for Managing Native-Nonnative Assemblages

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Introduction

Introductions or changes in abundance of nonnative species can threaten the ecological integrity of aquatic communities. Nonnatives frequently affect other species directly through predation or competition, or indirectly via alternative pathways through the food web. Even without direct trophic interaction, the distribution or behavior of species can be altered in response to predation risk (Eggers 1978; Clark and Levy 1988; Walters and Juanes 1993) or the presence of a superior competitor, consequently diminishing growth, survival, or reproduction of native species. Given the complex array of potential processes and interactions that can affect aquatic communities, a food web perspective is required for understanding how proposed or existing nonnative species introductions affect the structure and function of aquatic communities.

Bioenergetically-based food web models, when coupled with directed sampling for diet, growth, size structure, thermal experience, and estimates of relative or absolute abundance, provide an effective method for quantifying trophic interactions in a temporal, spatial, and ontogenetic framework (Ney 1990). By quantifying linkages in a food web, we can identify strong interactions that potentially regulate populations in aquatic communities (Brandt and Hartman 1993). For instance, by using this approach, we can evaluate the carrying capacity of a system and identify potential seasonal bottlenecks in food supply. We can also determine if predation imposes serious losses to vertebrate and invertebrate prey populations (Stewart et al. 1981; Kitchell and Crowder 1986; Luecke et al. 1990; Stewart and Ibarra 1991; Johannsson et al. 1994; Rand et al. 1995); moreover, we can describe the timing, duration, and location(s) of significant predation, identify the size range of predators that impose the greatest mortality, and define the size range of prey that are most vulnerable to predation. Since these models are physiologically based, they can also be useful for distinguishing between the effects of thermal regime and food supply on growth limitation. Thus, this approach provides managers and researchers with an effective, flexible tool for assessing the relative importance of existing impacts, and enables predictions about how aquatic communities might respond to potential manipulations (e.g., species introductions or enhancement) or environmental change.

The now widely-used Wisconsin bioenergetics model (Hewett and Johnson 1992, and Hanson et al. 1997) provides the core of this approach. The most common application of this model has been to estimate the biomass of food required to satisfy the observed growth of the consumer over specific time intervals. This model has been developed for a number of species, and has become a well recognized tool for managers and researchers. When compared to alternative methodologies, the Wisconsin model has performed well for black basses (Rice and Cochran 1984) and salmonids (Beauchamp et al. 1989, Brodeur et al. 1992, Ruggerone and Rogers 1992, Cartwright et al. 1998) with the model generally producing consumption estimates within ± 10% of estimates derived from more conventional, but intensive field-based stomach fullness and gut evacuation methods (e.g., Eggers 1978, Elliott and Persson 1978). Although still very useful, the model has not performed as well for some other species. Where the model has not performed as well, the cause has often resulted from "borrowing" physiological parameters from other species (Ney 1993), or from inadequacies in the data used to describe specific populations or processes .

Improving model performance in future applications and for a broader range of species will require more experimentation and greater attention to the design, implementation, and analysis of field sampling that is dedicated to supplying project-specific inputs to this type of modeling effort. Improving the model's ability to simulate the physiology of specific species will require additional laboratory experiments, particularly those directed at the effects of body size and temperature on maximum consumption rates and on respiration (Bartell et al. 1986). However, the magnitude of errors generated by these physiological parameters are often insignificant compared to the errors propagated from inadequacies in obtaining and applying field data of consumer growth, diet, thermal experience, abundance (absolute or relative), and survival. Thus, the utility of this modeling approach can be most enhanced by focusing on the key modeling inputs during design and implementation of field sampling efforts.

The purpose of this paper is to present a general approach for quantifying food web interactions and provide brief case studies as examples of the range of questions that can be addressed by this food web modeling approach, and to provide the context for describing the types of data and sampling design considerations that are generally most important for producing defensible simulations of critical trophic interactions within a temporal, spatial, and ontogenetic framework. My colleagues and I have applied this approach to a number of questions in lakes, reservoirs, and streams in western North America, generally involving resident or anadromous salmonids as one of the primary consumers or prey (Table 1). Results from a subset of these studies will be described to demonstrate different capabilities of this approach in the case studies section of this paper, but a this will be preceded by a description of the general approach with some emphasis on our current approaches for dealing with issues commonly encountered during the sampling design, implementation, analysis, or modeling phase.

General Approach

Trophic interactions can be quantified by estimating the biomass or number and size distribution of prey consumed by specific consumers in the food web. Consumers are generally categorized by their position in the food web and can be segregated into different life history stages or size categories, based on differences in diet composition. Consumption rates by individuals of each species or life stage of a species can be estimated using a bioenergetics model given estimates of: 1) incremental growth for each age class of consumer; 2) the temporal pattern in diet composition of each age class over the period of interest; 3) the average daily temperatures that the consumer experienced (termed “thermal experience”) over the period of interest; and 4) the energy density of the consumer and prey, and 5) the relative or absolute abundance of predators and prey. The model and suggestions for how data can be acquired and analyzed to provide basin-specific inputs will be described here briefly.

The Bioenergetics Model

The Wisconsin bioenergetics model is an energy-balance model which requires that over any specified time interval, total energy consumption **C** must satisfy the net gain or loss of weight **G** observed over that period plus the metabolic costs **M** and waste losses **W** that accrued over that period. Thus, the most basic form of the model is:

$$\mathbf{C = G + M + W},$$

Or if solving for growth given a known consumption rate (this is rare except perhaps in aquaculture situations):

$$\mathbf{G = C - (M + W)}$$

Embedded in each term of this basic equation are formulae which alter energy as functions of body size and temperature. In addition, metabolism **M** includes routine activity costs and specific dynamic action (SDA, the cost of processing a meal), and waste **W** may be scaled directly as a proportion of total consumption. The form and parameterization of these functions vary considerably among species based on laboratory experiments on the physiological processes of consumption, growth, metabolism, and waste. The model provides an estimate of the physiological response of a species, given the size and thermal experience of the organism, whereas the field inputs customize the response of that organism for the situation of interest by specifying the growth, diet, and thermal conditions experienced for each situation of interest. The model operates on a daily time step. Thus, estimates of consumption, metabolic and waste costs, and growth are generated for each day based on the size and thermal experience of the organism, then the status of the organism (i.e., size and energy density) is updated and computations proceed for the next day in the simulation. Consumption rates can be quantified for daily through annual periods by allowing the simulation to continue through the year or over the entire life span of an organism, if inputs for growth, diet, and thermal experience can be estimated from field data, obtained from reasonable values in the literature, or from on reasonable assumptions based on experience or biological intuition. Clearly, the accuracy and usefulness of these simulations will only be as good as the inputs that are provided. The following sections describe the most important factors that should be considered when designing a sampling program to supply field inputs to the model or when designing a general monitoring program that might support periodic resource assessments using a food web model.

Growth

The model estimates consumption primarily through changes in body weight over specified time intervals of up to a year. Routine monitoring data often provide estimates of annual growth, either by tracking the modal lengths of each age class through time, or by back-calculating size-at-age from otoliths, scales, or other appropriate bony parts. These length estimates can be converted to weight-at-age estimates using length-weight regressions, and thus provide a first approximation of annual weight change by different age classes in the consumer population. These accuracy and precision of these estimates will entirely dependent on ambient variability of the data and the adequacy of the sample sizes. Accuracy and precision of annual growth increments can be improved tremendously by generating size and growth estimates from a relatively short, consistent time of the year.

Aquatic organisms rarely grow at a constant rate throughout the year, because temporal changes in food supply, temperature, and other environmental stressors operate independently or in concert to produce seasonal growth patterns. Since consumption is generally estimated to satisfy the observed growth over specified time intervals, it is important to allocate growth rates as accurately as possible to the appropriate periods of interest during the year. For example, predation on a prey species of concern may be concentrated over a fairly short period (e.g., a week or month) when the predators’ growth is either much higher or lower than growth that would be computed from annual average rate. Consequently, errors in estimated consumption on the prey of interest would depend on how much the actual growth of the predators deviated from the average growth rate over the year. Ideally, the mean body weight of each age class could be tracked over each ecologically-significant period of the year, but sample size requirements and logistical or political constraints often preclude the sampling intensity needed to directly measure growth over the period of interest. Thus alternative ways to allocate growth to appropriate periods of the year are often employed. Seasonal changes in condition factor for groups of age classes (e.g., ages grouped as juveniles, subadults, adults, etc.) may allow more temporal resolution in growth allocation with considerably less data than would be required to estimate seasonal growth of each age class directly. For slow-growing, long-lived species (e.g., lake trout), most of the annual “growth” is elaborated as seasonal gain and loss of gonadal rather than somatic growth; therefore, attention to the mean loss in gonadal weight may be the single best estimate of growth for these species. The question then becomes whether adults spawn every year and whether the sex ratio of spawners is highly skewed toward one gender or the other. In general, the important consideration for using population-specific growth to estimate consumption will be whether growth is likely to vary dramatically among seasons for reasons other than simply a physiological response to temperature. If so, then it will be important to allocate weight changes for each age class of the predator into multiple growth cohorts within the year to estimate appropriate consumption rates for each ecologically-significant period.

Diet Composition

Feeding behavior and diet composition of most fishes changes considerably as they grow through various life history stages, occupy different habitats, and respond to seasonal availability of prey. At a minimum, diet composition should be sampled to detect changes seasonally and among size classes of the consumer. Spatial factors may also be influential in determining the diet composition of consumers among habitats (e.g., diet differences in nearshore versus offshore zones, Beauchamp 1990, Beauchamp et al. 1992; in the vicinity of tributaries or dams versus other areas during prey migrations Beamesderfer and Rieman 1991, Poe et al. 1991, Rieman et al. 1991; Vigg et al. 1991), but the combined effects of predator movement and prey dispersal may also homogenize the diets from different vertical or horizontal regions of the basin (Cartwright et al. 1998; Baldwin et al. in review).

The temporal scale of interactions can be extremely important when attempting to quantify consumption in response to specific events, and this should be a major consideration when designing a sampling program to measure predation on stocked fish or on a pulse of prey migrating through a population of predators. In systems where we have examined predation on stocked of juvenile salmonids, the response has been immediate, severe, and of relatively short duration (two days to two months). Thus sampling should be scheduled to detect whether the magnitude and duration of the predatory response is prolonged or short-lived. We have adopted a strategy of sampling a couple days prior to stocking to measure baseline diet composition of the predators, then on 3 consecutive days after stocking, then once every 2-3 days, followed by a progressively lower frequency of sampling trips. The reduction in sampling frequency can be adjusted by evaluating how quickly the proportional contribution (by weight or volume of the stomach contents) of the prey of interest changes between sampling dates. If the prey disappears from the diet quickly (e.g., within a couple days), then sampling can be reduced to measure monthly or seasonal changes as appropriate. If the diet composition changes measurably, but at a more moderate rate, then a relatively frequent sampling schedule should be maintained (e.g. sample once every 3-7 days) until the prey of interest disappears or stabilizes in the diet.

Diet information for any size class of consumer is entered as an input file into the bioenergetics model as proportional contribution of each prey category in the diet by wet weight (or volume) and the date or range of dates that correspond to each combination of prey in the diet. Consequently, diet data should be recorded as wet weight (or volumetric) proportions of the individual stomach samples. Each nonempty stomach is considered as a separate sampling unit, and the dietary proportions of each prey category from each stomach is averaged with all other nonempty stomach samples corresponding to each size class of predator during each time interval (e.g., season) over the period of interest. This analytical approach gives equal weight to the dietary proportions each nonempty stomach, regardless of the level of stomach fullness. Therefore, a stomach containing a 4-g kokanee (80% of the diet) and 1 g of zooplankton (20%) would be averaged equally with a stomach containing 0.1 g of kokanee bones (20%) and 0.5 g of zooplankton (80%). If these were the only two stomach samples available for that predator-size x time cell, then the average diet composition for that cell would be 50% kokanee and 50% zooplankton. This approach minimizes the influence of the rare stomachs containing large quantities of a particular prey and attempts to reflect the average diet composition of all consumers within the same size x time cell. This method is not without its own set of problems; however, I believe it currently represents the best compromise for reasonable accuracy with reasonable sampling effort. Important assumptions underlying this diet analysis approach can often be evaluated directly through pilot or supplemental studies if deemed important in specific situations. For instance, this approach assumes reasonably similar digestion rates for all major prey taxa, and is sensitive to diel differences in prey composition. Differential digestion is a lesser concern except if temperatures are in the warmer portion of the consumer's thermal range, or if the prey of interest are larval fish, which digest very quickly. Diel differences in prey composition can be important when consumers occupy relatively warm temperatures; however, this concern can be minimized by preliminary sampling to identify when peak stomach fullness occurs (i.e., at dawn, midday, before dusk, after dusk, or at night) and schedule net retrieval or active sampling to maximize the number of samples captured during or after the period of peak stomach fullness.

Thermal Experience

The thermal experience of a consumer can be determined several ways, based on field data or knowledge of their behavior and distribution patterns. For lotic species, average daily temperature recordings from temperature loggers may be sufficient for estimating thermal experience, unless organisms concentrate in thermal microhabitats (e.g., salmonids congregating in groundwater intrusions, etc.). For littoral or warm-water species like black basses, can be assumed to occupy epilimnetic regions of lakes during the summer, and the warmest (or only) temperatures available during stratification, destratification, and isothermal conditions.

For pelagic, demersal, or species with variable movement and distribution patterns, reconstructing thermal experience is more involved, because the combination of vertical distribution and movement patterns and the concurrent vertical temperature profiles determine the average daily thermal experience of these organisms. If vertical distribution information is available (e.g., diel hydroacoustic depth-specific densities planktivores, or depth-specific catch per effort data from gill nets), then for each sampling date, a weighted mean thermal experience for different species or size classes can be computed by first multiplying the proportion of the catch (for that species or size class) found in each depth interval times the mean temperature in that depth interval, then summing these products over all depth intervals. This sum represents the weighted average thermal exposure for the average individual of that species or size class in the population. When temporal depth distribution data or temperature profiles are unavailable, a commonly-used approach has been to assume "behavioral thermo-regulation" which means that fish will seek out available temperatures nearest their physiological optimum temperature for growth. This may ignore other important behavioral or physiological constraints like foraging opportunities, predator avoidance or tolerance for hypoxic conditions or other suboptimal environmental characteristics.

Energy Density of Predators and Prey

The energy density (in terms of calories or Joules per gram body weight [cal/g or J/g]) of prey will determine how much prey biomass must be consumed for a predator to obtain any given amount of energy. For example, a fish would need to consume at least 1.5 times more biomass of invertebrates with energy densities of 3,000 J/g than fish with 4,500 J/g to acquire the same amount of energy. Moreover, invertebrates generally contain a relatively large fraction of indigestible material in their exoskeleton (averaging 17% of their body weight across many taxa) compared to an average of 3% indigestible material in fishes. Of the energy ingested, waste losses are subtracted and metabolic costs are paid before any energy is allocated for growth. The remaining energy is divided by the energy density of the consumer to convert energy into new consumer biomass. So if a predator 's energy density was 6,000J/g, and 4,000 J of energy remained after all waste and metabolic costs were removed, that energy would be converted into 4,000 J/(6,000 J/g) = 0.67 g of new growth for the predator.

Energy density varies considerably among organisms, and can change seasonally or with increasing body size. In the Wisconsin bioenergetics model, energy densities are provided as default values in the parameter set for each of the 33 species or life stages provided in the existing model. The consumer's energy is held constant for most species; however, for salmonids and coregonids, energy density increases considerably with increases in body mass up to a threshold weight, then remains relatively constant thereafter. Although strongly recommended, energy densities of predators and prey have rarely been measured in conjunction with a bioenergetic analysis of trophic interactions (but see Luecke and Brandt 1993; Rand et al. 1994; Bryan et al. 1996). Energy densities of prey are generally taken from the literature (e.g., Cummins and Wuycheck 1971; Hanson et al. 1997).

Abundance of Predators and Prey

Ideally, consumption by individuals from each age class is expanded to population-level consumption over daily, monthly, seasonal, or annual time steps, and incorporates the initial abundance and mortality of each age class over the simulation period to provide the best possible estimate of population-level trophic interactions through time. Population-level predation rates can be compared to the temporal abundance of prey populations to determine if predation represents a significant or serious source of mortality. However, abundance of predators or prey commonly represents largest source of uncertainty in most population-level consumption analyses. Although hydroacoustic-midwater trawl assessments of pelagic species like juvenile sockeye salmon, kokanee, coregonids, smelts, and shads have become routine, population estimates for littoral species are often feasible, the efficacy and affordability of population assessments deepwater demersal or pelagic piscivore populations has generally been a major challenge to both managers and researchers. The need to invest in a formal population abundance estimate must often be quite compelling before the expense and political support can be justified. Despite these uncertainties, several steps can be taken to maximize the value of a food web analysis, evaluate whether a formal abundance estimate is required, and if so, provide strong justification for such an effort.

When consumer abundance estimates are lacking, a useful way to present model simulations is to report consumption demand in terms of consumption per standard unit of the predator population. For instance, if we considered a standard predator population unit of 1,000 predators, ranging in size from individuals in the smallest age class that exhibited predation on the prey of interest through the largest/oldest predators, and allocated these 1,000 predators into size classes in proportion to the size structure observed in the population, then we could multiply individual consumption by each age class by the corresponding number predators allocated to that age class from the pool of 1,000 predators to estimate the total consumption demand of each age class in a standard predator population unit of 1,000. Predation losses could then be reported in terms of the numbers or biomass of prey consumed per 1,000 predators per year or over specific time periods. This approach would also identify which size range of predators actually impose the greatest mortality on prey, because individual size-specific predation rates have been adjusted to reflect the relative abundance of each size class in the predator population. Given this information, managers can decide whether these unit-population predation rates are severe enough to warrant further concern. If so, they will either have sufficient information to proceed with management actions, or the rationale for justifying further examination into the abundance or dynamics of the predator population.

Case Studies

Lake Ozette: Examining Potential Limitations of Competition and Predation on Kokanee and Juvenile Sockeye Salmon

Lake Ozette, located on the Olympic Penninsula in Olympic National Park, Washington, had historically supported a modest run of sockeye salmon that was harvested by the Makah Tribe. The run declined and remained low even after harvest ceased in 1973. Meanwhile, increasing numbers of kokanee began spawning in tributaries previously used by anadromous sockeye salmon, and the remaining sockeye salmon appeared to spawn in the lake. Managers wanted to know if a program to re-establish and enhance anadromous sockeye salmon was feasible. Specifically, had kokanee expanded to fill the niche previously occupied by juvenile sockeye salmon, and would predation losses undermine enhancement efforts. We used the food web modeling approach to examine: 1) how much additional planktivore demand from a sockeye salmon enhancement program could be supported by the zooplankton forage base; and 2) how much mortality could be expected from predation by resident cutthroat trout and northern pikeminnow.

Beauchamp et al. (1995) determined that kokanee and juvenile sockeye salmon represented the predominant source of planktivory in the lake. The combined kokanee-sockeye salmon consumption represented less than 1% of the standing stock biomass of edible-sized (length > 1.0 mm) *Daphnia* in the lake during any month of the April-November growing season. These results did not change dramatically if we assumed that the planktivores could only consume larger (> 1.2 mm) *Daphnia.* Juvenile kokanee and sockeye salmon (40-140 mm fork length [FL]) represented 72% of the diet of limnetic northern pikeminnow $\geq$300 mm FL during winter-summer and 40% of the diet of large ($\geq$ 300 mm FL) limnetic cutthroat trout during spring-summer. Model simulations suggested that for every 1,000 cutthroat trout$\geq$300 mm FL, 139,000 age-0 salmon would be consumed per year. This represented 17% of the average estimated annual fry production. In contrast, only 0.7% of the annual fry production would be consumed annually per 1,000 northern pikeminnow $\geq$ 300 mm FL. The much lower predation by northern pikeminnow resulted from limited spatial and temporal overlap with juvenile salmonids in the limnetic zone; only 2-8% of the piscivorous northern pikeminnows inhabited the limnetic zone during spring and summer. Beauchamp et al. (1995) concluded that competition was unlikely limit salmonid production, but that predation could potentially undermine enhancement efforts. The predation per 1,000 cutthroat trout was sufficiently severe that it was an obstacle to further enhancement consideration. If managers wished to explore enhancement further, they now knew that some assessment of large cutthroat trout abundance would be needed, and the justification for estimating cutthroat trout density or abundance was the high per capita predatory demand they represented.

Lake Washington: Estimating Carrying Capacity for Planktivorous Fishes, and Examining Direct and Indirect Effects of Piscivory

Sockeye salmon support a valuable tribal fishery and an extremely popular sport fishery in Lake Washington, but smolt production and adult returns declined in the 1980s and 1990s. In 1980, rainbow trout stocking program was initiated in Lake Washington and was implicated in the decline of juvenile sockeye salmon. Evidence of significant direct predation by rainbow trout on sockeye salmon was minimal and could not explain the decline (Beauchamp 1990). However three piscivores, the native northern pikeminnow and cutthroat trout, and stocked rainbow trout, overlap spatially and temporally to some extent with juvenile sockeye salmon and the other major pelagic planktivorous fishes (longfin smelt and threespine stickleback), so rainbow trout might affect sockeye salmon indirectly by affecting other species in the food web. While the effects of rainbow trout predation were being debated, pilot enhancement efforts for juvenile sockeye salmon were initiated in the 1990s. Managers and scientists were concerned about exceeding the carrying capacity of the lake for the pelagic planktivorous community plus the young planktivorous stages of other fishes in the lake like yellow perch. Thus, the effects of multiple piscivores and multiple planktivores needed to be examined within a food web context to evaluate the relative importance of predation, competition, and temporal food supply on the production of sockeye salmon. Also, limitations to sockeye production needed to be attributed to the appropriate stage of their life history (i.e., mortality during riverine phase for eggs or fry versus lake-phase); thus an analysis of predation on migrant fry was also implemented.

<u>Estimating the Carrying Capacity of Lake Washington for Planktivorous Fishes</u>—Beauchamp (1996) compared temporal changes in biomass, size structure, and production of *Daphnia pulicaria* to consumption demand by the major planktivorous fishes in Lake Washington to determine whether food supply might limit fish production under current or enhanced population levels of sockeye salmon. *Daphnia* biomass and production were estimated from time series of *Daphnia* density, egg ratio, and temperature measurements (Paloheimo 1974; Gabriel et al. 1987) in 0-10 m during 1980-1986, and 10-20 m and 20-58 m during 1984. Consumption demand was estimated from bioenergetic model simulations for different fishes: age-0 sockeye salmon; age-0 and age-1 longfin smelt, rainbow trout, age-0 and age-1 yellow perch, and threespine stickleback. Seasonal data on size-specific diet composition, growth, thermal experience, abundance, and mortality were available from 1983-1991 and data from International Biological Program (IBP) studies during the 1970's. Planktivore predation rates were simulated for April 1989-March 1990, when age-1 smelt were abundant, and for April 1990-March 1991, when age-1 smelt were scarce. Simulations were run with sockeye salmon population abundance set first at current levels, then with projected abundances under different enhancement scenarios. Model simulations estimated that the combined consumption by rainbow trout, yellow perch, and threespine stickleback on *Daphnia* (annual consumption = 978 tonnes) exceeded consumption demand by longfin smelt and juvenile sockeye salmon (882 tonnes in 1989 and 163 tonnes in 1990). During the April-November growing season, combined consumption by all planktivorous fishes represented 0.5-11% of *Daphnia* biomass and 0.2-3.8% of production when sockeye and smelt were abundant, or 0.2-8.0% of biomass and 0.1-2.8% of production when they were scarce. However, Daphnia biomass and production were 2-10 times lower in 10-20-m than in 0-10-m depths. If sockeye salmon only had access to this deeper supply of *Daphnia*, their consumption demand represented approximately 30% of *Daphnia* biomass and production in 10-20-m depths when sockeye were abundant in 1989. When they were less abundant in the 1990 growing season, their consumption represented <10% of the *Daphnia* biomass and production in 10-20 m. Simulations of winter consumption indicated that most consumption demand could be attributed to sockeye salmon, followed by threespine sticklebacks and rainbow trout, and that up to 47% of production and 117% of standing stock biomass would be consumed by abundant natural populations if diet compositions remained the same in winter as during the growing season; however, most planktivores likely switched to benthos or more abundant copepods during winter.

Based on these simulations, the importance of the depth-specific availability of zooplankton to sockeye salmon became apparent. Is juvenile sockeye salmon could only utilize Daphnia below 10 m during summer stratification, then only modest enhancement of sockeye fry (i.e., no more than a doubling of current production) could be supported by the existing carrying capacity of the lake, and some density-dependent growth reduction might result.

Effects of Piscivory on Planktivorous Fishes in Lake Washington—Longfin smelt is the only other planktivorous fish inhabiting the limnetic zone throughout the year. Smelt live for two years. Although smelt populations were mildly cyclic before 1980, the amplitude of these cycles increased dramatically after rainbow trout stocking began, and even-numbered brood years became 5-15 times more abundant than odd–numbered years (Moulton 1974; Chigbu 1993). Hatchery rainbow trout predation concentrated on longfin smelt, whereas the native piscivores diversified their piscivory among three prey fishes: northern pikeminnow ate considerable amounts of sockeye salmon, longfin smelt, and prickly sculpin, while cutthroat trout ate sockeye salmon, longfin smelt, and threespine sticklebacks.

Patterns of consumption by the three piscivores differed between years when smelt populations were strong or weak. All three piscivore populations began eating pelagic planktivores (25-120 mm prey fork length) when predator fork lengths reached 250-300 mm. Large rainbow trout ate longfin smelt throughout the year (Beauchamp 1990). From model simulations, rainbow trout consumed an estimated 6.3 million (range in prey body mass, 3-18 g) from a strong year class of age-1 smelt, and 4.7 million smelt from a weak year class. Cutthroat trout ate 4.0 million smelt from the strong year class, but only 1.5 million smelt from the weak year class (Figure 3). When the smelt population was depressed, cutthroat trout ate more sockeye salmon parr (2.1 versus 1.4 million; range in body mass 5.0-13.1 g). Northern pikeminnow ate smelt in autumn-winter, and sockeye salmon fry, parr, or presmolts throughout the year. When smelt populations were depressed, northern pikeminnow consumed more sockeye salmon parr (1.7 million) than when smelt were abundant (1.0 million parr eaten), because sockeye parr were substituted for smelt during autumn-winter. The combined predation from the three piscivore populations totalled 10.8 million smelt 2.4 million sockeye salmon parr, and 200,000 sockeye salmon fry during strong smelt years versus 6.3 million smelt, 3.8 million sockeye salmon parr, and 1.2 million sockeye fry during weak smelt years.

Differences between smelt and sockeye in their overlap with sight-feeding piscivores during daylight or crepuscular periods explained the differences in their predation losses and revealed opportunities and constraints for prey-switching by predators. Longfin smelt overlapped extensively with all three piscivores in both time and space, whereas juvenile sockeye salmon overlapped vertically with cutthroat trout throughout the year, seasonally with northern pikeminnow, and only as migrant fry or smolts with rainbow trout. Thus, when longfin smelt were abundant, they absorbed the predation impact by all three piscivores and partially buffered sockeye salmon from predation by cutthroat trout and northern pikeminnow. However, when longfin smelt were scarce, rainbow trout continued to feed heavily on them, driving the population dangerously low, whereas cutthroat trout and northern pikeminnow switched to feed more heavily on juvenile sockeye salmon. Mortality rates for smelt and for the lake-resident phase of juvenile sockeye salmon were nearly doubled in years when age-1 smelt abundance was low compared to when smelt abundance was high. The additional predatory demand imposed by stocked rainbow trout on smelt altered the structure and function of the Lake Washington food web with management implications ranging from lake transparency to the production of commercially- and recreationally-important fishes (Beauchamp 1994).

Riverine Predation on Migrant Sockeye Salmon Fry—Potential riverine sockeye salmon fry predators were sampled once or twice per month in the lower 9.6 km of the Cedar River using a drift-boat mounted electroshocker during the fry migration period in 1983-1985. Of all the species sampled, only wild steelhead smolts contained fry. The proportion of fry in the diet of wild steelhead varied considerably over the migration period, ranging 2-52% and averaging 13% of the wild smolts' diet from February through mid-May. Hatchery-reared steelhead smolts were stocked during the latter half of the fry migration, but no evidence of fry predation was detected from the 18 hatchery smolts that were examined. The heaviest predation occurred during the early to middle portion of the fry migration (February to mid-April), then diets switched primarily to largescale sucker eggs and invertebrates. Fifty four different bioenergetic simulations were run to examine how uncertainties about predator growth, diet composition, thermal experience, and predator abundance might affect estimates of fry predation. The nominal simulation run which was based on the best estimates of each of the model inputs resulted in an estimated predation rate of 6.8 million fry; the range of estimates from all 54 predation scenarios was 2-44 million fry, but most estimates clustered within 4-10 million fry consumed (Beauchamp 1995). Thus, riverine predation represented a potentially significant source of fry mortality prior to entering the lake, but involved a desirable sensitive native species.

Impact of Non-native Lake Trout in Yellowstone Lake

When lake trout were discovered in Yellowstone Lake in 1994, the National Park Service needed to know whether this non-native predator represented a real threat to the ecological integrity of the Lake and surrounding ecosystem. The immediate questions that needed to be addressed included whether lake trout were naturally reproducing, was the population stable or increasing, and could their trophic interactions alter the dynamics of the native community through competition or predation.

Ruzycki and Beauchamp (1997) used some preliminary diet, distribution, growth, and size structure data collected for lake trout to simulate the seasonal and size-specific loss of the indigenous Yellowstone cutthroat trout due to predation by lake trout. Lake trout $\geq$ 270 mm FL began including cutthroat trout in their diet. Lake trout were capable of consuming cutthroat trout 50% their own body length, and the average size of fish prey was 25% of the predator’s body length. Little was known about the actual abundance of lake trout in Yellowstone Lake, but at least 25 year classes were well represented in the population. Based on the observed size structure of lake trout and the bioenergetic simulations, an estimated 59,000 cutthroat trout (100-300 mm FL) were consumed for every 1,000 lake trout $\geq$ 270 mm FL. This analysis provided managers important justification and public relations tool for aggressively pursuing a lake trout reduction program, because every lake trout > 270 mm consumed an average 59 cutthroat trout per year. Since the incidental catch of cutthroat trout was high, even when targeting lake trout in time, space, and with larger mesh sizes (Mahoney and Ruzycki 1997), the ratio of lake trout to cutthroat trout catch in these efforts could be viewed in terms of trading off incidental net mortality with reductions in annual predation losses.

Estimating Predation Losses Under Different Lake Trout Population Sizes and Kokanee Stocking Scenarios in Flathead Lake

Flathead Lake historically supported the largest kokanee fishery in North America. This population crashed in the mid-1980s coincident with the establishment of high densities of the opossum shrimp Mysis relicta which had invaded from lake upstream where they had previously been introduced (Beattie and Clancey 1991). Also coincident with the mysid increase was a marked increase in lake trout catch and declines in native bull trout and westslope cutthroat trout. Federal, state, and tribal managers attempted to re-establish the kokanee population by stocking up to a million yearling kokanee each spring, but they needed to know whether any of the proposed stocking strategies would result in reasonable adult returns to the fishery and spawning traps. Of primary concern was whether predation losses by lake trout would be too severe to allow sufficient kokanee recruitment satisfy a viable fishery and/or spawning operation.

Bioenergetic model simulations suggested that lake trout predation imposed serious losses on the kokanee population in Flathead Lake, accounting for 87% (in the nominal run) of the number stocked within the first year of their release (Beauchamp 1996). The heaviest predation in 1994 occurred during the first month after stocking 800,000 kokanee (120 mm FL) in June (351,000 kokanee eaten). Kokanee losses during this acute predation period exceeded total predation losses accrued during July-September (263,000 eaten). Lake trout in the 626-750 mm and 501-625 mm size class were responsible for more than 64% of the estimated predation, and 376-500 mm lake trout consumed another 21%. Kokanee disappeared from the diets of progressively larger predators over time suggesting that they rapidly outgrew the smaller, more abundant predators.

Different predation scenarios were modeled to examine the effects of different dietary responses by lake trout, different assumptions about the abundance and size structure of lake trout, and different stocking rates for kokanee. When modeling the effects of either an acute or higher chronic predation response by lake trout, kokanee survival over the first year in the lake declined from 13.2% in the nominal run to 4.6% in a chronic predation scenario, whereas no kokanee survived past midsummer in an acute predation scenario. Lake trout abundance might have been underestimated in model simulations, because size and abundance were based on a hydroacoustic survey in August 1995. Since standard hydroacoustic methods cannot detect fish ≤ 1 m from the bottom, some fraction (e.g., 10-50%) of the predator population might not have been detected. When larger lake trout populations were modeled, kokanee survival (from an initial stock of 800,000) dropped from 13.2% to 4.2% with a 10% increase in lake trout abundance, and no survival was predicted if the lake trout population was 50% larger than the acoustic-based estimate. Model simulations suggested that the kokanee mitigation program could not meet its goals under the current stocking regime of releasing 800,000-1,000,000 yearling kokanee in late spring. Predation losses alone accounted for nearly all of the kokanees stocked, but other sources of mortality would also reduce adult recruitment. Consequently, the kokanee mitigation program was terminated, because predation losses were too high and the expense and limited capacity to raise enough kokanee to swamp the predators was prohibitive.

Discussion

A general approach to modeling aquatic food web interactions was presented with some case histories to demonstrate the types of information that can be gained and the flexibility of this conceptual framework for quantitatively modeling a wide variety of problems. The case histories described above illustrated how food web modeling identified and quantified trophic interactions to determine whether predation, food supply, or competition were important factors limiting survival or production of various species or life stages of interest. These simulations also demonstrated which species or size classes were interacting most strongly, and when the periods of critical interactions occurred. The simulations could then be extended to examine the likely outcome of various scenarios to determine if various management options were feasible and to evaluate whether they might achieve the desired effect.

Initial simulations can also be constructed by using existing information from the system, supplemented by literature values and expert assumptions to generate an initial evaluation of the food web. The process of creating a model of the system is extremely valuable, because it allows managers and researchers to formalize abstract concepts of numerous potentially important processes into a visual and mathematical framework. This provides a process for filtering information and a mechanism to identify, quantify, and rank the relative importance of various processes that regulate populations, and thus help managers prioritize efforts to focus on the most critical processes first. This framework helps us to manage uncertainty. It allows us to continue with the analysis by making reasonable assumptions about our uncertainty and placing upper and lower bounds on the range values surrounding our uncertainty. These assumptions are flagged and can then be revisited using sensitivity analyses to quantify how important each particular source of uncertainty might be to the response by the system. For instance, juvenile salmon can represent 0-100% of the diet, but perhaps we can reasonably assume that the percentage in natural conditions will be 10-25%. Rather than allowing paralysis to set in over our lack of information, we can continue by first simulating predation using a some reasonable assumption about the diet composition of the predator, then repeat the simulations with the juvenile salmonid component of the diet that are changed ± 10% to evaluate: 1) how much an incremental change in diet translates into a change in predation rate on that prey; and 2) how important is this element of uncertainty. Based on initial simulations constructed from existing information, this modeling framework provides a comprehensive method for identifying and prioritizing management options and establishing the next tier of questions. This provides guidance and the rationale for designing subsequent studies or large-scale experiments within an adaptive management framework, and helps determine when to phase different tasks into the study.

The field effort required to obtain population-specific inputs for the model can be significant, but some of these activities are often already underway as part of a routine monitoring program. One of the purposes of this paper was to demonstrate the importance of collecting, recording, and analyzing routinely-collected data on relative abundance, length, weight, distribution, diet, age, growth, and basic limnological sampling. Sometimes subtle changes in sampling protocols may vastly improve the utility of the data with only a minor increase in effort.

An alternative and less data-intensive approach is the "qualitative mathematical analysis" described by Dambacher et al. (this volume) which enables an analysis of community stability based on information about whether interactions are positive, neutral, or negative, and has the advantage of incorporating positive and negative feedback loops explicitly into the food web analysis. These quantitative and qualitative modeling approaches each have strengths and weaknesses, but can serve as powerful complementary tools at different phases of a research or management program.

We should continue to strive for better predictive capability in our research and management tools. Some of the key weaknesses in the current modeling framework is that we can only guess at how organisms will respond to changing conditions (e.g., different environmental conditions, changes in the abundance or variety of predator, competitor, or prey species, changes in distribution and behavior of existing species, etc.). To this end, new approaches are being developed to enhance our ability to simulate responses to change, based on mechanistic processes that should drive behavior, but respond predictably to measurable factors. Some examples include visual foraging models for pelagic planktivores (Stockwell and Johnson 1997), and pelagic piscivores (Beauchamp et al. in press). The current planktivore does a nice job of predicting the diel vertical distribution and growth of kokanee in response to the zooplankton density distribution and vertical temperature profiles (Stockwell and Johnson 1997). The pelagic piscivore model predicts how the relative importance of piscivory (or alternatively, the contribution of prey fish to the diet of piscivores) changes as system productivity changes (e.g., water transparency and the density and distribution of forage fishes; Beauchamp et al. in press). Thus, managers could evaluate whether introduction of a new species or other manipulations in stocking, harvest, or enhancement would achieve the desired result or impose new challenges to the ecological integrity of the food web.

Table 1. A list of waters in western states where the food web modeling approach has been applied to various questions about temporal prey supply and demand.

SE Alaska- Margaret Lake: Predation by resident cutthroat trout on stocked sockeye salmon fry (Cartwright et al. 1998).

Lake Washington, Lake Ozette, Washington: Effects of predation, competition, and seasonal food supply on sockeye salmon production (Beauchamp 1990, 1994, 1995, Beauchamp et al. 1992, 1995, in press)

Oregon- Lake Billy Chinook: Effect of native bull trout consumption on kokanee and effect of cannibalism on bull trout recruitment (in preparation).

California/Nevada- Lake Tahoe: Examined the trophic interactions of lake trout and kokanee with regard for the potential for lake trout to regulate populations of native cyprinids, mysids, or kokanee (Thiede 1997), and the ability of kokanee or mysids to regulate zooplankton populations (Van Tassell et al. in preparation).

Montana- Flathead Lake: Model the predatory impact of lake trout on kokanee under current conditions, under various stocking regimes for kokanee, and in response to changes in the abundance or size structure of the lake trout population (Beauchamp 1996).

Wyoming- Yellowstone Lake: Evaluate the impact of non-native lake trout on the Yellowstone Lake ecosystem, particularly on native Yellowstone cutthroat trout (Ruzycki and Beauchamp 1997).

Utah/Idaho- Bear Lake and Strawberry Reservoir: Model the effects of piscivory on recruitment of juvenile Bear Lake-strain cutthroat trout by larger cutthroat trout, rainbow trout, or lake trout, and examine temporal consumption demand versus food supply to identify potential bottlenecks in the production and survival of trout (or kokanee) in oligotrophic Bear Lake versus meso-eutrophic Strawberry Reservoir (Baldwin et al. in review; Orme et al. in preparation).

Colorado River: Evaluate the potential impact of northern pike predation on the endangered Colorado pikeminnow. (Crowl et al. in review)

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Historical Reconstruction, Through Qualitative Modeling, Of The Effects Of Exotic Fish Introductions In Tenmile Lakes Oregon

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Abstract- *A general overview of qualitative modeling is presented in the context of fisheries management. A historic reconstruction of exotic fish introductions to Tenmile Lakes was qualitatively modeled based on foodwebs drawn from diet studies of the system. The history of species introductions in Tenmile Lakes can be characterized as one that has driven the system into neutral responses and neutral stability, with correlations between native species being inverted, certain species loosing their ability to respond to system input, and an overall loss of opportunity for management options. Expected outcomes to predator-prey interactions were not supported by model predictions, due to indirect effects from complex interactions between the mix of native and introduced species. The use of exotic fish predators to control undesirable species was predicted to have an effect that was opposite to management objectives. In its present state the system, as modeled, defies predictable management.*

Introduction

> "...he will learn little if he limits himself to that species. He must evidently study also the species upon which it depends for its existence, and the various conditions upon which *these* depend. He must likewise study the species with which it comes in competition, and the entire system of conditions affecting their prosperity." (Forbes 1887)

In 1887, Steven A. Forbes laid out in unmatched prose the complexity of a lake environment, and the imperative to study the entire "microcosm" presented by biological systems, both in terms of the context of their physical environment, and in terms of the interactions between species in the community. It remains today an enormous challenge. While the ecosystem has long been defined as a unit of study (Tansley 1935), its arrival into management and ecological research has only been recently emphasized (McIntosh 1985). And while the need to research and manage whole communities and ecosystems rather than just single species, has been recognized, working notions of how to accomplish this daunting task have been vague. Biologist striving to gain understanding of complex biological systems, inevitably turn to models of the world as a means for organizing their hypotheses and approaches.

Modeling approaches

Levins (1966) ascribes three properties to all models: 1) *generality*, 2) *realism*, and 3) *precision*. For a model to be manageable only two of these can be maximized in a given application; to emphasize all three would require the impossible task of duplicating nature. The critical decision then, is to decide which property to sacrifice for the other two. Models that sacrifice generality for realism and precision can be described as *Mechanistic models*, they are commonly applied by natural resource managers, especially in fisheries (e.g. stock recruitment and yield models, bioenergetic models). Intensive data collection and comprehensive equations yield precise and testable predictions, but applications are restricted by a narrow range of initial conditions. *Statistical models*, which sacrifice realism, are useful for describing general patterns with measured confidence, but correlations are not transferable into causalities, and one is left with little understanding of the workings of the real world. *Qualitative models* sacrifice precision in favor of generality and realism. They are free from the constraints of extensive and expensive data collection, and while their predictions are only qualitative (i.e. only the direction of change in a system, and not the absolute amount, is predicted), they are nonetheless rigorous in their derivation, and produce testable hypotheses. Levins (1974, 1975; Puccia and Levins 1985) developed a method of modeling interactions among populations, termed *loop analysis*, but which is also specifically referred to as *qualitative analysis*, that is ideally suited to the study of complex biological systems with many interacting variables.

Application of qualitative modeling to management of biological communities

Qualitative modeling meets the requirement of community and ecosystem level models. It accommodates large temporal and spatial scales, is generally applicable, mathematically rigorous, and has high correspondence between model parameters and the biology of ecosystem. It has simple data requirements. Essentially the data input describes the interactions among species, in large part this is simply foodweb structure, as modified by competition, parasitism, etc.. Model outputs are used to evaluate community stability and predict ecological change, through a prediction matrix. These in turn can be used to focus research efforts on critical interactions and develop testable hypotheses of system behavior. Below we present a general overview of the qualitative modeling method, followed by an example application to the problem of introduced fish species in Tenmile Lakes, Oregon.

Overview of qualitative modeling

General Methodology

Detailed procedures for qualitative modeling are described in Puccia and Levins (1985). Li et al. (In Press) present convenient methodology for using symbolic mathematical PC based software. Qualitative models build up from the population level to the community level by way of interaction terms between populations. Implicit within these models are the Malthusian parameters of population size, birth rate, death rate, and mean generation time. Interaction terms are drawn from per capita effects within Lotka-Volterra equations (Figure 1). Qualitative analysis omits quantitative expression of these terms, and instead relies only upon which species are present, and the nature of their interactions. These relationships are generally depicted by signed digraphs (a.k.a. sign-directed graphs), which contain all of the essential information needed for qualitative modeling. Signed digraphs can be used to depict all possible relationships between species (Figure 2), in terms of trophic interactions, competitive interactions, and self-regulation. Self-regulation in the context of qualitative models stems from a species gaining resources from outside the model system. All that is used in qualitative modeling is the sign of the interaction terms for each species in a community, and together these interaction terms form the basis for the community matrix (Figure 3). The community matrix contains all the information of the signed digraph, and its analysis yields two basic products: 1) an assessment of community stability through system feedback, and 2) a prediction matrix that details the response of populations, in terms of abundance, to input to the other populations within the system. System stability is described numerically, in part, by overall system feedback (Figure 4), and can be placed in the three general categories of stable, unstable, and neutrally stable states. Prediction matrices are developed directly through algebraic manipulations of the community matrix (transpose$(-A)^{-1}$, where A is the community matrix). These predictions are essentially testable hypotheses about how the system responds to chronic (press) disturbances (Bender et al. 1984).

Model example

An example of a signed digraph and prediction matrix is presented in Figure 5, which describes a system of interacting populations of invertebrates, fish consumers, and a specialized predator that feeds exclusively on one of the fishes. The prediction matrix depicts the numerical response of populations to positive input to the system. Positive input is viewed in terms of increases to the birth rate, or decreases in the death rate of an individual population. Input to the system is read along the rows, and population responses are read down the columns. In ecological terms positive input can be in the way of fertilization to nutrient poor systems, or increased cover for a herbivore to escape from its predator, or conversely increased cover for a predator to ambush its prey. To depict increases in the death rate of a population, one merely reverses the signs of the responses in the prediction matrix. For instance, in Figure 5, increasing the production of invertebrates through an increase in their food supply (which is read along the first row) is predicted to create no change in the population size of invertebrates, an increase in Fish A, no change in Fish B, and a decrease in the predator population. Competition between the two fish consumers creates positive feedback in the system through the A-to-B-to-I-to-A loop (i.e. multiplying the signs of each interaction term (-,-,+) in this loop yields a positive term). In this instance, the positive feedback creates counterintuitive behavior in the model; an increase in the predators birth rate is predicted to create a decrease in the size of the predator population! However, such a system is not likely to exist, as overall feedback in this model is positive, which would likely create unstable population fluctuations. Although subsystems of large stable communities can contain positive feedback loops that create similarly counterintuitive behavior. Hence an essential use of qualitative modeling is to identify interactions that are critical to system behavior. And while this can be advantageous in forecasting the effects of changes in community structure or management actions, it can also be useful in understanding past system behavior, so that present management actions can be considered within a historical context.

Exotic Fish Introductions to Tenmile Lakes, Oregon

Historic reconstruction of community structure

Tenmile Lakes are an interconnected series of shallow freshwater lakes formed behind sand dunes along the southern coast of Oregon (Figure 6). The lakes are eutrophic, and have dense growths of aquatic vegetation covering soft bottom sediments of sand and silt. The native fish community of the lake system included coho salmon (*Oncorhynchus kisutch*), steelhead (*O. mykiss*), cutthroat trout (*O. clarki*), threespine stickleback (*Gasterosteus aculeatus*), prickly sculpin (*Cottus asper*), eulachon (*Thaleichthys pacificus*), and lamprey (*Lampetra* spp.) ammocoetes. There is an extensive history of introductions of warmwater exotic fishes since the 1920's (Table 1), including yellow perch (*Perca flavescens*), brown bullhead (*Ictalurus nebulosus*), bluegill (*Lepomus macrochirus*), largemouth bass (*Micropterus salmoides*), a hybrid of striped bass (*Morone saxatilis*) x white bass (*M. chrysops*), and black crappie (*Pomoxis nigromaculatus*). All of these introductions were unauthorized except for largemouth bass and hybrid bass (ODFW 1991). During the 1940's the Tenmile Lakes watershed was logged extensively, which accelerated sedimentation in the lake and stream systems. The Brazilian waterweed (*Elodea densa*) was first noted in 1947, and quickly spread throughout the lake system, forming thick beds; other introduced macrophytes include water milfoil (*Myriophilum verticillatum*), and the water lily (*Nymphaea ordorata*). The increased sedimentation of the lake enhanced macrophyte production, which in turn created favorable conditions for the reproduction and rearing of warmwater fishes. The coho salmon population declined dramatically, and competition and predation from warmwater fish were thought to be the major cause, although habitat degradation has also been implicated. A large-scale rotenone treatment was done in 1968 to curb the effects of a superabundant population of bluegill as well as other warmwater fishes. The treatment eradicated yellow perch, but not bluegill and brown bullhead. The bluegill population rebounded immediately, and largemouth bass were introduced in 1971 for the purpose of their control, and also for the purpose of supporting recreational fisheries. Hybrid bass, which were expected to be sterile, were planted in the lake system from 1982 to 1998, for the same management goals. The program was discontinued when it was discovered that some hybrid bass had reproduced. In the mid 1980's yellow perch were apparently reintroduced illegally, however their appearance in sport catches and sampling efforts has been rare. The latest introduction was of black crappie, which were found to be widespread in the lake system in 1994.

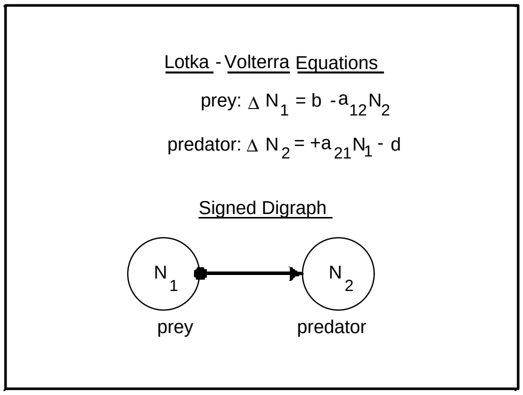


Figure 1. Lotka-Volterra equations for simple predator-prey relationship, and corresponding signed digraph; N_j: population size of species j, b: birth rate, d: death rate. Prey 1 has a positive per capita effect on predator 2, denoted by the arrow, and symbolized by the interaction term $+a_{21}$. Predator 2 has a negative per capita effect on prey 1, denoted by filled circle, and denoted by interaction term $-a_{12}$.

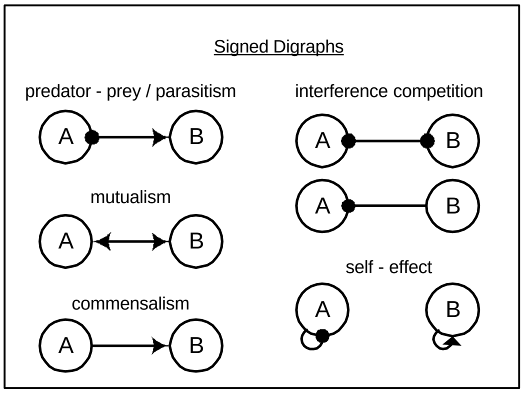


Figure 2. Signed digraphs of possible interaction pairs and self regulation for two species, A and B. Arrows denote positive feedback, filled circles negative feedback.

community matrix

$$\begin{bmatrix} 0 & -a_{12} \\ +a_{21} & 0 \end{bmatrix}$$

Figure 3. Qualitative community matrix with simple predator-prey interaction terms expressed symbolically. These terms can also be numerically expressed as -1 ($-a_{12}$) and +1 ($+a_{21}$).

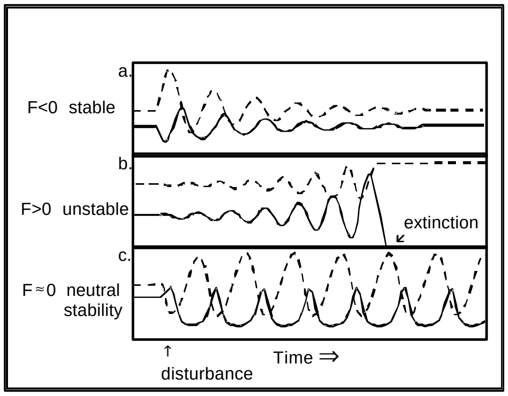
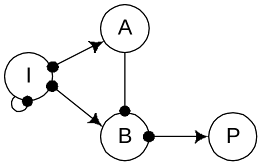


Figure 4. Generalized pattern of population fluctuations, following disturbance in communities, with (a.) overall system feedback (F)<0, creating stable dampened oscillations, with (b.) F>0, creating unstable oscillations with increasing amplitude, and with (c.) F≈ creating unregulated oscillations. Stable systems with negative feedback return to equilibrium following a disturbance. Extinctions are likely in unstable systems where overall feedback is positive. Systems that are near neutral stability tend to drift randomly with no tendency towards equilibrium conditions.



Prediction matrix

		Response of:			
		Invert.	Fish A	Fish B	Pred.
Positive input to:	Invert.	0	1	0	-1
	Fish A	-1	1	0	-1
	Fish B	0	0	0	1
	Pred.	0	1	-1	-1

Figure 5. Prediction matrix depicting population response to system input in terms of positive (1), negative (-1), or neutral (0), changes in population abundance; Invert.: invertebrates, Pred.: predators. System inputs are in terms of increases to birth rates of model populations. In this example positive feedback in the A-to-B-to-I-to-A loop produces the counterintuitive response of a decrease in the predator population from an increase to the birth rate of predators (adapted from Puccia and Levins 1985).

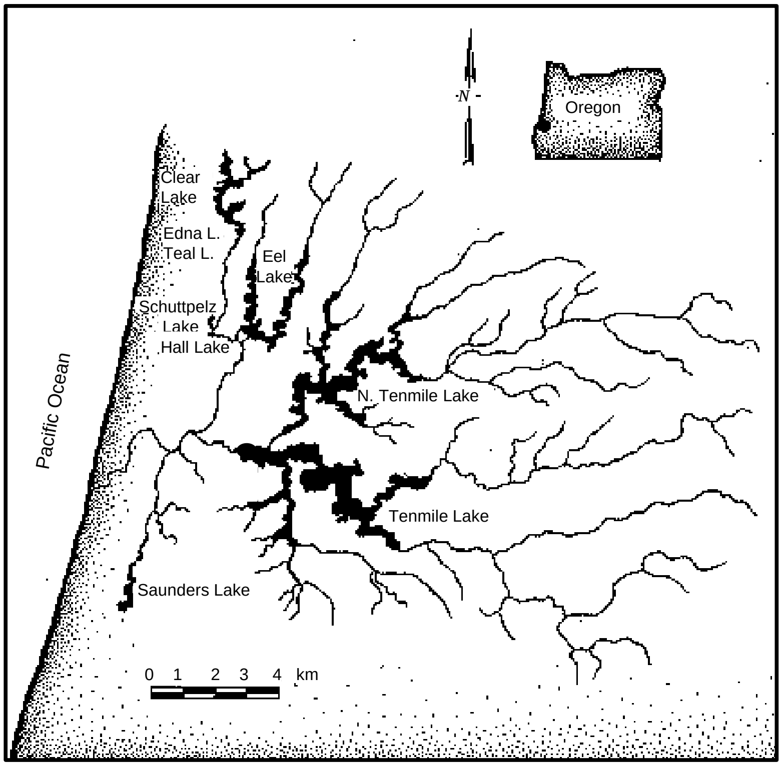


Figure 6. Map of the Tenmile Lakes basin (adapted from Gestring 1991).

Table 1. History of introductions and management in Tenmile Lakes, Oregon, and corresponding community models 1-6.

Species	1920 ⌈ 1930 ⌈ 1940 ⌈⇓[a] ⇓[b] ⌈ 1950 1960 ⌈ ⇓[c] ⌈ 1970 1980 ⌈ 1990 ⌈ 2000 ⌈
yellow perch[d]	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
brown bullhead	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
bluegill	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
largemouth bass	xxxxxxxxxxxxxxxxxxxxxxxxxxxxx
hybrid bass[e]	xxxxxxx
black crappie	xxxxxx
Model #:	1 | 2 | 3 | 4 | 5 | 6

[a]: 1940's-basin logged, sedimentation of lake and stream habitat.

[b]: 1947-Brazillian waterweed (*Elodea densa*) introduced, later introductions of water milfoil (*Myriophilum verticillatum*), and the water lily (*Nymphaea ordorata*).

[c]: 1968-rotenone treatment of entire lake system.

[d]: unauthorized reintroduction in the mid 1980's, population at very low levels.

[e]: hybrid of striped bass (*Morone saxatilis*) x white bass (*M. chrysops*), predominantly sterile.

To illustrate the effects that community structure has had upon management options for coho salmon in the Tenmile Lakes system, we analyzed 6 foodweb models that spanned a time series from pre-1920's to the present (Table 1). Foodweb structure was based on stomach contents sampling (1985-1990 sampling; unpublished data, Oregon Department of Fish and Wildlife), and reference texts for fish (Scott and Crossman 1973) and invertebrates (Merrit and Cummins 1984). The most important food item for fish in the system is the mysid (a.k.a. oppossum) shrimp (*Neomysis mercedis*), which during their peak abundance, can dominate the water column of the lake. The models focused on the community associated with juvenile coho salmon rearing in the lake system. Eulachon and steelhead were not included in the models, as they use the lake primarily for migration, and do not appear to have significant trophic interactions with the lake system. The introduction of hybrid bass was not depicted in the models, since it was for the most part sterile, it did not contribute to system feedback. Its effect on the system is equivalent to assessing isolated negative input to its prey, which is primarily mysid shrimp and bluegill (Gestring 1991). The reintroduction of yellow perch also was not modeled, as their populations appear to remain at very low levels, and likely do not have a significant affect on trophic dynamics in the lake system.

Where trophic relationships were uncertain, alternate models were constructed to judge the robustness of the results. Assertions of results presented in the follow 6 models were supported by all alternate models; in the following analysis we briefly describe each model, its predictions, and explain management implications.

Model 1, the pre-1920's native community

The native community of Tenmile Lake depicted in Model 1 (Figure 7) consisted of four resident fish species, with cutthroat trout as a top predator. In this model, and all subsequent models, juvenile coho salmon are depicted as being self-regulated, owing to the contribution of production from outside the model system during the stream and ocean phases of their life cycle. Basal species are also self-regulated, which accounts for their role as primary consumers. This model was stable, and had a relatively high amount of negative feedback. The prediction matrix for this model (Table 2) shows positive input to any one species in the system to produced a positive response in the population of that species. These self-responses are viewed along the diagonal trace of the prediction matrix. In this system coho salmon and cutthroat trout appear to be negatively correlated in terms of their response to changes in the system. To observe this negative correlation, note the responses in their respective columns of the prediction matrix; they are of opposite sign in 10 out of 13 rows. This suggests that when populations of coho salmon were at a relative high, cutthroat trout would usually have been at a relative low. Also note that coho salmon in this model would have been responsive to direct management input to itself, or by input to the food web.

Model 2, the 1920-1963 community

Model 2 depicts the introduction of yellow perch and brown bullhead (Figure 8). While this model was stable, the fate of coho salmon in the system was dramatically altered. Note that for coho salmon an increase in their birth rate is predicted to elicit no change in their population size, and a positive increase in their predator the yellow perch (Table 3). Coho salmon in this model appear to be largely isolated from input to the system, with most of their population responses being nil. Neutral responses are predicted for coho salmon to all increases in their food except for mysid shrimp. To observe this examine the response of coho salmon in columns associated with AM, EP, DI, CP, and OD in Figure 8. This suggests that for coho salmon in Model 2, increases in production from an increased food supply would be passed on to their predator, the yellow perch, with no net gain for coho salmon. Thus with the first introduction of exotic species in the system, direct management control of coho salmon was lost.

In Model 2 the system as a whole appears to have been less responsive to input. Every row, except those for mysid shrimp and prickly sculpin contain neutral responses; in Model 1, only five rows exhibited neutral responses. In Model 2 responses by coho salmon and cutthroat trout are either neutrally, or positively correlated with each other, but not negatively correlated as they primarily were in Model 1 of the native community model.

Model 3, the 1964-1968 community

Model 3, which is stable, illustrates the unauthorized introduction of bluegill (Figure 9, Table 4). The addition of bluegill to the community appeared to restore the responsiveness of the system, in contrast to Model 2. The community is this configuration predicted the direct management control of coho salmon; and an increases to the population of coho salmon resulting from inputs to their food base. This model is similar to Model 1 of the native community, in that coho salmon exhibit no neutral response to any input to the system, but it differs from Model 1 in that coho salmon and cutthroat trout show a more equal mix of positively and negatively correlated responses to each other as affected by input to the system.

Model 4, the 1969-1970 community

Model 4 (Figure 10) , which is stable, depicts the rotenone removal of yellow perch, and the persistence of brown bullhead, bluegill, and all native species. Historically it is a trivial model, as it represents only 2 years of the system. But it is noteworthy that the prediction matrix (Table 5) for coho salmon, and the system as a whole, is again filled with neutral responses as in Model 2, and therefore the community would have been less responsive to management in this configuration.

Model 5, the 1971-1993 community

Model 5 (Figure 11), which is stable, illustrates the purposeful introduction of largemouth bass and hybrid bass to control an overpopulation of blue gill. While largemouth bass are widely employed as a means of controlling bluegill populations elsewhere, model 5 predicts the opposite effect for the Tenmile Lakes fish community. Increases to largemouth bass effect an increase in the bluegill populations (i.e. see bottom row of Table 6 for column associated with BG for bluegill). The effect of hybrid bass in Model 5 can be interpreted as negative input to its prey mysid shrimp and bluegill. To determine the effects of negative input in a prediction matrix, the sign of the responses are reversed. In Table 6, a negative input to the two prey species of hybrid bass (mysid shrimp and bluegill) each predict a decrease in the population of coho salmon, which again is opposite to the desired management objectives. Similar to Models 2 and 4, Model 5 is filled with neutral responses in the prediction matrix, especially for coho salmon. In this system responses of coho salmon and cutthroat trout are either neutrally, or positively correlated with each other.

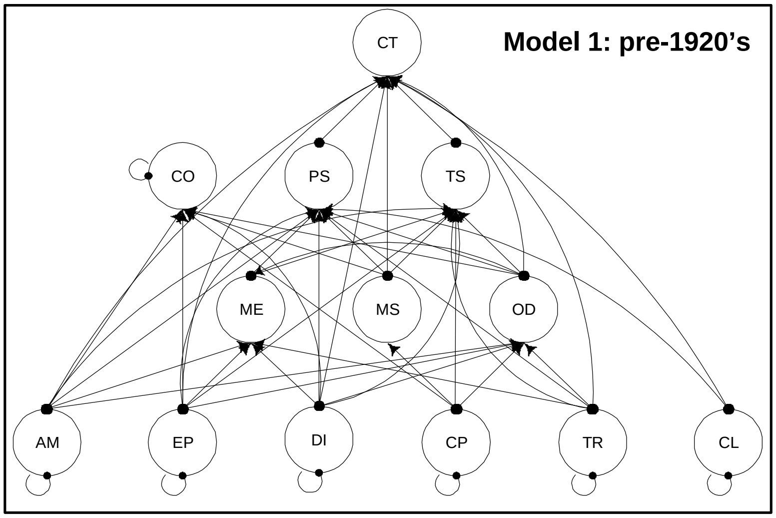


Figure 7. Signed digraph of native Tenmile Lakes fauna, circa pre-1920's; AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, CT: cutthroat trout.

Table 2. Model 1 prediction matrix for native Tenmile Lakes fauna, circa pre-1920's; AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, CT: cutthroat trout.

	AM	EP	DI	CP	TR	CL	ME	MS	OD	CO	PS	TS	CT
AM	1	-1	-1	1	-1	1	0	-1	1	1	1	1	-1
EP	-1	1	-1	1	-1	1	0	-1	1	1	1	1	-1
DI	-1	-1	1	1	-1	1	0	-1	1	1	1	1	-1
CP	-1	-1	-1	1	1	1	0	1	-1	1	-1	1	1
TR	1	1	1	1	1	1	1	1	-1	-1	-1	1	1
CL	-1	-1	-1	1	1	1	0	1	-1	1	1	-1	1
ME	1	1	1	1	-1	1	1	1	-1	-1	-1	1	1
MS	1	1	1	1	1	1	1	1	-1	1	-1	1	1
OD	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	-1	-1
CO	-1	-1	-1	-1	1	-1	-1	-1	1	1	1	-1	-1
PS	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	-1	-1
TS	1	1	1	1	-1	1	1	1	-1	-1	-1	1	1
CT	1	1	1	1	1	1	1	1	-1	-1	-1	1	1

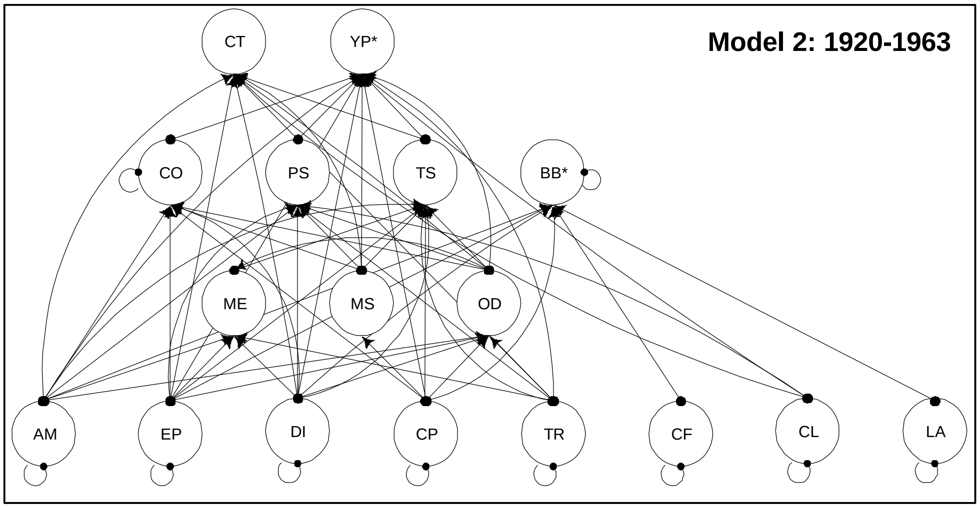


Figure 8. Signed digraph of Tenmile Lakes fauna, ca.1920-1963, with 2 introduced species (*); AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, BB*: brown bullhead, CT: cutthroat trout, YP*: yellow perch.

Table 3. Model 2 prediction matrix for Tenmile Lakes fauna, ca.1920-1963, with 2 introduced species (*); AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, BB*: brown bullhead, CT: cutthroat trout, YP*: yellow perch.

	AM	EP	DI	CP	TR	CF	CL	LA	ME	MS	OD	CO	PS	TS	BB*	CT	YP*
AM	1	-1	-1	0	-1	-1	1	-1	1	-1	0	0	-1	1	1	0	1
EP	-1	1	-1	0	-1	-1	1	-1	1	-1	0	0	-1	1	1	0	1
DI	-1	-1	1	0	-1	-1	1	-1	1	-1	0	0	-1	1	1	0	1
CP	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	1
TR	-1	-1	-1	0	1	1	1	1	1	1	0	0	-1	1	-1	1	-1
CF	-1	-1	-1	0	1	1	-1	-1	-1	1	0	0	1	-1	1	0	-1
CL	1	1	1	0	1	-1	1	-1	1	1	-1	0	-1	-1	1	1	1
LA	-1	-1	-1	0	1	-1	-1	1	-1	1	0	0	1	-1	1	0	-1
ME	1	1	1	0	1	-1	1	-1	1	1	-1	0	-1	1	1	1	-1
MS	1	1	1	-1	1	-1	1	-1	1	1	-1	1	-1	1	1	1	-1
OD	-1	-1	-1	0	-1	1	-1	1	-1	-1	1	0	1	-1	-1	-1	-1
CO	0	0	0	0	0	0	0	0	0	-1	0	0	1	0	0	-1	1
PS	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	1	-1	1	-1	1	-1	1
TS	-1	-1	-1	0	-1	1	1	1	-1	-1	1	0	0	1	-1	0	-1
BB*	-1	-1	-1	0	1	-1	-1	-1	-1	1	0	0	1	-1	1	0	-1
CT	0	0	0	0	1	0	1	0	1	1	-1	1	-1	0	0	1	-1
YP*	1	1	1	-1	-1	-1	1	-1	1	1	-1	-1	-1	1	1	0	1

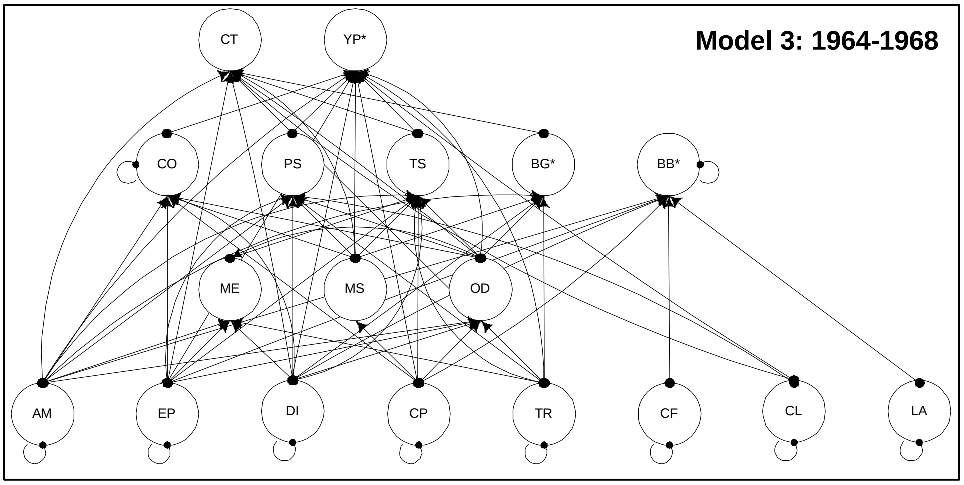


Figure 9. Signed digraph of Tenmile Lakes fauna, 1964-1968, with 3 introduced species (*); AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, BG*: bluegill, BB*: brown bullhead, CT: cutthroat trout, YP*: yellow perch.

Table 4. Model 3 prediction matrix for Tenmile Lakes fauna, 1964-1968, with 3 introduced species (*); AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, BG*: bluegill, BB*: brown bullhead, CT: cutthroat trout, YP*: yellow perch.

	AM	EP	DI	CP	TR	CF	CL	LA	ME	MS	OD	CO	PS	TS	BG*	BB*	CT	YP*
AM	1	-1	-1	1	-1	-1	1	-1	1	-1	1	1	-1	1	1	1	0	1
EP	-1	1	-1	1	-1	-1	1	-1	1	-1	1	1	-1	1	1	1	0	1
DI	-1	-1	1	1	-1	-1	1	-1	1	-1	1	1	-1	1	1	1	0	1
CP	-1	-1	-1	1	1	1	-1	1	-1	1	1	1	-1	-1	1	-1	0	1
TR	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1	1	-1	-1	1	-1
CF	-1	-1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	1	0	-1
CL	1	1	1	1	1	-1	1	-1	1	1	-1	1	-1	-1	1	1	1	1
LA	-1	-1	-1	-1	1	-1	-1	1	1	1	-1	-1	1	1	-1	1	0	-1
ME	1	1	1	-1	1	-1	1	-1	1	1	-1	-1	-1	1	-1	1	1	-1
MS	1	1	1	-1	1	-1	1	-1	1	1	-1	1	-1	-1	1	1	1	-1
OD	-1	-1	-1	-1	-1	1	-1	1	-1	-1	1	-1	1	-1	-1	-1	-1	-1
CO	-1	-1	-1	1	1	1	-1	1	-1	-1	1	1	1	-1	1	-1	-1	1
PS	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	1	-1	1	-1	1	1	-1	1
TS	1	1	1	-1	-1	-1	1	-1	1	-1	1	-1	-1	1	-1	1	0	1
BG*	-1	-1	-1	1	1	1	-1	1	-1	1	1	1	1	-1	1	-1	0	-1
BB*	-1	-1	-1	-1	1	-1	-1	-1	1	1	-1	-1	1	1	-1	1	0	-1
CT	1	1	1	-1	1	-1	1	-1	1	1	-1	1	-1	1	-1	1	1	-1
YP*	-1	-1	-1	1	1	1	-1	1	-1	1	1	1	-1	-1	1	-1	0	1

Model 6, the 1994-1999 community

Model 6 details the unauthorized introduction of black crappie (Figure 12). This model has zero overall feedback, and as such is neutrally stable. Reliable prediction matrices cannot be developed for neutrally stable systems. Such systems can be characterized by having no response to input, and are essentially unmanageable through the biota of the system. System behavior is chaotic, and unpredictable. Recovery time from disturbances can be uncommonly long, and likely longer than the typical return time of the natural disturbance regime. Input to the system is not desirable. In the least, input will not produce consistent long term results, or at worst it could induce large fluctuations that propagate through a long time series, and produce unpredictable and unintended consequences.

Consequences of introduced exotics

Inspection of the prediction matrix for Models 1 through 5 indicate that the native community, free from exotics, was the most manageable system. Positive input to a species uniformly produced increases in the abundance of that species; and vice versa, a negative input induced decreased abundance. Management of this system could have proceeded directly through the biota. Increases in the birth rate of coho salmon, for instance via a hatchery program, or decreases in death rate, via harvest regulation, was predicted to have elicited the desired effect of an increased population. With the introduction of brown bullhead and yellow perch in Model 2, direct input to coho salmon produced no effect, and thus direct management of coho salmon was lost. Introduction of bluegill in Model 3 reestablished positive response in coho salmon to input, but subsequent Models 4 and 5, which detail the removal of yellow perch, and the introduction of largemouth bass, show coho salmon to be unresponsive to system input. Through the general history of in fish introductions in the Tenmile Lakes system, coho salmon generally exhibit a loss of responsiveness to system input.

This modeling exercise suggests that the introduction of exotic fishes can alter the relationships between native species, as was exhibited by the inverted patterns of correlation between coho salmon and cutthroat trout. It also calls into question commonly accepted beliefs regarding the generality of some predator-prey relationships. While the ability of largemouth bass to control bluegill is routinely employed as a management tool in the communities in which these fish are native, when introduced into a “foreign” community, unexpected indirect effects can be promulgated through complex webs of interactions, and produce results that are directly opposite to those intended.

This historical analysis of Tenmile Lakes imparts immediacy to Stephen Forbes’ century old imperative to consider the whole system, and makes clear the need for managers to think explicitly about the consequences of system feedback when considering actions that alter community structure. The behavior of trophic systems can be counterintuitive to traditional notions based solely on direct effects, when in fact indirect effects, acting through the foodchain, can be more important. Experience gained from introductions in other systems (Li and Moyle 1993), has often shown exotic species to invoke such novel and intense interactions that system stability is compromised, and ensuing extinctions cause a loss of biodiversity (Zaret and Paine 1973, Hughes 1986, Spencer et al. 1991). Tenmile Lakes presents a somewhat different experience, with not a loss of species diversity, but rather a loss of management options and control. The lessons being that 1) introduction of a species can, through indirect effects, change the relationships between other species, and nullify or reverse the results of management actions in the system. 2) The ability of a predator to control a prey population is dependent on the structure of the community in which they occur. 3) As more species are added to a community, the system becomes less responsive to input, and target species can become isolated from direct control. 4) When introductions are taken to an extreme, system feedback can become so weak (neutrally stable) that the entire system does not respond to input at all.

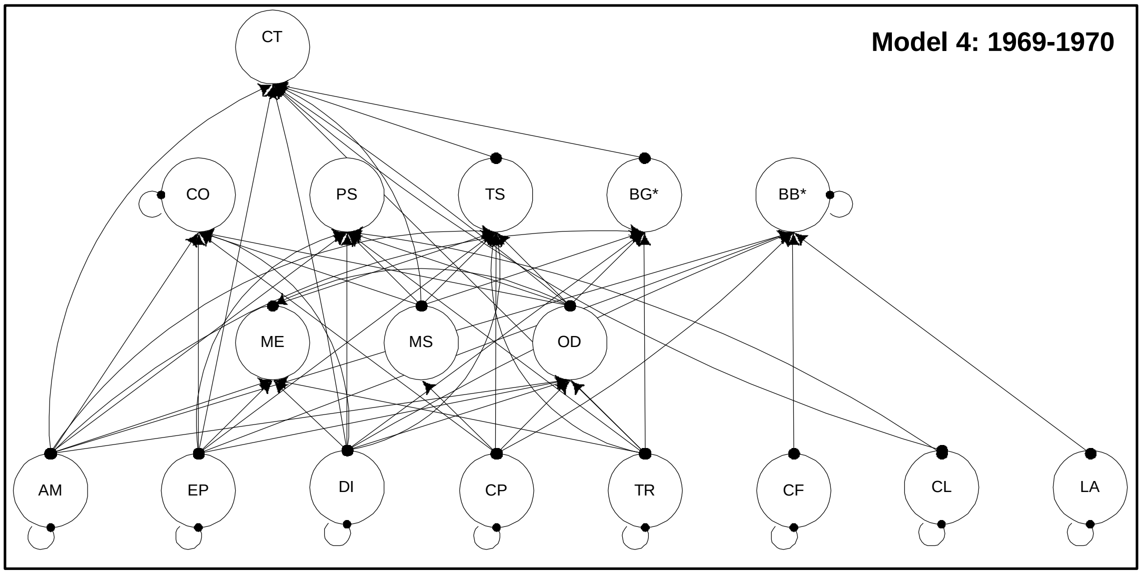


Figure 10. Signed digraph of Tenmile Lakes fauna, 1969-1970, with 2 introduced species (*); AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, BG*: bluegill, BB*: brown bullhead, CT: cutthroat trout.

Table 5. Model 4 prediction matrix for Tenmile Lakes fauna, 1969-1970, with 2 introduced species (*); AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, BG*: bluegill, BB*: brown bullhead, CT: cutthroat trout.

	AM	EP	DI	CP	TR	CF	CL	LA	ME	MS	OD	CO	PS	TS	BG*	BB*	CT
AM	1	-1	-1	0	-1	-1	1	-1	1	-1	0	0	-1	1	-1	1	0
EP	-1	1	-1	0	-1	-1	1	-1	1	-1	0	0	-1	1	-1	1	0
DI	-1	-1	1	0	-1	-1	1	-1	1	-1	0	0	-1	1	-1	1	0
CP	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0
TR	-1	-1	-1	0	1	1	1	1	1	1	0	0	-1	-1	1	-1	1
CF	-1	-1	-1	0	1	1	-1	-1	-1	1	0	0	1	-1	1	1	0
CL	1	1	1	0	1	-1	1	-1	1	1	-1	0	-1	1	-1	1	1
LA	-1	-1	-1	0	1	-1	-1	1	-1	1	0	0	1	-1	1	1	0
ME	1	1	1	0	1	-1	1	-1	1	1	-1	0	-1	1	1	1	1
MS	0	0	0	0	1	0	0	0	0	1	-1	1	-1	-1	1	0	1
OD	-1	-1	-1	0	-1	1	-1	1	-1	-1	1	0	1	-1	1	-1	-1
CO	0	0	0	0	0	0	0	0	0	-1	0	0	1	1	-1	0	-1
PS	1	1	1	0	-1	-1	-1	-1	-1	-1	0	-1	1	1	-1	1	-1
TS	1	1	1	-1	-1	-1	1	-1	1	-1	0	-1	-1	1	-1	1	0
BG*	-1	-1	-1	1	1	1	-1	1	-1	1	1	1	1	-1	1	-1	0
BB*	-1	-1	-1	0	1	-1	-1	-1	-1	1	0	0	1	-1	1	1	0
CT	0	0	0	0	1	0	1	0	1	1	-1	1	-1	-1	1	0	1

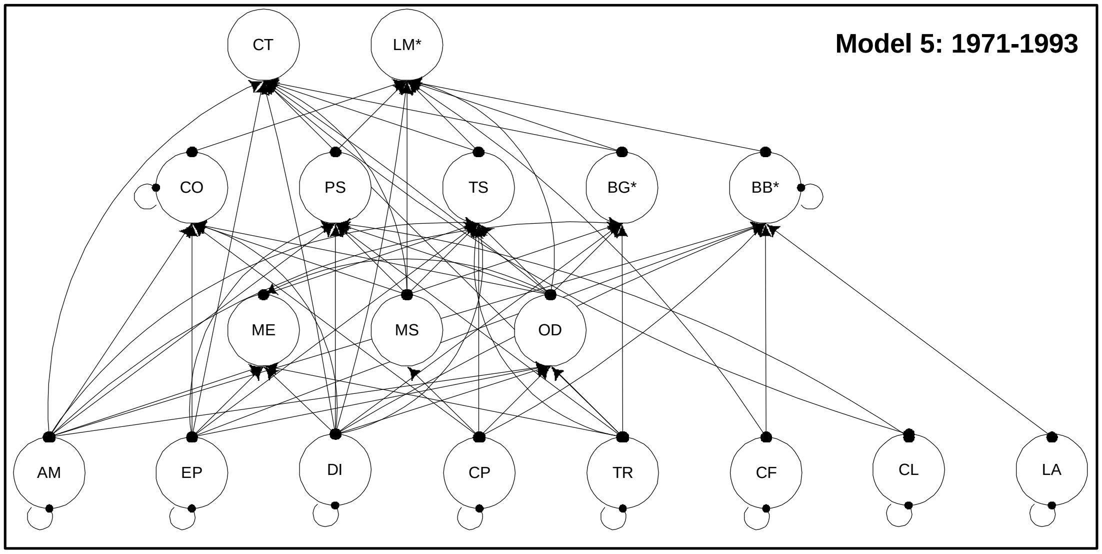


Figure 11. Signed digraph of Tenmile Lakes fauna, 1971-1993, with 3 introduced species; AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, BG*: bluegill , BB*: brown bullhead, CT: cutthroat trout, LM*: largemouth bass.

Table 6. Model 5 prediction matrix for Tenmile Lakes fauna, 1971-1993, with 3 introduced species; AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, BG*: bluegill, BB*: brown bullhead, CT: cutthroat trout, LM*: largemouth bass.

	AM	EP	DI	CP	TR	CF	CL	LA	ME	MS	OD	CO	PS	TS	BG*	BB*	CT	LM*
AM	1	-1	-1	0	-1	-1	-1	-1	-1	-1	1	0	1	1	-1	1	-1	-1
EP	-1	1	-1	0	-1	-1	-1	-1	-1	-1	1	0	1	1	-1	1	-1	-1
DI	-1	-1	1	0	-1	-1	1	-1	1	-1	-1	0	-1	1	-1	1	1	1
CP	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0
TR	-1	-1	-1	0	1	1	1	1	1	1	1	0	-1	-1	1	-1	1	-1
CF	1	1	-1	0	1	1	1	-1	1	1	-1	0	-1	-1	1	1	1	1
CL	-1	-1	1	0	1	1	1	-1	1	1	-1	0	1	1	-1	1	1	-1
LA	-1	-1	-1	0	1	-1	-1	1	-1	1	-1	0	-1	-1	1	1	1	1
ME	-1	-1	1	0	1	1	1	-1	1	1	-1	0	-1	1	1	1	1	-1
MS	0	0	0	0	1	0	0	0	0	1	-1	1	-1	-1	1	0	1	0
OD	-1	-1	-1	0	-1	1	1	1	1	1	1	0	1	-1	1	-1	-1	1
CO	0	0	0	0	0	0	0	0	0	-1	0	0	1	1	-1	0	-1	0
PS	1	1	1	0	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	1	-1	1
TS	1	1	1	-1	-1	1	-1	-1	-1	-1	1	-1	1	1	-1	1	-1	-1
BG*	-1	-1	-1	1	1	-1	1	1	-1	1	1	1	-1	-1	1	-1	1	1
BB*	-1	-1	-1	0	1	-1	-1	-1	-1	1	-1	0	-1	-1	1	1	1	1
CT	-1	-1	1	0	1	1	1	-1	1	1	-1	1	-1	-1	1	1	1	-1
LM*	1	1	-1	0	1	-1	1	1	1	1	-1	0	-1	1	1	-1	1	1

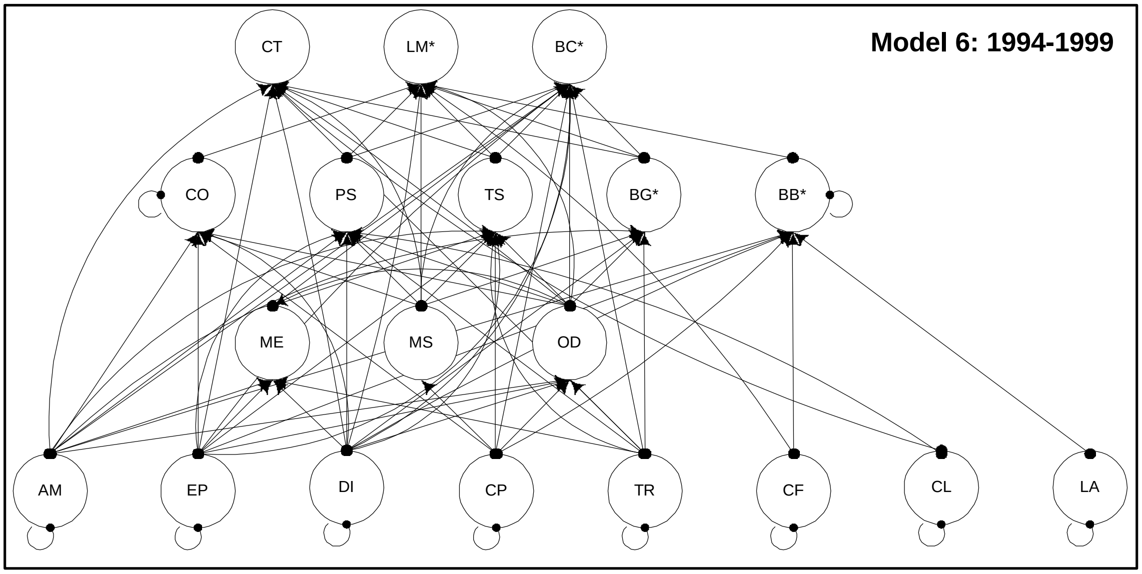


Figure 12. Signed digraph of Tenmile Lakes fauna, 1994-1999, with 4 introduced species (*); AM: amphipod, EP: Ephemeroptera, DI: Diptera, CO: copepod, TR: Tricoptera, CF: crayfish, CL: clam, LA: lamprey ammocoetes, ME: Megaloptera, MS: mysid shrimp, OD: Odonata, CO: coho salmon parr, PS: prickly sculpin, TS: threespine stickleback, BG*: bluegill , BB*: brown bullhead, CT: cutthroat trout, LM*: largemouth bass, BC* black crappie.

Utility of qualitative modeling

While a historical approach was employed in this study, qualitative modeling can also be used to complement ongoing research and management programs, and to pose and test competing hypotheses regarding the stability or behavior of natural systems. In systems where community structure is uncertain, it can be employed in a heuristic manner to quickly develop testable hypotheses, and to direct research questions for adaptive management. The construction of alternate models and comparison of prediction matrices can be used to assess the robustness of model results, and weigh the risks associated with alternate management options.

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Managing Fish Predators and Competitors:
Deciding when intervention is effective and appropriate

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Abstract- *Fisheries management agencies are increasingly being asked to weigh tradeoffs between game, nongame, native, and nonnative species management. Oregon has recently considered or is considering a variety of activities aimed at protecting and rebuilding depleted native fishes or otherwise improving production of gamefishes. Activities range from reduced harvest restrictions on fish predators and competitors to more aggressive removal programs. Chemical treatment and predator hazing have also been considered for potential benefits to more "desirable" fish populations. This presentation describes a systematic decision-making process to determine for any given case: 1) if predation or competition is likely to be important; 2) if potential predators or competitors can be affected by changes in harvest or with other management actions; and 3) if biological benefits outweigh costs and social/political considerations. This process is applied to several of Oregon's problems to help identify examples where intervention might prove effective and appropriate.*

Introduction

Like most fish biologists, I spent a significant period of time in institutions of higher learning before reaching my current prestigious and highly-paid government position with the Oregon Department of Fish Wildlife. Like most students, I liked some teachers better than others. One of my favorites as a fresh undergraduate at the University of California at Davis was Peter Moyle. Dr. Moyle is an expert on native nongame fishes and fish ecology. The Davis fishery program in general, and Dr. Moyle in particular, taught me to be passionate in the defense of native nongame fishes and critical of game fish management at the expense of native fishes. Now however, in one of life's cruel ironies, I've turned on everything I learned. I may now be one of the least favorite students of my favorite teachers: a blot on an otherwise sterling record. For you see, my first real job was on the Columbia River pikeminnow management program - where people are paid bounties to catch and kill the native nongame fish.

This background has caused me great internal conflicts and I've done a lot of soul searching to reconcile my education with current professional activities. In this paper I'd like to share with you some of my observations and conclusions. I want to take a stab at the "so what?" questions: How do we decide when to intervene in managing one species for the benefit of another? When do we have some hope of reducing predation or competition between some nasty undesirable species and a preferred type? Where should we drop fishing limits, pay bounties, or break out the rotenone? This article describes: 1) The three questions every manager should weigh in considering whether to intervene; 2) Some rules of thumb to help answer the three questions without costing millions of dollars and thousands of lives; and 3) The application of this systematic decision-making process to some real life examples.

The Three Questions

Is it significant, is it affectable, and is it acceptable? These three questions form the basis for a systematic decision-making process for considering when to implement management actions on one species for the benefit of another. Is it significant: Is significant predation or competition occurring? Is species A reducing the productivity of species B directly by eating them or indirectly by outcompeting them for a limited resource? Is it affectable: Can you affect the predator or competitor enough to provide benefits? Can you impede, harass, or remove enough of the right individuals to reduce predation or competition with the desired species? Is it acceptable: Is intervention socially, politically, or legally acceptable? What nonbiological considerations need to be weighed? The answer has to be yes to every one of these questions for intervention to be effective and appropriate (Figure 1). If any one answer is negative, there's probably no point in proceeding further.

It's fairly obvious that there's not going to be a benefit if there's no interaction. But it's also true that even if there is a problem, you're stuck with it if there's no way to reasonably affect the predator or competitor. When El Niño attracts hordes of hungry salmon-eating mackerel to the Pacific Northwest, it's obviously not feasible to rotenone the ocean. Some problems have to be managed around. Likewise if there is a problem and we know how to deal it, a variety of constraints might preclude us from doing so. For instance, even that ocean mackerel situation might be manageable with enough rotenone but some people frown on the indiscriminant distribution of large quantities of chemicals and there's probably some law against it anyway.

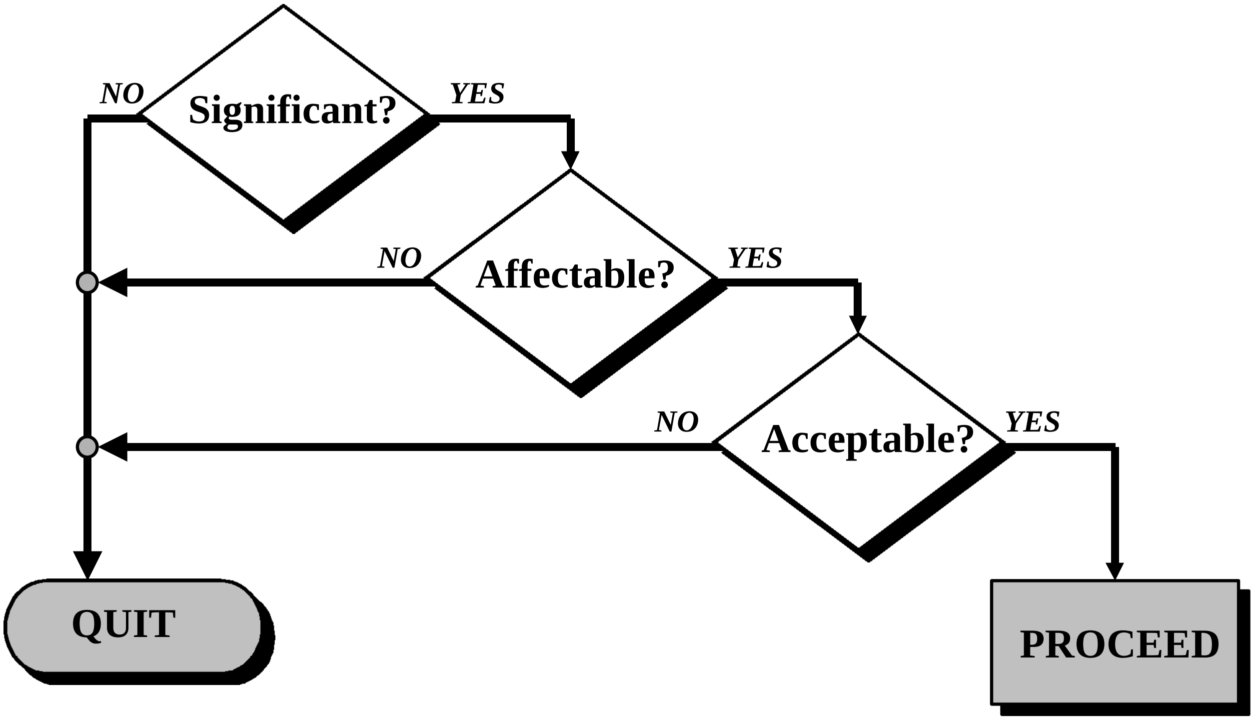

Figure 1. Algorithm for considering intervention in species interactions for the benefit of desirable species.

Rules of Thumb

How can we answer the three questions without the time, money, and staff to conduct in-depth field research on each problem? Species interaction research is extremely time-consuming and expensive and there are three approaches. The ideal method is an empirical approach where you add or remove one species and see if the other responds. For instance, if we want to know if seals and sea lions reduce salmon returns, we could remove all the seals and sea lions and see if we get more salmon. However, populations naturally ebb and flow in response to a whole variety of other factors and so a valid experimental design requires a control to distinguish a response from background noise. And further, we need replicates for the test and control groups for a valid statistical conclusion. Good empirical studies are rare although there have been some excellent case histories where native populations were monitored following a species introduction.

Another method for evaluating species interactions is a mechanistic approach where the relationship is broken into its components, each is evaluated, and then results are added back together. To prove competition, for instance, you would show that both species use the same resource, use by one species precludes use by the other species, the resource is in limited supply, and resource abundance regulates the effected species. For competition, it's generally easy to show common use of a resource but limitation and regulation are extremely difficult to demonstrate. A general problem with mechanistic studies also comes in initially identifying all the appropriate links between cause and effect. You're not testing what you think you are if a key relationship or interaction is overlooked. Mechanistic studies of complicated systems can be likened to trying to put a car engine together when you've never seen one before, you don’t have instructions, and you're not even sure you have all the parts.

A third alternative involves drawing useful generalizations from case studies and general ecological principles and then applying those principles to similar cases. These rules of thumb can help infer where problems are likely to occur. Rules of thumb can also help narrow the list of problems and prioritize which ones warrant further action. So let's work through some examples and see if we can develop some generalizations.

The first question in deciding whether to intervene concerns the significance of predation or competition. Let's consider a predation example for pikeminnow on salmon smolts in the Columbia and Willamette rivers (Figure 2). Juvenile salmonids are a significant diet item for pikeminnow from the Columbia River (Poe et al. 1991). Columbia river pikeminnow are estimated to be eating perhaps 16 million salmon and steelhead smolts per year or about 8% of the run (Beamesderfer et al. 1996). Rewards or bounties have been paid for pikeminnow from the Columbia River since 1990 and over 1 million pikeminnow have been dispatched. In contrast, pikeminnow in the Willamette River eat few smolts although large numbers of salmonids migrate through the system (Buchanan et al. 1981). Pikeminnow predation is a problem in the Columbia and not in the Willamette, because the dams have disrupted prey and predator behavior in the Columbia. Predation is low in areas such as the mainstem Willamette where smolts migrate normally: offshore, going with the flow, up in the water column where they avoid the bottom- and shoreline-oriented pikeminnow (Brown and Moyle 1981). This example demonstrates rule of thumb #1: ***Perceived interaction problems are often a symptom of an underlying habitat alteration problem***.

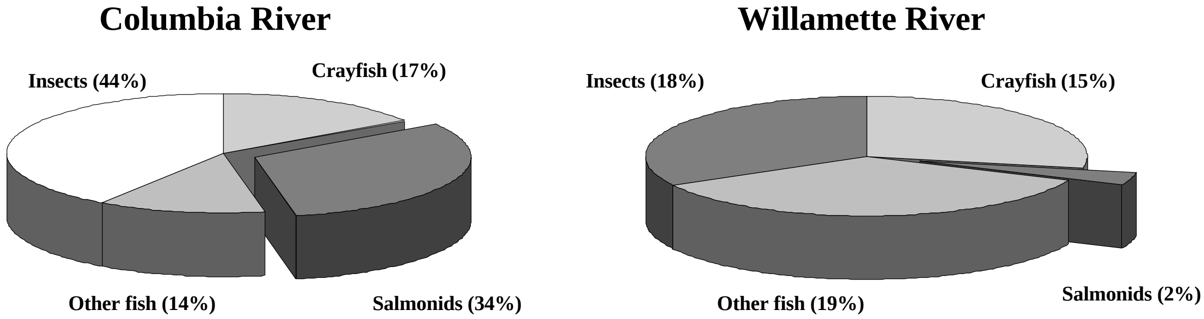

Figure 2. Frequency of occurrence of diet items of northern pikeminnow from the Columbia and Willamette rivers.

Complex interactions in complex communities often compensate and cancel the benefits of intervention. This rule of thumb (#2) is illustrated by a comparison of salmon predation in the Columbia (a large river mainstem) versus Tenmile Lakes (several small coastal lakes). Pikeminnow control is likely to increase salmon production in the Columbia because it is a fairly simple system. Pikeminnow eat smolts on their way from freshwater rearing habitats where density-dependent regulating mechanisms occur to the ocean where survival is largely density-independent (Beamesderfer et al. 1996). If x% of smolts are saved, x% more adults return. However, the food chain is much more complex in Tenmile Lakes. Predators in Tenmile Lakes include bass, bluegill, and bullheads. Coho smolts pass through on their way to the ocean and coho parr also rear in the lakes. Unlike the Columbia, compensatory regulating mechanisms are still operating on coho parr. Predators eat smolts and parr but also eat and compete with each other. The net effect of all these links and feedback mechanisms is extremely difficult to predict. Intervention has a much better chance of working in a simple density-independent community like the Columbia mainstem, than in a complex density-dependent community like Tenmile.

The second question in deciding whether to intervene was: "Can you affect predators and competitors?" Let's reexamine smolt predation in the Columbia River but this time let's compare pikeminnow and walleye. The bigger the pikeminnow, the more smolts they eat (Figure 3). Relatively low exploitation rates amortize through time to reduce survival to large piscivorous sizes. As a result, relatively small annual exploitation rates of only 10-20% should reduce pikeminnow predation by half (Beamesderfer et al. 1996). On a fish per fish basis, walleye are every bit as voracious a smolt predator as pikeminnow. However, walleye eat fewer smolts as they get older and so fishing has relatively little effect on smolt predation by walleye (Beamesderfer and Nigro 1989). Most smolts are eaten by walleye smaller than those caught by anglers and so a walleye bounty or unlimited walleye fishing provides little salmon benefit. Smallmouth bass are similar to walleye in that most predation occurs among bass too small to be affected by fishing (Beamesderfer and Ward 1994). Rule of thumb #3 is: ***Intervention benefits will be small unless you can affect most of the problem animals.***

Another example concerns Tenmile Lakes. In 1968, Tenmile Lake and it's tributaries were chemically treated for bullheads and bluegill. Treatment cost $179,000 1968 dollars and required 755, 50-gallon drums of rotenone (Campbell and Locke 1968, Grenfell and Montgomery 1969). A big spike in coho production immediately followed treatment. However, benefits were short-lived as warmwater fish quickly repopulated (Figure 4). In fact, record bluegill numbers followed their recovery. So not only were treatment benefits short lived for coho, but the recovery spike for warmwater fish might ultimately have depressed coho further than they would have been if we had just left the system alone. But didn't I just get done telling you that intervention in Tenmile Lakes would be confounded by the complex community? Well yes but Tenmile Lakes are very simple communities after rotenone eliminates all the gill-breathing organisms. This chemical simplification is one of the reasons "rehabilitation" produces significant short term results. As usual, this Tenmile Lake example demonstrates a rule of thumb (#4): ***Benefits will be temporary unless you can sustain the effects.***

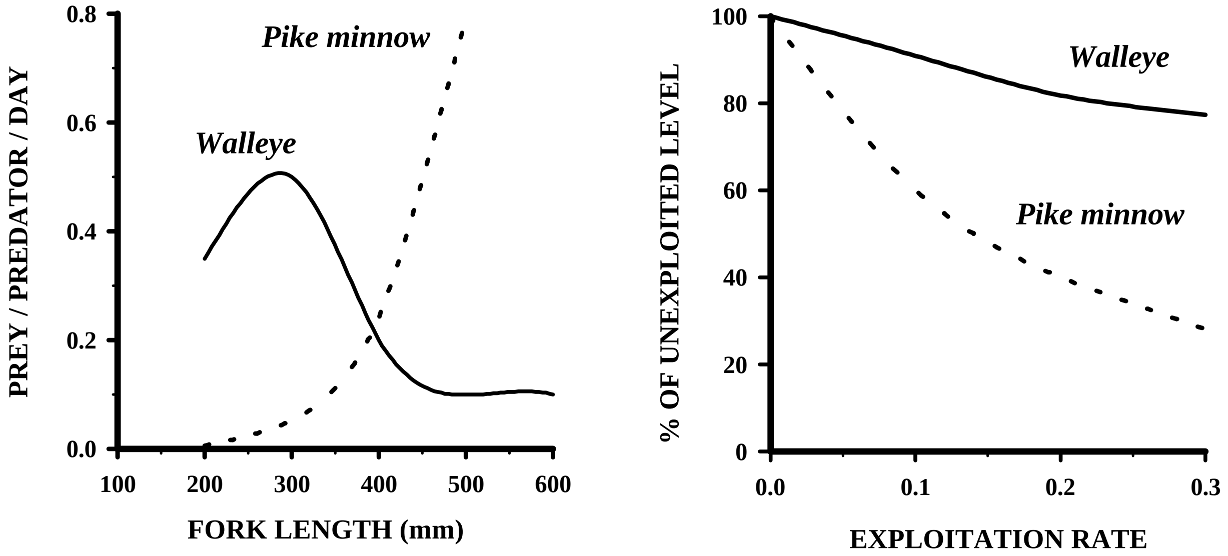

Figure 3. Predation rate on salmonids and the reduction in net predation expected with exploitation of walleye and northern pikeminnow in the Columbia River.

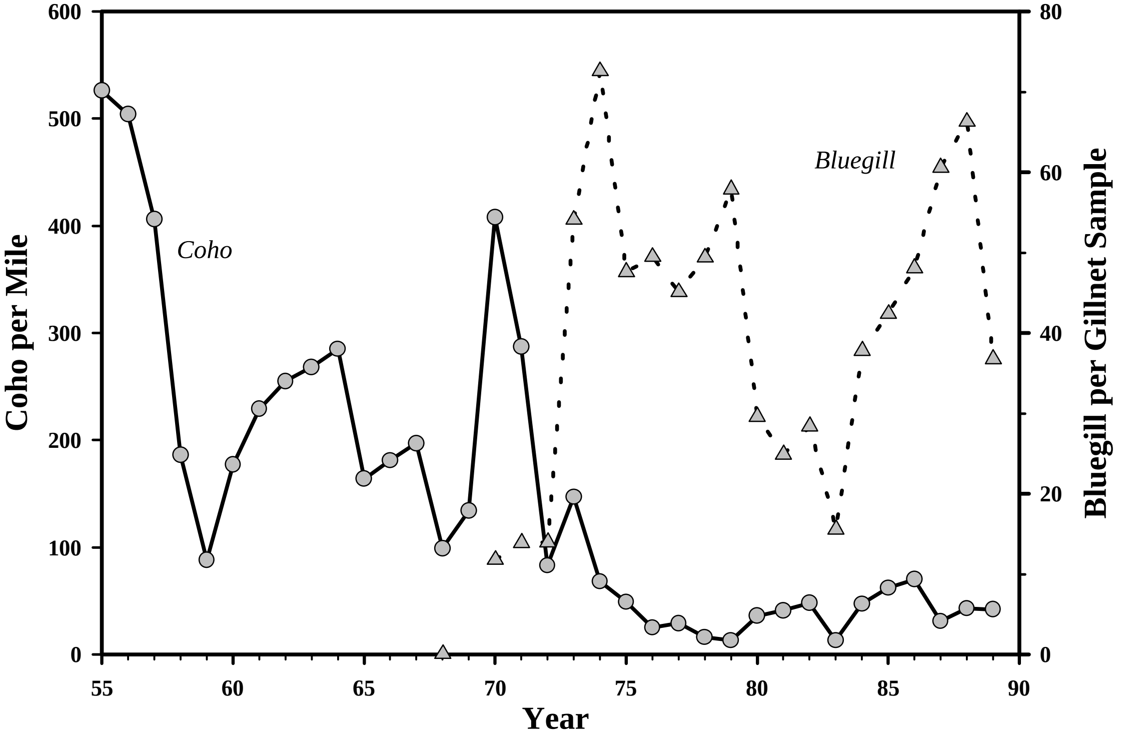

Figure 4. Relative abundance of coho salmon and bluegill before and after chemical rehabilitation of the Tenmile Lakes system in 1968.

Our third question in deciding when to intervene concerns whether it's socially, politically, or legally acceptable. These nonbiological constraints include relative costs: nobody would be willing to pay millions of dollars for pikeminnow bounties unless it's a substitute for more costly measures. Nonbiological constraints include social conventions: can you imagine the uproar if someone proposed a bounty program on Caspian terns? Constraints also include politics: if Oregon removes bag limits on walleye in the Columbia River, does it do any good if Washington doesn't? And of course there are often legal issues: for instance, the Marine Mammal Protection Act limits any nefarious schemes we might entertain if we think seals and sea lions really are a problem. One general rule of thumb addresses these constraints (#5): ***the probability of success is inversely proportional to the number of governmental agencies involved.***

Interaction/Intervention Rules of Thumb

1. ***Perceived interaction problems are often a symptom of an underlying habitat alteration problem.***
2. ***Complex interactions in complex communities often compensate and cancel the benefits of intervention.***
3. ***Intervention benefits will be small unless you can affect most of the problem animals.***
4. ***Benefits will be temporary unless you can sustain the effects.***
5. ***Probability of success is inversely proportional to the number of governmental agencies involved.***

Example Applications

Let's now combine the three-step decision process with the rules of thumb and apply to some examples. The first example is the Pikeminnow bounty program in the Columbia. The interaction is significant because millions of salmonids are being eaten each year. The interaction is not independent of habitat changes because predation is exacerbated by dam construction and operation but the program has been implemented anyway in lieu of more costly changes in the hydropower system. Simple interactions give intervention some chance of success. Interaction is affectable because removals are adequate and sustained. Finally, we can conclude such a program is acceptable since it's already been implemented.

Columbia River Pikeminnow Bounty?		
A. Significant?	Yes	<u>Implement</u>
1) habitat independent?	*No**	
2) simple interaction?	*Yes*	
B. Affectable	Yes	
3) adequate removals?	*Yes*	
4) sustained?	*Yes*	
C. Acceptable?	Yes	

Willamette River Pikeminnow Bounty?		
A. Significant?	No }	<u>No Action</u>
1) habitat independent?		
2) simple interaction?		
B. Affectable		
3) adequate removals?		
4) sustained?		
C. Acceptable?		

The same process leads to a conclusion that there's no need for a bounty program on pikeminnow in the Willamette River. Little smolt predation occurs in the Willamette because it is a relatively unaltered system from a predator-prey behavior point of view. The interaction is not significant and we don't need to go any further because it takes only one "no" to conclude no action.

Unlimited Walleye Fishing - Columbia River?		
A. Significant?	Yes	No Action
1) habitat independent?	No*	
2) simple interaction?	Yes	
B. Affectable	No	
3) adequate removals?	No	
4) sustained?	Yes	
C. Acceptable?	???	

Unlimited Bass Fishing - Tenmile Lakes?		
A. Significant?	No	No Action
1) habitat independent?	Yes	
2) simple interaction?	No	
B. Affectable	?	
3) adequate removals?	?	
4) sustained?	Yes	
C. Acceptable?	?	

Removing all fishing regulations on walleye in the Columbia River is not a promising strategy. Walleye predation is significant but fishing regulations do not remove significant numbers of walleye of predaceous sizes. Anglers don't catch the small walleye that are doing the damage and probably couldn't achieve a high harvest rate even with walleye bounties. The acceptability of a walleye removal program depends on who you ask. There is certainly an active and vocal walleye angling community that would object strenuously to a walleye reduction program.

Similarly, unlimited bass fishing in Tenmile Lakes would not be expected to provide significant benefits. Tenmile Lakes is not a simple system where we can expect a benefit from predator removal. It is questionable whether we could even affect bass predation by increasing harvest rate because bass resemble walleye where most of problem occurs in small fish not subject to fishing. Acceptability issues also limit the likelihood of success. Many bass anglers practice catch and release already and wouldn't keep significantly more bass.

The three-step decision process and rules of thumb illustrate that another chemical rehabilitation of Tenmile Lakes would not provide sustained benefits. The 1968 program showed that treatment can benefit coho, hence we can conclude that species interactions are a significant constraint on coho production. Treatment works in part because it simplifies a complex system. Removals are definitely significant but benefits are not sustained unless treatments are repeated periodically. Further, chemical rehabilitation is much less acceptable in 1998 than it was in 1968.

Chemical Rehabilitation - Tenmile Lakes?		
A. Significant?	Yes	No Action
1) habitat independent?	Yes	
2) simple interaction?	Yes*	
B. Affectable	No*	
3) adequate removals?	Yes!	
4) sustained?	No*	
C. Acceptable?	No	

One last example considers sea lion control at Willamette Falls. Sea lions currently eat several hundred spring chinook and steelhead per year and can cause passage problems if they sit in the ladder entrance. The problem is not habitat independent but no one's proposing removal of all the development at the falls. The interaction is fairly simple, so compensation would not be expected to erode the benefits of intervention. There are only a few problem animals and the lethal removal methods of the past would effective resolve the problem. However, lethal removal of marine mammals is no longer acceptable or legal. Lethal control methods are not an immediate option but nonlethal methods such as gratings might prove effective in keeping animals out of the fish ladder. This example demonstrates that there is often more than one way to address interaction problems and that we can often manage problems indirectly rather than overtly.

Willamette Falls Sea Lion Control?		
A. Significant?	Yes	Maybe
1) habitat independent?	No*	
2) simple interaction?	Yes	
B. Affectable	Yes	
3) adequate removals?	Yes	
4) sustained?	Yes	
C. Acceptable?	No*	

Conclusions

Summary of Examples	
Action	Intervene?
Pikeminnow bounty - Columbia River	Yes
Pikeminnow bounty - Willamette River	No
Unlimited walleye fishing - Columbia River	No
Unlimited bass fishing - Tenmile Lakes	No
Chemical rehabilitation - Tenmile Lakes	No
Sea Lion Control - Willamette Falls	Maybe

My intention with this paper was to identify an organized method for considering interactions and intervention, and to provide some guidelines for deciding when intervention might be effective and appropriate. The examples addressed illustrate the difficulties of implementing effective intervention programs. The Columbia River pikeminnow bounty program is the lone exception where we think an interaction is significant and affectable, and intervention is acceptable. Clearly, efforts aimed at prevention of undesirable introductions hold greater promise than attempts to affect populations after they become established.

Interaction problems are extremely difficult to diagnose and even harder to affect. Just because one species eats another or uses the same space or food doesn't mean that the interaction is significant. Even when interactions are significant, it's a rare case where intervention will be effective. Perceived interaction problems are often a symptom of underlying habitat alteration problems. Introduced species often do well in altered habitats where native species are poorly-suited and corrective habitat actions are usually more appropriate than fish population manipulations. Even when interactions are significant, intervention benefits are small unless most of the problem animals can be affected and the effect can be sustained. Complex interactions in complex communities may cancel the benefits of intervention or even exacerbate the problem.

Political and social issues compound consideration of any intervention effort and success often hinges not on biology but on public perception. Some might even suggest considering actions with marginal biological benefits in order to affect public perception and stimulate a broader and more effective response. Examples of beneficial intervention can be found but my closing challenge to all who would consider intervention, is to be smart about sorting the real opportunities where we can have an impact from the false cases that look good but accomplish nothing.

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