NON-NATIVE SPECIES IMPACTS ON NATIVE SALMONIDS IN THE COLUMBIA RIVER BASIN

Including Recommendations for Evaluating the Use of
Non-Native Fish Species in Resident Fish Substitution Projects

Independent Scientific Advisory Board

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ISAB

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Cover photo: American shad in the Bonneville Dam fish ladder, Tim Counihan, USGS.

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Executive Summary

Humans have intentionally and unintentionally accelerated the movement of animal and plant species into ecosystems where they are non-native. The major causes for these unprecedented species movements have been post-1900 increases in inter-continental trade, travel, and tourism, as well as import and export of exotic pets, ornamental plants, foreign foods, and crop plants. The negative impacts of non-native species invasions, along with habitat loss and degradation, are recognized as the two leading causes of native species imperilment in North American freshwater ecosystems.

While intentional and unintentional introductions of non-native species have accounted for initial establishment of non-native species, *habitat change* is currently the major factor causing the expanding distribution and increasing abundance of non-native species in the Columbia River Basin. Most of the free flowing river habitats in the Snake and Columbia rivers have been converted into reservoir habitats through dam building, intended for hydroelectric power generation and for flow regulation for irrigation diversion and flood control. The reservoirs have created hotspots of non-native species, which become source populations of non-natives, facilitating secondary spread of these species throughout the basin.

This review's results, presented in the body of this report, indicate that the potential impacts and risks to native salmonids and other native fishes from non-native species are significant, with most subbasins in the Columbia River Basin already dominated by non-native fish species. The *predatory effects of some of these non-native fish species on native salmonids* are the most well documented of all non-native impacts on salmonids in the Pacific Northwest, and in some habitats non-native fishes can consume significant numbers of emigrating juvenile salmon.

In addition to predation, non-native species pose a number of other significant impacts to natives species, including *competition for food and habitat* (e.g., larval/juvenile American shad have reduced zooplankton species food base favored by subyearling Chinook), *food web alterations* (e.g., native resident fish communities in littoral habitats of Columbia River reservoirs are being replaced by non-native species), *interbreeding* (e.g., genetic introgression between cutthroat trout and non-native rainbow trout), and *disease transmission and parasites* (e.g., American shad is a carrier of a protozoan parasite of salmon). Native species are also significantly impacted by *non-native invertebrates* (e.g., the freshwater Asian clam which has replaced native mollusks in the Columbia River Basin), and *non-native plants* (e.g., Eurasian milfoil, which is widespread in Columbia River reservoirs and is altering littoral habitats).

ISAB Recommendations for Actions to Address Non-native Species Impacts

Because of these impacts, the ISAB recommends that the Northwest Power and Conservation Council (Council) and the Fish and Wildlife agencies in the Basin elevate the issue of non-native species effects to a priority equivalent to that of habitat loss and degradation, climate change, and human population growth and development.

The ISAB also provides the following specific recommendations:

- **Exploratory Surveillance and Monitoring –** Exploratory surveillance and monitoring of fish, plant, and invertebrate populations needs to be increased for early detection of invasive non-native species and tracking of their distribution and abundance in the future. In addition to informing immediate management actions, this monitoring will provide information to evaluate the effectiveness of prevention and control measures. Early detection of rare non-native species is challenging and may sometimes require use of sophisticated sampling designs and estimation techniques. However, the cost of control after spread of undesirable species thoroughly justifies the effort.

- **Enforcement –** Federal, Regional, and State Policies and regulations regarding non-native species exist, but enforcement seems to be weak or non-existent. Improved enforcement of current regulations should be a high priority.

- **Fisheries Management –** Smallmouth bass and channel catfish support significant sport fisheries in the lower Snake and Columbia rivers. Walleye are the subject of significant sport fisheries in the mid-Columbia, extending into the lower Columbia River. State fisheries agencies in Washington, Oregon, and Idaho have simultaneously adopted management policies that in some cases seem aimed at perpetuating or even enhancing populations of these introduced predators. The ISAB recommends that the Council urge the state agencies to relax (or eliminate) fishing regulations that may be enhancing populations of non-native species (both predators and competitors), especially those that directly or indirectly interact with juvenile and adult salmonids.

- **Prevention –** Direct removal by physical (e.g., netting or electrofishing) or chemical (e.g., rotenone or antimycin) means have had very little success in eliminating or controlling non-native species, once they are well established. Therefore, prevention is the best hope for dealing with non-natives and certainly the most cost-effective.

- **Habitat Restoration –** One of the best strategies for protecting native species and minimizing the establishment and spread of non-native species is to maintain and restore habitats (including riparian habitats). When native species are provided with habitat for which they are best adapted, they have an improved chance of out-competing or persisting with non-native species. Restoring physical features (including natural flow and thermal regimes) may make native species more likely to persist in environments now occupied by non-natives.

- **Planning** – Planning for future actions to prevent, control, and minimize non-native species' impacts to native species and their ecosystems should be a high priority. The Council should encourage revisions in the Fish and Wildlife Program Subbasin Plans to include plans for addressing non-native species threats and impacts.

- **Education –** Public awareness of the threats that non-native invasive species pose to aquatic ecosystems and the native species therein is critical for curtailing the introduction and spread of new non-native species. A wide range of groups and educational actions can contribute to public awareness including public schools; watershed councils; television and radio public service announcements; billboards; sport fishing organizations; and other environmental organizations such as The Nature Conservancy.

- **Research –** Research needs are many, including (1) mapping the vulnerability of the landscape to non-native species introduction, establishment, and spread; (2) examining the impacts of non-native predators on native salmonids and other native species at regional scales and where many species co-occur; (3) determining the potential for transmission of diseases and parasites to native species, (4) improving understanding of the effects of competition between non-native and native species, and (5) exploring the potential synergistic interactions of climate change, land use, and non-native species spread.

ISAB Recommendations for Evaluating the Use of Non-native Fish in Resident Fish Substitution Projects

The Council's Fish and Wildlife Program recognizes that construction of Grand Coulee Dam on the Columbia River in 1941 and Brownlee Dam on the Snake River in 1959 completely blocked over 18,000 miles of streams that had been historically accessible to anadromous salmon, approximately 38% of the historic range. The Council's Program mandates that anadromous fish losses due to the blockage need to be partly mitigated by assuring that populations of resident fish species remain healthy. Part of this mitigation includes a resident fish substitution policy that, among other actions, allows for stocking of non-native species that are compatible with the continued persistence of native resident fish.

However, the Fish and Wildlife Program does not establish the specific limits (i.e., how much risk) or the methods (i.e., risk management protocols) to evaluate whether a proposed project is reasonably benign and likely to provide benefits, without undesirable consequences. Moreover, the introduction or enhancement of non-native species is seldom a controlled research experiment, and it is difficult to reliably forecast the effects of such introductions or enhancements on native species. In the absence of clear knowledge of expected effects, which would most often require a lengthy research study, an alternative approach to evaluate a resident fish substitution project would be to complete an environmental risk assessment before initiation of the introduction or enhancement of a non-native species. Such an assessment should be included as part of the review material for evaluation of non-native species substitution proposals.

ISAB Recommendation

- **Environmental Risk Assessment -** A thorough Environmental Risk Assessment of potential negative impacts on native fish species should be completed and submitted, concurrently with project proposals, for all resident fish substitution projects in which a non-native species is to be selected for substitution. The ISAB understands that the Council, Independent Scientific Review Panel, and fish and wildlife managers would need to be involved in development of a final Environmental Risk Assessment template and that *this recommendation is a starting point and not an endpoint*.

The ISAB appreciates the efforts of the resident fish and wildlife managers to provide briefings on resident fish substitution, site visits to view affected habitats in the blocked areas of the Columbia River Basin, and constructive comments on a draft risk assessment approach.

Non-native Species Impacts on Native Salmonids in the Columbia River Basin

INTRODUCTION

Review Objectives

Expanding populations of non-native invasive species represent major impediments to the restoration of native salmonids in the Columbia River Basin. Since the mid-1990s, the Independent Scientific Review Panel, ISAB, and others have recommended that non-native species should receive serious attention. In 2007, the ISAB's partners – the Council, NOAA Fisheries, and the Columbia River Indian Tribes – approved the ISAB to evaluate the state of knowledge of the impact of both intentional and unintentional introductions of non-native aquatic species on native salmonids in the Columbia River Basin.

This report is intended to help the Council (1) develop guidelines for implementing the Fish and Wildlife Program to minimize future impacts from non-native species and (2) frame scientific guidance and propose criteria for deciding the limitations and appropriate use of non-native fishes to mitigate hydrosystem losses through resident fish substitution.

Specifically, the primary objectives of this report are to:

- describe the economic and cultural context for non-native species introductions and review the current federal and state policies in place to protect native species from non-natives;
- review and document the biological impacts and risks to native salmonid populations from unintentionally and intentionally introduced non-native species;
- review and describe the current status of management actions taken to reduce or eliminate such impacts (e.g., brook trout and lake trout eradication efforts);
- recommend strategies for protecting against or eliminating non-native invasive species; and
- recommend scientific criteria for evaluating resident fish substitution projects.

The review focuses on fish species but also generally discusses other organisms such as non-native aquatic plants and invertebrates, which can alter aquatic ecosystems and food webs.

Throughout this report, we will primarily use the term **non-native species** (referring to species that are not native to an ecosystem) rather than the more broadly applied term,

invasive species (referring to a non-native species, introduced unintentionally or intentionally) whose introduction causes or is likely to cause economic or environmental damage or harm to human health, directly or indirectly. Our rationale for this choice of terminology follows Colautti and MacIsaac (2004) and springs from the considerable uncertainty that exists about the knowledge of the indirect harm caused by non-native species (e.g., competition in a natural setting is usually assumed and rarely verified). A non-native species may or may not be classifiable as invasive, depending on whether indirect harm has ever been verified. The two terms are not interchangeable, and there are non-native species that are not invasive. Having acknowledged that, this report derives from the explicit realization that many **non-natives** have been introduced deliberately and a substantial number have become **invasive**.

General Background on Non-natives

Biological invasions are widely recognized as a significant component of human-caused environmental change and a primary threat to native biodiversity. The negative impacts of species invasions, together with the consequences of environmental degradation, are recognized as the two leading causes of species imperilment in North American freshwater ecosystems (Richter et al. 1997, Wilcove et al. 1998). The costs incurred to control invasive species in the United States in 2005 were estimated at greater than $137 billion (Pimentel 2005). The monetary costs are much easier to calculate than the biological significance of the impacts, which is often very poorly known.

The Pacific Northwest is home to 119 threatened or endangered species, and most of these are found within the Columbia River Basin (Frissell 1993 and Sanderson et al. unpublished manuscript in review, 2008). While a large number of those 119 threatened or endangered species are plants, the majority of fauna listed under the Endangered Species Act (ESA) are fishes, including various populations of Pacific salmon (*Oncorhynchus spp.)* and steelhead (*O. mykiss)*. At this time, the number of listed native species is increasing, and a recent count of the number of non-native species now present in the three states of WA, OR, and ID exceeds 900 (Sanderson et al., unpublished manuscript, 2008) (Figure 1).

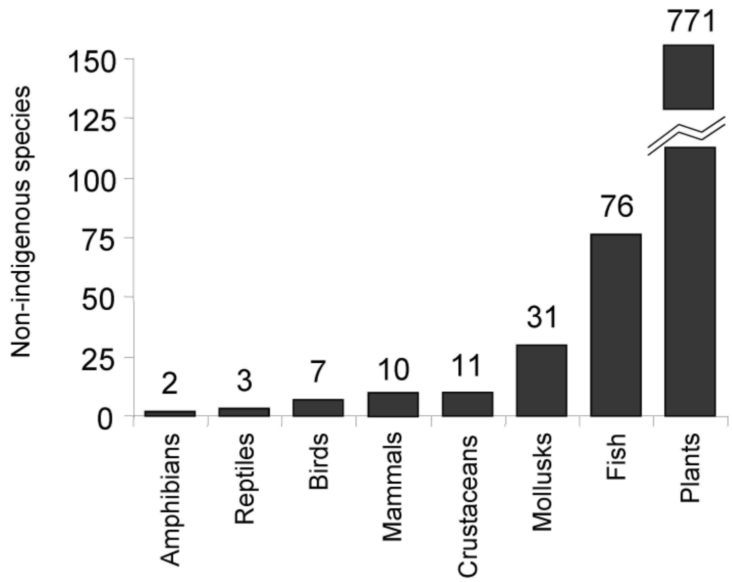

Figure 1. Numbers of non-native species, by major taxonomic group, currently present in the Pacific Northwest. (Courtesy of Sanderson et al., unpublished manuscript in review, 2008.)

In the western United States, one in four fishes is non-native in origin (Schade and Bonar 2005), and, in some parts of the Columbia River Basin, the balance has shifted dramatically, to introduced species being a majority of the species present. For example, the littoral fish composition in John Day Reservoir was dominated by natives in 1985, but by a decade later, non-native species dominated (Barfoot et al. 2002). In 2003, 50 of the 91 species of fish recorded in Washington State were native and 41 were non-native (Wydoski and Whitney 2003). A more recent update by Sanderson et al. (2008) indicates that non-natives constituted 54%, 46%, and 60% of the resident fish species in Washington, Oregon, and Idaho, respectively, and many of the subbasins throughout the Basin have 20 to 30 species of non-native fishes (Figure 2).

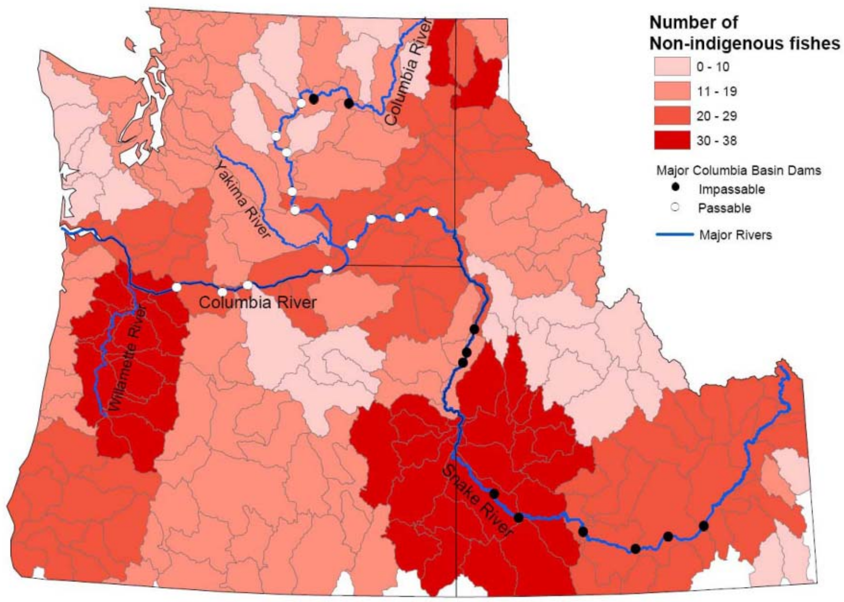

Figure 2. Number of non-native fish species per watershed (4th field Hydrologic Unit Code) in WA, OR, and ID as of 2007. (Courtesy of Sanderson et al. unpublished manuscript in review, 2008.)

History of Non-native Fish Species in the Columbia River Basin

There is a long history of intentional introductions of non-native fish species into the Pacific Northwest, as in virtually all parts of the globe that have experienced large-scale human immigration. Federal and state agencies intentionally introduced non-native species into the Pacific Northwest, attempting to initiate new fisheries with species native to the United States east of the Rockies, and from western Europe, dating from the late 1800s through the mid -1900s. For example, 29 of the 41 non-native fishes listed for the State of Washington were recorded before 1950 (Wydoski and Whitney 2003). Intentional introductions by management agencies slowed from the 1950's through 1980's (Table 1). This pattern of reduced numbers of intentional introductions by fisheries management agencies has occurred throughout all western states (Wydoski and Whitney 2003).

Table 1. Chronology of Fish Introductions into Washington State

This table is adapted from Appendix 5 in Wydoski and Whitney (2003), which includes additional information on the history of the introductions and the present status of the species.

Year	Species	Location of introduction/discovery	Present status
1880s			
1876	American shad, *Alosa sapidissima*	Columbia River	Established
1881	Common carp, *Cyprinus carpio*	Columbia River	Established and stocked
1883	Brown bullhead, *Ameiurus nebulosus*	Silver Lake	Established and stocked
1885	Tench, *Tinca tinca*	Fourth-of-July, Fetz, Diamond lakes	Established
1890	Largemouth bass, *Micropterus salmoides*	Sprague/Loon lakes; Lake Washington	Established and stocked
1890	White crappie, *Pomoxis annularis*	Lake Washington	Not established from the introduction
1890	Green sunfish, *Lepomis cyanellus*	Loon/Deer/Sprague (Colville) Lakes	Established
1890	Grass pickerel, *Esox americanus vermiculatus*	Rock Creek Drainage	Established
1890	Bluegill, *Lepomis macrochirus*	Loon/Deer/Sprague (Colville) Lakes	Established and stocked
1892	Warmouth, *Lepomis gulosus*	Loon Lake	Established
1892	Channel catfish, *Ictalurus punctatus*	Clear Lake; Deer Lake	Established
1893	Pumpkinseed, *Lepomis gibbosus*	Lower Columbia River	Established
1893	Black crappie, *Pomoxis nigromaculatus*	Lower Columbia River	Established
1893	Rock bass, *Ambloplites rupestris*	Lower Columbia River	Established
1893	Yellow perch, *Perca flavescens*	Loon/Sprague (Colville) Lakes; Lake St. Clair, Lower Columbia River	Established
1894	Brook trout, *Salvelinus fontinalis*	Unknown	Established
1895	Yellowstone cutthroat trout, *Onchorhynchus clarki lewisi*	Streams west and east of Cascade Mtns.	Stocked
1899	Lake whitefish, *Coregonus clupeaformis*	Lake Washington; La Comas & Silver Lakes	Established
1900s-1920s			
1900	Lake trout, *Salvelinus namaycush*	Eastern Washington	Established
1905	Yellow bullhead, *Ameiurus natalis*	Columbia River	Established
1905	Black bullhead, *Ameiurus melas*	Columbia River	Established
1920	Rainbow trout, *Oncorhynchus mykiss*	Various Waters	Established
1923	Brown trout, *Salmo trutta*	Eastern Washington	Established
1924	Smallmouth bass *Micropterus dolomieui*	Blakeley Island	Established

Year	Species	Location of introduction/discovery	Present status
1930s-1960s			
1936	Golden trout, *Oncorhynchus aquabonita*	Skykomish River system	Established
1936	Striped Bass, *Morone saxatilis*	Columbia River	Established
1942	Goldfish, *Carrasius auratus*	Lake Washington; Moses Lake	Established
1945?	Arctic grayling, *Thymallus arcticus*	Upper Granite Lake	Established
1950s	Walleye, *Stizostedion vitreum vitreum*	Lake Roosevelt on Columbia River	Established
1968	Lahontan cutthroat trout, *Oncorhynchus clarki henshawi*	Omak Lake	Stocked
1970s-1980s			
1970	Northern pike, *Esox lucius*	Spokane River	Established
1970	Mosquitofish, *Gambusia affinis*	Columbia River ponds	Established
1972	Tadpole madtom, *Noturus gyrinus*	Snake River	Established
1975?	Flathead catfish, *Pylodictis olivaris*	Snake and Columbia rivers	Established
1988	Tiger muskellunge, *Esox lucius X Esox masquinongy*	Mayfield Reservoir	Stocked
1990s-2000			
1990s	Grass carp, *Ctenopharyngodon idella*	Various waters	Stocked
1990s	Banded killifish, *Fundulus diaphanus*	Columbia River	Established
1990s	Brook stickleback, *Culaea inconstans*	Chapman Lake	Established
1996	Atlantic salmon, *Salmo salar*	Puget Sound; Columbia River	Unknown
1990s	Golden shiner, *Notemigonus crysoleucas*	Long Lake	Established
1990s	Fathead minnow, *Pimephales promelas*	Muck Creek, Pass and Squalicum Lakes; Yakima County	Established
1997?	Oriental weatherfish, *Misgurnus anguillicaudatus*	Union Bay, Lake Washington	Established

The history of American shad (*Alosa sapidissima*) in the Columbia River provides a fine example of how a non-native species population may grow and become extremely abundant in a new ecosystem. American shad, first introduced into the Sacramento River, California in 1871 (Green 1874), quickly migrated up the coast to the Columbia River, where it was first recorded in 1885 (Smith 1896). Shad has subsequently (and dramatically) increased in abundance and distribution in the Columbia River Basin, as shown by passage counts of adult shad over time at Bonneville Dam (1938- 2007) (Figure 3).

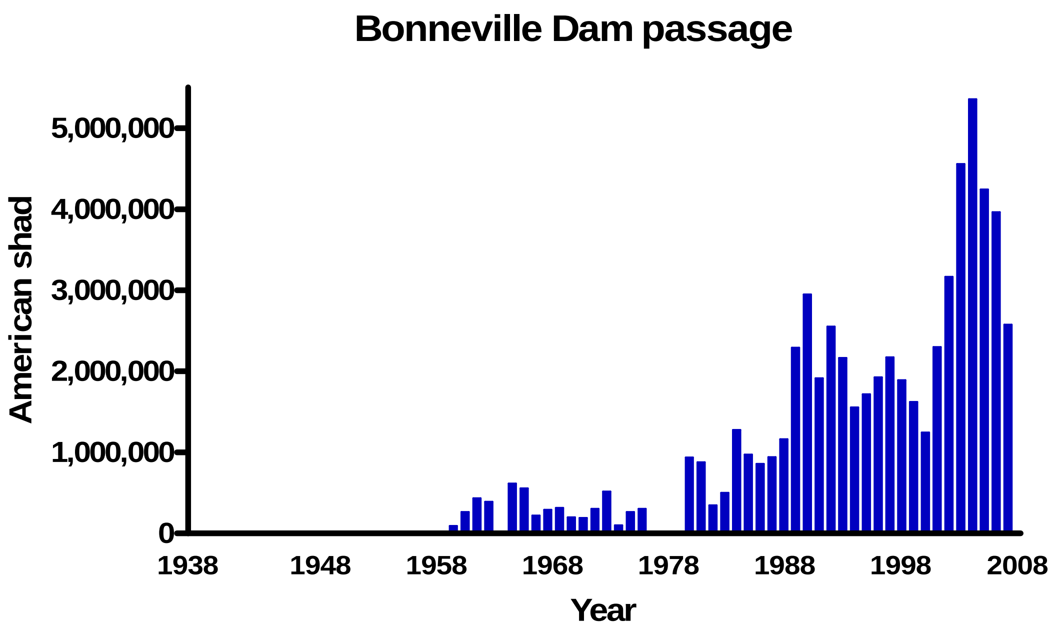

Figure 3. Counts of adult American shad in the Columbia River at Bonneville Dam (1938– 2007). (Columbia Basin Research, Data Access in Real Time, DART)

Note that the marked increase in the number of adult shad passing Bonneville Dam occurred after construction of dams on the lower Columbia River (The Dalles Dam in 1959, John Day Dam in 1968, and McNary Dam in 1954) and the lower Snake River (the four dams late '60s to mid '70s). Modifications of adult fish ladders for salmon and steelhead apparently allowed shad easy access to newly created reservoirs that were optimum habitat for shad (Petersen et al. 2003).

A recent summary of non-native species expansions in the lower Columbia River and estuary was provided by Sytsma et al. (2004), who reported that from the 1880s to the 1970s, a new introduced species was discovered in the lower Columbia about every five years. The discovery frequency of new aquatic nuisance species (ANS) is increasing worldwide (OTA 1993, Ruiz et al. 2000, cited in Sytsma et al. 2004), however, and the rate of discovery of introduced invertebrates in the lower Columbia River mirrors this trend. Over the past ten years, a new invertebrate species has been discovered about every five months. The increasing rate of new discovery is due to increasing frequency of introductions and to the number and type of surveys conducted. In contrast to the increasing rate of invertebrate discovery, the rate of non-native fish discovery peaked in the 1950s. This trend was likely due to a decline in intentional fish introductions by both individuals and fish and game agencies (Sytsma et al. 2004).

Detailed histories for a large number of non-native species (introduced intentionally, unintentionally, or representing major range extensions from neighboring regions) are beyond the scope of this review, so we will content ourselves here with some general remarks. For more detailed information, we refer the reader to several recent sources, Sanderson et al. (2008), Boersma et al. (2006), and the U.S. Geological Survey (USGS) invasive species website (http://nas.er.usgs.gov). The USGS website provides good information on the distribution and history of non-indigenous aquatic species throughout the United States, as well as for the Pacific Northwest. Review information and historical data can also be found in the U.S. Fish Commission Reports, starting in the late 1890s (e.g., Smith 1896).

The Ecological Context and Habitat Changes

While intentional and unintentional introductions of non-native species account for initial establishment, habitat change is currently the major factor causing the expanding distribution and increasing abundance of non-native species in the Pacific Northwest. Many of the free flowing river (lotic) habitats in the Snake and Columbia rivers have been converted into reservoir (lentic) habitats through dam building, intended for hydroelectric power generation and for flow regulation for irrigation diversion and flood control. The reservoirs have created hotspots of non-native species (Havel et al. 2005), which become source populations of non-natives, facilitating secondary spread of these species throughout the basin. The phenomenon of dams facilitating the spread of non-native aquatic species in altered habitats is well documented in California (Marchetti and Moyle 2001, Marchetti et al. 2004) and the lower Colorado River (Olden et al. 2006). Forestry practices, agricultural development, and urbanization have also significantly impacted Columbia River Basin aquatic ecosystems in ways sometimes favorable to non-native species.

In addition to the creation of reservoirs and their altered habitats, the blockage of Columbia River Basin mainstem and tributary habitats that are required by native anadromous and resident salmonids for immigration, spawning, incubation, rearing, and emigration has been a major stimulus for the establishment and subsequent spread of many non-native species, which have subsequently impacted native salmonids, both directly and indirectly. Lack of access by salmonids to previously used habitat may be the major cause of the spread and eventual domination of fish communities by non-native fish species, and the expansion and domination by non-native species may be a symptom of a much larger habitat-alteration problem.

ECONOMIC AND CULTURAL CONTEXT

People have moved familiar organisms to wherever they have moved themselves. They have transported and stocked fish for food, for recreation, and for sentimental attachment. Lampman (1946), writing about the first eastern settlers in the Columbia River Basin, talked about how they "honed for the fishes they had known in the mill ponds of the homes they had left," feelings that led to a long process of non-native fish introductions. Non-native fish have also been introduced by accident, by illegal actions, and by deliberate efforts to provide substitutes for native species that have been casualties of major habitat change.

Case History of the Common Carp

An important historical example of the short-term economic and cultural rationales and long-term consequences of introducing a non-native fish is provided by the history of the common carp (*Cyprinus carpio*) in North America. Many of the historical events and rationales surrounding the introduction and dispersal of carp are nearly identical to those that today surround the introduction of other non-native species in the Pacific Northwest and elsewhere.

Initially, the carp spread intentionally and accidentally along with global patterns of human migration. From its wild origins in central Asia, the carp is thought to have spread naturally into China and into eastern Europe, as far west as the Danube River. From the Danube, it was later transported by travelers into other parts of Europe (Austria, Germany – 13th Century; Sweden – 16th Century) and North America (19th Century) (Cole 1905; Balon 1974). Cole (1905) describes in detail the first well-documented introduction of carp into North America. In 1872, J.A. Poppe shipped 83 carp from Germany to New York (only eight survived) and from there to California (five survivors). Those five fish grew well and spawned, however, and by the following year more than 3,000 young carp were in his ponds. Those fish were sold to other farmers and fish culturists in the region. As people and cultures familiar with the species migrated, they brought carp with them.

There was also strong economic rationale for introducing carp. European immigrants valued the species highly as a food fish in their native areas. Agencies and governments also focused on the economic value of the fish. Spencer Baird, First U. S. Fish Commissioner, saw carp as an important food fish, whose addition to North America would be beneficial, especially in waters with degraded conditions not suitable for other species. In an early defense of the merits of carp, S.P. Bartlett (1901: page 114) of the U.S. Fish Commission stated that "the carp have produced in the State of Illinois more money than all other fish put together **. . .** there are more carp eaten on the hotel tables **. . .** [of Illinois] than any other fish." Baird correctly identified the high fecundity, adaptability, rapid growth, colonizing abilities, and edibility of the species as desirable attributes of any economically valuable fish (but incorrectly saw the species as largely vegetarian and as generally harmless to other species).

Fisheries professionals also bear some of the responsibility for carp introductions and range expansion. The U. S. Fish Commission began culturing carp in the late 1870s from varieties intentionally imported from Europe. By 1880, states and private entities submitted nearly 2,000 applications to the Commission for carp. So widely distributed were carp that they were sent to 298 of 301 congressional districts (Cole 1905). Between accidental escapes of fish and avid stocking, carp spread rapidly and widely, so that by 1897 no more carp were being raised and no additional requests were being made for them (Fritz 1987).

At the time carp were being actively stocked and dispersed, so little was known about the biology and ecology of the species that the impacts on other species were not seriously considered. By the early 1900s, however, legitimate questions were being raised as to the desirability of the species and its effects on habitats for other species (Bartlett 1901; Cole 1905). In subsequent decades, numerous studies have documented the impacts of carp on aquatic habitats (Cahn 1929), aquatic vegetation (Anderson 1950; Tryon 1954), other fish species (Rose and Moen (1953), and waterfowl (Robel 1961). Eventually, carp populations were determined to be a nuisance, but their removal from waters has been extraordinarily difficult, notwithstanding continuing eradication efforts, commercial fishing, and maintenance control (Gerking 1950; Cahoon 1953; Rose and Moen 1953).

Over time, the local context for non-native species introduction has evolved, through changing economic goals, cultural values, and policies. The current context within the Council's Fish and Wildlife Program is one of trying to achieve a balance among expectations of use of non-native species and policies for protecting and enhancing native fish. All of that said, it seems clear that similar stories of non-native species' colonization and spread continue to unfold in the Northwest. By way of example, walleye, (*Sander vitreum)* and northern pike (*Esox lucius)* spread west into the Pacific Northwest (McMahon and Bennett 1996), along with westward human migrations in the twentieth and early twenty-first centuries. Attractive economic benefits (e.g., recreational value) are being presented to support present-day expansion of such non-native species. Although "bucket biology" (Rahel 2004),), the term now used to describe the unacceptable practice of transplanting non-native fish into a body of water where they do not belong (Johnson 2006), continues to be an issue, it has to be acknowledged that fisheries professionals are the primary distributors of non-native species, especially where important fisheries benefits are perceived to exist. We still know little about the potential impacts of walleye and northern pike on native fish of the Northwest, and what little we do know is focused on the native species of economic value (McMahon and Bennett 1996), primarily salmonids. By contrast, information gaps are large about the impacts of non-native species on many native species of little immediate economic value. Often, problems have not been anticipated until they arise, typically long after timely intervention might have been effective and when eradication or removal attempts are too little, too late (e.g., brook trout).

Economic Goals

Restoration: The goal of restoring depleted fish populations spurred the first transcontinental exchange of non-native species. In New England, Atlantic salmon were over-fished by the late 1800's. People saw fish culture as a promising substitute for natural production, without the painful constraints of regulation on harvest, and the federal Fish Commission was established by Congress in 1871, at the behest of the American Fish Culturists Association (Lichatowich 1999). Its first director, Spencer Baird, was a "scientist-entrepreneur" who built a Congressional constituency for fish culture (Taylor 1999). The first salmon hatchery on the West Coast was established in 1872, on a tributary of the Sacramento River, for the purpose of providing Chinook salmon eggs to reseed Eastern streams (Lufkin 1991; Blumm 2001). Establishment of the Sacramento River hatchery was followed closely by hatcheries on the Columbia River and the subsequent expansion of Columbia Basin salmon fisheries (Lichatowich 1999).

Commercial fisheries: Expanding natural production and establishing new markets quickly developed as goals for non-native fish. American shad (*Alosa sapidissima)* was the first species transported to the West Coast, from New York's Hudson River to the Sacramento River in 1871, from which it subsequently spread to Oregon, Washington, and Alaska. During the late 1800s, shad was stocked extensively throughout the western states, including the Willamette and Columbia rivers, for forage, food, sport, and commercial fishing (Smith 1896, Wydoski and Whitney 1979, Fuller 2007). For native salmonids, economic expansion was seen to depend on the extent to which damage done to fish and their habitats, and by extension to their fisheries, through the operations of dams, mills and timber harvest, could be mitigated by the construction of hatcheries. Under the assumption that hatcheries could fully compensate for habitat loss, by 1910 the policies of both Oregon and Washington were to allow dam builders to build hatcheries instead of fish passage (Blumm 2002). In this period, the practice of transferring fish and eggs between rivers became widespread (Lichatowich 1999).

Recreational fisheries: The goal of providing recreational fisheries has driven many non-native species introductions in the Columbia River Basin. As early as the mid-1800's, brook trout (*Salvelinus fontinalis*) and non-native rainbow trout (*O. mykiss gairdneri*) were stocked for sportfishing. Brook trout now inhabit about 40% of bull trout (*S. confluentus*) streams in Montana. Largemouth (*Micropterus salmoides*) and smallmouth bass (*M. dolomieui*) have also been widely introduced as sport fish (Fuller 2007).

Walleye has been intentionally stocked as a food and sport fish in the Basin, and has also been illegally and accidentally introduced. Livingston Stone released the first walleye into the Sacramento River in 1874 (Smith 1896). Walleye may have been stocked accidentally with yellow perch (*Perca flavescens*) in Idaho (Linder 1963), with the first introduction to southern Idaho reservoirs taking place in 1974 (McMahon and Bennett 1996). The initial date of walleye introduction into Washington is uncertain, but a thriving sport fishery had developed in Lake Roosevelt by the 1960s (McMahon and Bennett 1996). The Lake Roosevelt walleye fishery is a good example of how constituencies develop around non-native species and influence the direction of subsequent fisheries management. In Montana, walleye were illegally stocked in Canyon Ferry Reservoir (first found in the early 1990's) and also in Noxon Reservoir on the Clark Fork of the Columbia River in western Montana (McMahon and Bennett 1996, Fuller 2007).

Settlers and agencies introduced salmonids into fishless wilderness mountain lakes to create and enhance recreational fisheries. This practice ended in most western national parks by the 1970s and 1980s (Knapp et al. 2001), reflecting the growth of environmental awareness and changing public perspectives in the 1960's (Pister 2001). Although the 1964 Wilderness Act grants the authority for fish stocking to the states, judicial interpretation of the law allows the federal agencies to be directly involved in decisions about fish stocking in wilderness areas (Landres et al. 2001). Wilderness fish stocking continues to be controversial, with differing perspectives among state and federal managers, often resulting in support for fish stocking within state agencies and objections to the practice within federal agencies (Pister 2001).

Blocked area substitutions: The Lake Rufus Woods Subbasin Plan provides a good example of how non-native fish species have come to dominate upriver ecosystems in the Columbia River Basin where hydropower development has altered habitat conditions. Prior to the construction of the Chief Joseph and Grand Coulee dams, the native fish assemblages within the Lake Rufus Woods Subbasin included both resident and anadromous species. The dams eliminated spawning and rearing habitat and blocked the upstream migration of adult salmon, resulting in their extirpation. The dams have also altered aquatic environments, replacing free-flowing rivers with reservoirs and impoundments. These alterations have created conditions more suitable for non-native species than for native species (Scholz et al. 1988). Reflecting the changed habitat conditions, the Upper Columbia Blocked Area Management Plan (1998) addresses the role of non-resident species in supporting harvest. The overarching vision is to achieve a healthy Columbia River ecosystem that supports viable and genetically diverse fish species that in turn provide direct benefits to society, including harvest. Managers are charged with providing subsistence and recreational fisheries in the Blocked Area. Blocked Area fish managers have defined two alternative visions that reflect a desire to return to pre-dam habitat conditions:

(1) Development of a stable Upper Columbia River, producing sustainable resident fish populations and harvest, equal to the level of historical (pre-dam) conditions, and/or

(2) Re-introduction of anadromous salmon and steelhead runs above Chief Joseph and Grand Coulee dams in areas where they historically occurred and to restore anadromous and resident fish abundance and harvest to historical levels.

Marine trade: Goals for expanding marine trade increase the potential for introductions of non-native aquatic species. Ship ballast water has been a concern since the early 1990s, in response to the introduction of the zebra mussel into the Great Lakes and findings that the discharge of ballast water results in unintentional introductions of non-native species (GAO 2005). Under the authority of the Non-indigenous Aquatic Nuisance

Prevention and Control Act (NANPCA) (1991) and the National Invasive Species Act (NISA) (1996), the Coast Guard has promulgated guidelines and regulations on ballast water management required of certain ships entering all U.S. ports. In 2004, the International Maritime Organization adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments to apply to all shipping worldwide. To enter into force, the Convention requires ratification by 30 countries, representing 35% of the world's merchant shipping tonnage, a level of ratification that has still not been reached (GAO 2005[1]).

Marine aquaculture: Commercial net pen salmon operations are located in the coastal waters of Washington and British Columbia. Washington State is a small producer of farmed salmon, but British Columbia is the world's fourth largest producer (British Columbia Salmon Farmers Association 2005, cited in Bisson 2006). Atlantic salmon make up 85 percent of British Columbia's net-pen reared fish. The majority of salmon that escape from net pens do so during severe storms that damage the pens and have resulted in escapes of between 100,000 to 450,000 fish (Washington Department of Fish and Wildlife 2001; Canada Department of Fisheries and Oceans 2003). Reported net pen losses are probably underestimates of actual losses. Volpe et al. (2000) presented evidence for the successful spawning in the wild of aquaculture-escaped Atlantic salmon (*Salmo salar*) in British Columbia. Bisson (2006) examines the evidence for invasion of Pacific Northwest streams by escaped Atlantic salmon and assesses their potential impact on native fishes inhabiting streams on National Forest System lands in the Pacific Northwest. He concludes that although the current risk of Atlantic salmon invasions appears to be low and geographically limited, long-term risks to native salmonids of parasitic infections, sea lice, disease or local adaptations may be substantial (see section on **Disease transmission and parasites**, below).

These examples illustrate how economic goals for non-native fish have changed over time. In the early Euro-American settlement of the Columbia River Basin and well into the 20th century, non-native species were deliberately introduced for the benefits they provided. Now non-native species are more likely to be viewed in terms of their costs than their benefits. The damages caused by non-native species were estimated to cost $137 billion per year for the United States in 2005 (Pimentel 2005; Simberloff et al. 2005). Estimates are crude, as the scale and scope of the problem, the value of opportunities lost, and appropriate remedial strategies are all characterized by high uncertainty (Eiswerth and van Kooten 2002). Sometimes, the uncertainty extends to ecosystem-level interactions among native and non-native species that lead to unintended outcomes. A good illustration is the uncertain effect of interactions among grizzly bear, cutthroat trout and introduced lake trout (*Salvelinus namaycush*) in Yellowstone Lake, described by Settle and Shogren (2002).

[1] www.imo.or/Conventions/mainframe.asp?topic_id=867

Changing Cultural Values

Underlying the evolution of economic goals for non-native species over time are changing public values concerning the role of native species and the ecosystems that support them.

In describing live shad transport from the east coast to the west in the late 1800's, Lampman (1946) characterized the transport problem as "**. . .** one of economic and sentimental importance, and plainly related to the enrichment and happiness of the generations **. . .**" A subsequent account of the development of fish farming referred to the practice of (non-native) fish planting as taking place "without rhyme nor reason except for the desire of some 'immigrants' from the East who longed for a taste of white-meated fish to supplant the available native supply of pink-meated trout and salmon" (Washington Department of Fisheries 1959).

Historically, expansion was another value associated with Euro-American settlement. Expansion was accompanied by the confident expectation that people could manipulate and improve nature, as they had for centuries in the practice of livestock husbandry. People valued the opportunity to develop new fisheries or manage the variability of natural ecosystems by engineering the production of eggs and habitat. Opportunities to expand non-native species were aggressively pursued.

Over time, values supporting efforts to customize ecosystems are being supplanted by values respecting the integrity of natural ecosystems. Some conservation programs for native trout species in the western United States now use piscicides such as rotenone or antimycin to reverse the outcome of earlier actions by attempting to remove non-native fish from lakes and streams in preparation for native trout re-introductions. The introduction of non-native species is more likely to be seen as "biological pollution," in view of their invasive potential (Horan et al. 2002).

The transfer of fish among water bodies, once freely practiced, is now discouraged or illegal. In June 2007, Montana's Lion Lake (near Hungry Horse Reservoir) was described as the "latest casualty in Montana's ongoing epidemic of bucket biology" (Columbia Basin Bulletin 2007). Sample netting conducted by Montana's Department of Fish, Wildlife and Parks caught northern pike, black crappie, and a white sucker not native to western Montana. Crappie and pike prey on juvenile trout, jeopardizing the state's attempts to maintain a rainbow and cutthroat trout fishery. Lion Lake is one of more than 500 Montana waters where fish have been illegally introduced; in the past two years, 40 different species have been planted in 29 waters (Columbia Basin Bulletin 2007).

Managers of non-native species are often caught between conflicting goals, with the challenge of maintaining fisheries based on non-native species, while minimizing their effects on natural processes. The stocking of non-native fish into wilderness lakes in the West is a good example of this difficult balance (Knapp et al. 2001). Constituencies have developed around introduced species, and efforts to control non-native species may be controversial, with the philosophy of non-native control and its derivative actions labeled as "nativism" or "xenophobia" (Simberloff 2003).

Non-native Species Laws, Policies, and Plans

Non-native species populations span many geographic and jurisdictional boundaries across the United States and Canada, and the need to actively prevent and control the introductions and spread of non-natives has been partially addressed by passing federal and state laws and regulations. Appendix A provides an annotated listing of most of these federal and Northwest states laws, policies, and regulations.

Federal and State Coordination and Planning

During the 1980s and early 1990s, efforts to slow the spread of non-native species were ineffective. A partial cause may have been the challenge of coordinating federal, state, and regional actions. There are 13 federal departments and agencies with various levels of responsibility for prevention, regulation, and research on non-native invasive species, and the challenge of coordinating these proved difficult in the 1980s and 1990s.

In 1997, in response to such difficulties in coordination, more than 500 scientists and land and resource managers from across the United States wrote the Administration to express their deep concerns about non-native invasive species. In response to the letter, the Administration developed and President Clinton signed Executive Order 131122 on Invasive Species (64 Fed. Reg. 6183, Feb. 8, 1999). The Executive Order was intended to better coordinate federal agency actions to prevent, control, and minimize the impacts of invasive species. Executive Order 13112 established an interagency National Invasive Species Council (NISC) charged with developing a National Invasive Species Management Plan and providing national leadership on non-native invasive species. The specific focus of the Council is to ensure that activities of federal and state agencies activities are coordinated, complementary, cost-efficient, and effective.

The NISC is required to produce a Management Plan. The Management Plan will encourage planning and action at the local, tribal, State, regional, and ecosystem levels; develop recommendations for international cooperation; provide guidance on incorporating prevention and control of invasive species into the National Environmental Policy Act; facilitate development of a communication network to document, evaluate, and monitor impacts from invasive species on the economy, the environment, and human health; and initiate the development of an information-sharing system that facilitates the exchange of information concerning invasive species.

The first National Management Plan[3] was released in early 2001. Currently, a draft plan 2008-2012 National Invasive Species Management Plan -- Draft for Public Comment

[2] www.invasivespeciesinfo.gov/laws/execorder.shtml
[3] www.invasivespeciesinfo.gov/council/nmp.shtml

(143 KB)[4] which updates the 2001 plan, is out for public comment and approval. Following the first national plan in 2001, the Invasive Species Councils in the Northwest states of Montana (in 2002), Idaho (in 2003), Oregon (in 2005), and Washington (in 2008) have developed Invasive or Aquatic Nuisance Species management/action plans, which are referenced and described in Appendix A.

Western U.S. Regional Policies and Programs

Northwest Power and Conservation Council (Council) Fish and Wildlife Program: The Fish and Wildlife Program specifies planning assumptions and scientific principles. One important assumption is that the program is habitat based, "rebuilding healthy, naturally producing fish and wildlife populations by protecting, mitigating, and restoring habitats and the biological systems within them, including anadromous fish migration corridors. Artificial production and other non-natural interventions should be consistent with the central effort to protect and restore habitat and avoid adverse impacts to native fish and wildlife species." Two of the Program's scientific principles involve non-native species.

> Principle 5. Species play key roles in developing and maintaining ecological conditions. Each species has one or more ecological functions that may be key to the development and maintenance of ecological conditions. Species, in effect, have a distinct job or occupation that is essential to the structure, sustainability and productivity of the ecosystem over time. The existence, productivity and abundance of particular species depend on these functions. Loss of species and their functions lessens the ability of the ecosystem to withstand disturbance.

> Principle 6. Biological diversity allows ecosystems to persist in the face of environmental variation. The diversity of species, traits and life histories within biological communities contributes to ecological stability in the face of disturbance and environmental change. Loss of species and their ecological functions can decrease ecological stability and resilience. More diversity is not always good; introduction of non-native species, for example, can increase diversity but disrupt ecological structure. Diversity within a species provides a range of possible solutions to environmental variation and change. Maintaining the ability of the ecosystem to express its own species composition and diversity allows the system to remain productive in the face of environmental variation.

More discussion of specific Fish and Wildlife Program's language regarding non-native fish species can be found in the section below on developing an environmental risk assessment to evaluate the use of non-native fish species in resident fish substitution programs. In additions, other various western regional initiatives have formed around the issue of non-native species, characterized as nuisances and these are listed in Appendix A.

[4] www.invasivespeciesinfo.gov/council/mpdraft07.pdf

Canadian Federal and Provincial (BC) Laws and Policies

The Canadian federal government enacted a *National Code on Introductions and Transfers of Aquatic Organisms* in 2003. This code set in place procedures for assessing proposals to move aquatic organisms from one body of water to another and also provided risk assessment procedures for assessing the potential impacts of intentional introductions of aquatic organisms. In addition, the Federal Department of Fisheries and Oceans has recently established a national Centre of Expertise for Aquatic Risk Assessment, which deals with non-native species.[5]

The British Columbia Ministry of Water, Land, and Air Protection has recently adopted a guidance document (*Invasive Alien Species Framework for BC: Identifying and Addressing Threats to Biodiversity* 2004), supporting a science-based approach to address threats to BC's environment and economy posed by invasive alien species.

Non-Native Species Positions of Scientific Professional Societies

Several national scientific societies have taken positions and made recommendations for U.S. national policies and practices on biological invasions by harmful non-native species. Two examples include the American Fisheries Society (AFS) and the Ecological Society of America.

In 1972 the AFS developed, with membership endorsement, a comprehensive policy statement on introductions of Exotic Aquatic Species.[6] The AFS membership re-affirmed this policy in the late 1980s with minor modifications. The stated goal of the AFS policy is "to formulate a broad mechanism for planning, regulating, implementing, and monitoring all introductions of aquatic species." The policy recommends a course of fairly detailed actions focused on prevention, regulation, risk assessments, and research of non-native aquatic species.

Over the years the AFS has been active in urging the federal government to prevent introduction and spread of aquatic non-native species. For example, the AFS, recently sent a letter to the U.S. Congress and administration (July 24, 2007), that strongly supported the need for the National Aquatic Invasive Species Act, a legislative act to help prevent the introduction and spread of exotic species in our aquatic ecosystems. The AFS letter further recommends legislative initiatives to: (1) prevent ship-vectored introductions into the Great Lakes and other ports, (2) prevent ill-considered import of new species, and (3) where possible, to contain or reduce any negative impacts from introduced species.

The Ecological Society of America has recently published a report in *Ecological Applications* (Lodge et al. 2006) that recognizes that the current best scientific knowledge indicates that invasions by harmful non-native species are increasing in number and area,

[5] www.dfo-mpo.gc.ca/science/cears/
[6] www.fisheries.org/afs/docs/policy_15f.pdf

with increasing damage to ecosystems, economic activity, and human welfare. The Society recommends that the federal government take a leadership role, in cooperation with state and local governments, to increase the effectiveness of prevention of invasions, detect new invasions, and slow and control the spread of existing invasions. The Society further recommends six detailed actions to construct a comprehensive program to address all aspects of invasive species management. Briefly, the recommendations focus on better management of commercial and other pathways to reduce the transport and release of potentially harmful species; better risk analysis of every species proposed for import into the country; increased active surveillance and sharing of information; support of efforts to slow the spread of existing invasive species, respond to emerging invasions, and protect uninvaded ecosystems; and coordination of efforts.

Biological Impacts and Risks to Native Salmonid Populations from Non-native Species

Predation

There is more information on the direct effects of non-native fish species as predators on native salmonids than there is regarding any other impact. One of the first studies examining the relative impacts of non-native predators on juvenile salmonid mortality was conducted from 1983-86 in John Day Reservoir to determine the significance of predation on emigrating juvenile salmonids (Rieman et al. 1991; Vigg et al. 1991; Poe et al. 1991). Results indicated that three non-native fishes -- walleye, smallmouth bass and channel catfish -- consumed significant numbers of juvenile salmon and steelhead, although the native predator (northern pikeminnow) accounted for the highest losses of smolts. Other non-native fishes that have been documented to prey on juvenile salmonids include largemouth bass, yellow perch, and crappie (unidentified to species) (Bennett et al. 1983; Poe et al. 1994). In addition to the suite of papers on this subject, a recent paper by Tabor et al. (2007) shows that smallmouth bass are generally greater predators on Chinook salmon in the Lake Washington system than largemouth bass.

Sanderson et al. (2008) provides a good recent update and a comprehensive overview on the impacts of predation basin-wide and discusses the significance and limitations of the existing data. They conclude that predation was indeed the best documented of all non-native impacts on salmon in the Pacific Northwest and that in some habitats non-native fishes can consume significant numbers of emigrating juvenile salmon. They further found that most of the studies were at relatively small scales, such as individual stream reaches or single reservoirs and often looked at impacts of only one non-native species. They suggested that cumulative impacts could be enormous, so regional scale, multi-species research studies were needed to determine the true impacts of non-natives on native salmonids.

Competition for Food and Habitat

The effects of non-native feral fish or hatchery resident fish on the food webs of streams and lakes where they have been introduced or stocked are poorly known. Introduction of brook trout into a fishless lake in the Rocky Mountains drastically changed the food web of the lake by eliminating two important plankton species. Following removal of the brook trout, only one of the species returned, indicating a long-term effect on the pelagic food web (Parker et al. 2001). Another study (Drake and Naiman 2000) found that the aquatic ecosystems in once fishless alpine lakes may have been irrevocably altered by introductions of non-native trout; although the non-native trout were eradicated, restoration of the food web did not follow.

There is some evidence that planktivorous American shad have an impact on *Daphnia* abundance and size in Columbia River mainstem reservoirs (Haskell et al. 2006).

Daphnia is an important food resource for subyearling Chinook salmon, so this may be a concern for their fitness and survival. However, conclusive documentation of competition for food would require data on food supplies as well as on spatial and temporal overlap of the potentially interacting species (Fresh 1997). The introduction of mysid shrimp (*Mysis relicta*) into Lake Pend Oreille in northern Idaho provides one of the best examples of the effects of a non-native invertebrate on native invertebrates. The mysids displaced other zooplankton species that were the favored food of kokanee (Rieman and Falter 1981).

Another possible impact of shad on anadromous salmonids is the disruption of upriver immigration passage in the fish ladders at Bonneville Dam. The upriver run of adult shad overlaps that of spring Chinook and sockeye salmon in May and June. There can be more than five times as many shad in the Columbia River as there are salmon. During those periods the shad amass in the ladders and at ladder entrances in such great numbers that they delay salmon passage over the dams (Monk et al. 1989).

There are examples of competitive effects of non-native trout on native trout in watersheds of western North America. Many studies have examined effects of brook trout invasions on native cutthroat trout, but many of these studies were equivocal, according to Dunham et al. (2004). de Stasio and Rahel (1994) showed that brook trout can outcompete native cutthroat trout in Utah, depending on the temperature, with brook trout tolerating warmer habitats. Nadolski et al. (2007) found that brook trout expansion into subbasins of a Utah watershed may be limited by water chemistry properties such as conductivity. Bonneville cutthroat trout (*Oncorhynchus clarkia utah*) were found in rivers with different conductivity.

Food Web Changes

There is evidence that the resident fish assemblages in shallow nearshore habitats of Columbia River reservoirs are changing at a fairly rapid rate. In 1995, Barfoot et al. (2002) replicated a 1984-85 study (Palmer et al. 1986) and found that relative fish species composition, though very similar in 1984 and 1985, changed dramatically by 1995. In 1984-85, four native taxa (chiselmouth, northern pikeminnow, suckers, and sand rollers) dominated the catch (90%) and introduced species comprised 1.3%. By 1995, the same four native species comprised only 37.7% of the fish fauna, while the proportion of introduced taxa (primarily sunfishes and yellow perch) had increased to 33.9%, with the remaining 28% consisting of sculpin, peamouth, and several species of minnows. One of the primary explanations for this shift in composition was that the impoundments had created sloughs and backwater habitats where water exchange was very low and summer water temperatures were often several degrees higher than in nearby main-channel habitats (Gadomski and Barfoot 1998). These higher late summer temperatures have probably caused native taxa to move out of backwaters, while introduced warm-water taxa have moved into these habitats and remained there (Barfoot et al. 2002).

Concurrent with temperature increases in backwater and shallow water habitats of mainstem reservoirs, introduced warm-water and cool-water piscivorous fishes, such as centrarchids (sunfishes, e.g., bass, bluegill, and crappies) and percids (e.g., walleye and perch) are expanding their distribution and numbers (Poe et al. 1994). In some areas of the mainstem Columbia River, smallmouth bass have been documented to prey selectively on subyearling wild fall Chinook (Tabor et al. 1993). Any future increases in temperature will certainly favor further expansion of warm-water piscivores, particularly largemouth bass and channel catfish, which are already present in mainstem reservoirs (Poe et al. 1991).

American shad also may have significant impacts on the food webs of the Columbia and lower Snake rivers. Larval and juvenile shad are suspected to significantly reduce the abundance and size of *Daphnia* spp. in two lower Columbia River reservoirs during summer (Haskell et al. 2006) thereby reducing the food resources for subyearling Chinook, which prefer *Daphnia* spp. and rear in these reservoirs (Rondorf et al. 1990). Temperature increases and flow decreases in summer also may alter food web dynamics by causing zooplankton abundance, primarily cladocerans and copepods, to peak earlier in summer. This could reduce the availability of *Daphnia*, currently an important food source for emigrating subyearling fall Chinook, by enabling the juvenile shad to deplete this important food source before the subyearling Chinook salmon enter the mainstem reservoirs (Haskell et al. 2006). Future increases in water temperature due to climate change will likely continue the expansion of shad in the Columbia River Basin. Research is needed to examine the potential interactions between juvenile salmonids and larval, juvenile, and adult shad (Petersen et al. 2003).

Interbreeding

An extensive literature, dating at least back to Hubbs (1955), shows that where introduced non-native fish have close relatives among the native populations, we can expect hybridization and introgression between them, genetically disrupting adaptation of the native species to their habitats. In the particular context of salmonids in the Columbia River Basin, Utter (2001), reviewing the literature of conspecific introduction, points out that the frequency of hybridization is much greater in freshwater trout than in anadromous salmon, interpreted as a consequence of the more complex adaptations in life history required for the anadromous life-style. As a general rule, anadromous species are more resistant to introgression from any but the closest of relatives, because even limited genetic infiltration can disrupt the normal geographic structure of local adaptation.

There is, however, a greater risk of local anadromous stocks being supplanted by introduced conspecific stocks from elsewhere. For strictly fresh-water species, on the other hand, the adaptive consequences of genetic exchange with conspecific stocks introduced from elsewhere are more widely tolerable, and a greater amount of infiltration is observed. As a consequence, we may already be well along the path to a new geographic structure of adaptive variation within some of our resident trout species, assemblages that are quite different from the assemblage that was present before Euro-Americans arrived, though better adapted to the now-prevailing environmental conditions.

At the inter-specific level, hybridization is a serious threat to fresh water salmonid biodiversity (Perry et al. 2002). For example, hybridization and genetic introgression between cutthroat trout subspecies (*Oncorhynchus clarkii*) and non-native rainbow trout (*O. mykiss*) in southern Idaho and neighboring states occurs frequently and generally to the considerable detriment of the cutthroat (e.g., Campbell et al. 2007, Kozfkay et al. 2007, Meyer et al. 2007, Waknitz et al. 2008). Non-native brook trout (*Salvelinus fontinalis*) are widespread throughout the Columbia River Basin (e.g., Spruell et al. 2001), and they hybridize with native bull trout (*Salvelinus confluentus*), generally to the detriment of the latter. Typically, male brook trout mate with female bull trout, and the hybrids have reduced fertility, resulting in substantial wasted gametic output for bull trout spawning with hybrids (Kanda et al. 2002). Although Atlantic salmon (*Salmo salar*) can be hybridized with Pacific salmonids (with difficulty in the lab, though seemingly not in the wild), Atlantic salmon will hybridize with introduced Brown trout (*Salmo trutta*) from Europe, occasionally under natural conditions (reviewed in Waknitz et al. 2003).

Disease Transmission and Parasites

Waknitz et al. (2003), in reviewing a large literature, point out that several infectious diseases of freshwater salmonids occur regularly in hatchery populations, caused by both bacteria (e.g., furunuclosis, bacterial gill disease, bacterial kidney disease, botulism, enteric red mouth disease, cold water disease, and columnaris) and viruses (e.g., infectious hematopoietic necrosis, infectious pancreatic necrosis, viral hemorrhagic septicemia, and erythrocytic inclusion body syndrome). There are also numerous parasitic infections, among them ceratomyxosis, costia, gyrodactylus, ichthyophonis, nanophyetus, proliferative kidney disease, trichodina, and whirling disease. Hatchery-related diseases can also be found in seawater net pen enclosures and are typically most severe in dense hatchery (or net-pen) populations. Monitoring and treatment for the diseases is routine, mandated, and generally effective, but continuing vigilance is necessary.

There are also pathogens, such as *Vibrio anguillarum*, and various other parasites that are unique to the marine environment, and these can be acquired by out-migrating anadromous stocks, upon entry into the marine habitat (Kent and Poppe 1998). Moreover, salmonids – like virtually all other species, can carry infectious agents without themselves being clinically affected, so pathogens and parasites can be widely disseminated. All of these native diseases also occur in wild populations (Amos and Appleby 1999), and there is geographic variation in frequency of occurrence, in both natural and wild populations, presumably dependent on local environmental conditions. Any change in local ecology can lead to altered susceptibility of native organisms to their normal array of parasites, and the aquatic habitats of the Columbia River Basin have been seriously impacted by hydrological changes.

The question arises of the extent to which dense hatchery or net-pen populations of salmonids act as a reservoir of infection for diseases that are not native to the Pacific Northwest. There are documented examples of transfer of diseases from cultured salmonids to wild relatives, but they are not common (Brackett 1991), though a serious problem when they do occur. Two examples should suffice. Atlantic salmon (*Salmo salar*) smolts were transferred from infected Norwegian hatcheries into Norwegian rivers introducing the freshwater parasite, *Gyrodactylus salaris*, leading to extirpation of wild stocks of Atlantic salmon in many river systems (Johnsen and Jensen 1988). Infectious hematopoietic necrosis was introduced to Japan in a shipment of infected sockeye salmon (*Oncorhynchus nerka*) eggs from an Alaskan hatchery, leading to epizootic mortality in Japanese chum salmon (*O. keta*) and in two species of landlocked salmon that are endemic to Japan (McDaniel et al. 1994). Both examples illustrate what can happen when a novel pathogen is introduced into a naïve population.

In an aquacultural context, some concern has been expressed that Atlantic salmon, cultured on the West Coast, may serve as a source of infection of West Coast fish with non-native diseases. However, the Atlantic salmon stocks imported from New England to the West Coast were inspected for disease free status, prior to shipment, and have been periodically checked for possible diseases of Atlantic salmon (Waknitz et al. 2002). They have probably acquired the normal suite of Pacific Coast parasites and pathogens, since importation, but they are apparently not contributing non-native diseases from the Atlantic. It has been suggested that net-pen aquacultural populations of both Pacific salmonid and Atlantic salmonid species, are increasing exposure of anadromous stocks of Pacific salmonids to copepod sea lice (*Lepeophtheirus salmonis*) and reducing their survival as a consequence (e.g., Krkošek et al. 2007), though such claims have been challenged (Brooks and Jones 2008).[7] In any event, the issue is net-pen aquaculture, rather than non-native Atlantic salmon *per se*. The louse is a natural parasite of Pacific salmonids, and is also found on sticklebacks and coastal stocks of Pink salmon (*O. gorbuscha*) that are not associated with aquaculture.

Recently, American shad was reported to be a vector for the protozoan parasite, *Ichthyophonus spp,* (Mike Parsley, USGS, personal communication) which may cause prespawn mortalities in adult Chinook (Kocan et al. 2003). Pacific herring, *Clupea pallasi,* (a clupeid fairly closely related to shad) from Puget Sound also have been found to be carriers of this parasite.

Invertebrates

The ecological effects of non-native invertebrates in the Columbia River Basin have been poorly described, but zebra mussels (*Dreissena polymorpha*) and the overbite clam (*Corbula amurensis*) have changed food web and energy flow pathways in the Great Lakes and San Francisco Bay, respectively. However, the impacts of non-native invertebrate species have not been researched in the Columbia River Basin, and their potential effects on salmonids in the Basin are largely unknown. Sytsma et al. (2004) sampled at 134 stations in the lower Columbia River and estuary and documented 269 aquatic species (and 55 other distinct organisms that they were unable to identify to the

[7] See NW Fishletter article #242, February 7, 2008: www.newsdata.com/fishletter/242/4tory.html

species level). Of the 269 species identified, 54 (21%) were introduced, 92 (34%) were native, and 123 (45%) were of uncertain origin but likely non-native. In some instances, the occurrences are single records, which do not necessarily indicate a species is established and spreading.

Vectors of introduction for non-native invertebrates are more diverse relative to those of fish. In addition to the movement of freshwater organisms from the east (via recreational boats and cargo barges/tugs, intentional or accidental release of bait, and releases from home aquaria), numerous non-native invertebrates have been introduced to the Columbia River Estuary via deep-sea shipping. Deep-sea ships can transport non-native invertebrates via ballast water, ballast tank sediment, and hull fouling. Non-native invertebrates can also be moved into the estuary with live seafood and into the river and estuary by releases from home aquaria. A number of non-native invertebrates have been documented in the Columbia River Basin including the following:

- Freshwater Asian clam – The Freshwater Asian Clam, *Corbicula fluminea*, was first reported in the Columbia River Basin in 1938 (Burch 1944, cited in Cordeiro et al 2007). When in high densities, it displaces native bivalve species and can also clog cooling water intakes (Boersma et al 2006). The species is abundant in sediments of the lower Columbia River (McCabe et al 1997) where it is eaten by white sturgeon.

- Quagga mussels – The quagga mussel, *Dreissena rostriformis bugensis*, which is indigenous to the Dnieper River drainage of Ukraine has been reported from Lakes Mead and Havasu in Arizona. Recent reports (www.100thMeridian.or) indicate that the quagga mussel is moving rapidly northward (e.g., recent find in the San Justo Reservoir, southeast of San Francisco) and its presence in the Columbia River Basin is anticipated soon, if preventive measures are not taken.

- New Zealand mud snail – The New Zealand mud snail, *Potomopyrgus antipodarum*, is a small single shelled mollusk that is present in very large numbers (e.g., 500,000 per m^2 in Idaho, Boersma et al 2006) in streams and reservoirs in the Columbia River Basin. The ecological impact of the snail has not been studied, but some researchers think it could be out-competing native invertebrates, notably those used by juvenile salmonids, for algal food.

- Red Swamp or Ringed crayfish - The red swamp crayfish, *Orconectes (Procericambarus) neglectus neglectus*, native to the south central United States, has been reported in "dense concentrations" in the Rogue and John Day Rivers, Oregon (Adams, 2005) and has also been reported in several lakes in Washington. The ecological impact of the crayfish is not well known but as with other non-native species overlap in food use with endemic species could be an issue. Native fish also use the invertebrate fauna as food, though direct competition between the dense crayfish populations and salmonids, sculpin, or other native fish has not yet been documented (Adams 2005).

Plants

Non-native macrophytes and other non-native aquatic vegetation can change aquatic habitats by occupying shoreline space, shading, clogging spawning substrates, reducing currents, and creating conditions favored by non-salmonid fishes. It is also well known that riparian vegetation has large effects on aquatic communities (Naiman et al. 2000). Recent work with Russian olive (*Eleagnus angustifolia*) indicates the substantial ecosystem consequences that a non-native riparian species can have. Russian olive was introduced to the western United States from Eurasia early in the 20th century and is now widespread. Recent comparative research in Idaho shows that a stream reach along which Russian olive is now established has biotic communities with lower invertebrate diversity, biomass, and secondary production than were present 30 years ago. In comparison, a previously similar stream reach in which Russian olive is not present had not changed in those attributes (Mineau et al., 2008). Non-native plants, both aquatic macrophytes and riparian species, can therefore have direct or indirect effects on native fish. The following are examples of non-native plants and notes of the problems that they may cause:

- Eurasian milfoil, *Myriophyllum spicatum, is* the most widespread non-native macrophyte in the Columbia River Basin (Sanderson et al. 2008). The conversion of free-flowing river habitat to reservoirs has favored the spread of this species along shorelines throughout the Basin.

- Purple loosestrife, *Lythrum salicaria,* is a non-native vascular plant found in wetlands that are regularly flooded. Purple loosestrife can crowd out native vegetation and can also alter detrital-based food webs (Blossey et al. 2002), including those supporting salmonids (Grout et al. 1997).

- Reed canary grass, *Phalaris arundinacea*, occurs as both a native and as an invasive European cultivar (Meriglinao and Lesica (1998). It is a riparian or wetland plant that out-competes native grasses and other wetland vegetation. This species can be a problem when restoring habitat, since it rapidly spreads into disturbed areas such as replanted vegetation.

- Yellow iris, *Iris pseudacorus,* is another non-native wetland plant that can crowd out native vegetation in the region (Boersma et al. 2006).

- Japanese knotweed, *Fallopia japonica,* is a rhizomatous perennial that grows to two to three meters in height and increases rapidly in disturbed riparian areas where it forms dense thickets and where water flow disperses rhizome fragments.

- The rock slime diatom, *Didymosphenia geminate*, has been found in the Canadian portions of the Columbia River Basin[8] and is well known as a problematic non-native species in several other parts of North America.

The vectors for non-native vegetation include intentional introduction via the nursery trade and accidental movement of fragments on boats, boat trailers, boots, hull fouling, fragments associated with the live seafood trade, dispersal by river currents, and spread of seeds by birds and mammals.

[8] www.env.gov.bc.ca/wat/wq/didy_bcstrms.html

Current Status of Management Actions Taken to Reduce or Eliminate Non-Native Species Impacts

Education, Identification, and Prevention

Public education is critical for curtailing the introduction and spread of non-native species. An aware citizenry will not only recognize the danger to the ecosystem but will also assist in alerting authorities in the identification of non-native species. Several of the modes of education include public and private classes for youth and adults; watershed councils; television; and the internet, including the distribution of images of non-native plants and animals. An example of media education is an hour-long program on Oregon Public Broadcasting, repeated several times, on the impacts of invasive species.[9] This program included an invasive hot-line website and telephone numbers that the public could use to report invasive species that were observed. It also included a plea for the public, including boaters, anglers, gardeners, outdoor enthusiasts, pet owners, consumers, and travelers to become involved. Education of sporting organizations, such as fishing clubs, could inform on the problems of intentional or inadvertent release of non-native fishes, invertebrates, and plants in the environment. Engaging citizens, non-governmental organizations (NGOs), and conservation groups can help avoid unintentional introduction of non-native species by such mechanisms as transfer between watershed via bait buckets and accidental loss from home aquaria[10] or live seafood holding tanks (see above).

There are several major regional or international initiatives in place to identify non-native species in an early warning system and help interrupt their movement into the Columbia River Basin. In addition to individual state programs, the major regional programs are the Western Panel[11] and the coordination efforts of the Pacific Northwest Aquatic Monitoring Program. The Western Panel introduced the 100th Meridian Initiative in 2003 to curb the spread of the zebra mussel from watershed east of the Rockies. Important checkpoints include surveillance activities such as watching for non-native invertebrates and weeds on boat trailers. Surveillance programs often include efforts to increase awareness of the risks associated with non-native species using educational materials such as posters and videos. Conservation groups such as The Nature Conservancy are active in distributing information on control measures for certain non-native species (e.g., reed canary grass, Tu, 2004). Mid-ocean exchange of ballast water is the current technology used in the prevention and control of non-native species entering the Columbia River Estuary by foreign shipping. Inspection procedures are conducted by the U.S. Coast Guard and the States of Washington and Oregon (Sytsma et al. 2004). Models have also been developed to predict potential vulnerable habitats for non-natives and predict their spread (Vander Zanden et al. 2004; Mercado-Silva et al. 2006).

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[9] See Oregon Public Broadcasting's "The Silent Invasion" Web page: www.opb.org/programs/invasives/

[10] See Habitattitude: www.habitattitude.net/

[11] See www.fws.gov/answest/contact.htm

Habitat Restoration

Habitat restoration may be the best hope for protecting or restoring native species. When native species are provided with habitat for which they are best adapted, they have an improved chance of out-competing or holding their own against non-native species. Native fish populations in headwater streams have been shown to be less susceptible to domination by non-native species in locations with relatively undisturbed, high-quality habitats (Fausch et al. 2001; Olsen and Belk 2005). However, there are reported instances where non-native species are very successful even in relatively unaltered aquatic habitats (Marchetti and Moyle 2001), suggesting that introduction of non-native fishes has the potential to impact native communities, regardless of habitat condition. Once habitats are made available by removing barriers, recolonization of unoccupied habitat appears likely, particularly in free-flowing river areas where non-native fish are not present (Fausch *et al*. 2006).

Even when removal of a non-native species is successful, the desired restoration of an ecosystem may not follow. For example, Drake and Naiman (2000) studied alpine lakes that had been stocked with non-native trout, which were subsequently removed after detrimental effects on native amphibians were noted. However, paleoecological research showed that the diatom community of those lakes had changed sharply at the time of introduction of the non-native trout, but did not show signs of returning to the pre-introduction state when the non-native trout were removed and had not done so 20 to 30 years after the removal. Although it is not understood why this particular case resulted in an apparently stable and lasting shift in the biotic community of a set of lakes, a large body of research describes similar phenomena and the general mechanisms that can cause them.

Such major or lasting shifts in ecosystems that result from comparatively minor changes in presence of abundance of one species can result from threshold dynamics and can reflect alternative stable states. There are now many reviews of the theory, examples, and implications of threshold dynamics and alternative stable states in ecology (e.g., Carpenter 2001; Beisner et al 2003; Suding et al. 2003; Groffman et al. 2006). We refer the interested reader to these for more information about a topic that is complex, but nevertheless of high importance to natural resource management. We note also that management implications are explicitly considered in many of these papers. For instance, Carpenter (2001) concludes that, even if the probability of alternative stable states of an ecosystem is low, the high costs of attempted restoration from such a state are so high that caution, accompanied by careful experimentation to determine risks, is the recommended strategy.

The more general conclusion is that avoiding introduction of non-native species is the surest means for avoiding problems.

Population Control Measures

A variety of approaches have been employed in the Columbia Basin to reduce the impact of introduced fish species on bull trout (*Salvelinus confluentus*), cutthroat trout (*Oncorhynchus clarki*), and redband trout (*O. mykiss gairdneri*) (Dunham et al. 2002; Novinger and Rahel 2003). In streams, the primary targets of control efforts have been brook trout (*S. fontinalis*) and rainbow trout (*O. mykiss*). There also are several instances in the Columbia Basin where lake trout (*S. namaycush*) introductions are having undesirable effects on native species and at least one effort is ongoing to reduce impacts from this species (Hansen 2007). Generally, the approaches that have been applied to control the impacts of these introduced species on native salmonids have involved either reducing or eradicating the population of the introduced species, constructing obstacles to prevent access by introduced fish or employing both approaches in concert (i.e., eradication followed by barrier construction).

In the Columbia River Basin, a variety of fish-removal methods have been employed to reduce populations of brook or rainbow trout in streams (Dunham et al. 2002; Fausch et al. 2006) and lake trout in some of the larger lakes in the basin, most notably Lake Pend Oreille (Hansen 2007). The techniques' effectiveness has varied among projects. Eradication of introduced species has occasionally been achieved in small streams and ponds. Eradication becomes increasingly difficult as the size, depth, and habitat complexity of a water body increases, and proximity to other source populations that provide the opportunity for re-colonization (Fausch et al. 2006). It appears highly unlikely that any technique, or combination of techniques, can eradicate introduced species in large lakes (Peterson and Maiolie 2005).

Several of the most common methods of population control include use of toxicants, electrofishing, netting, and targeted sport angling. These techniques all reduce populations of the target fishes, at least short-term. However, populations of the target species are rarely totally eradicated, especially in large lakes. As a result, control measures need to be applied on a regular basis to ensure populations of the introduced species do not recover to pre-treatment abundance. Most of these removal methods also have negative effects on aquatic habitats and desirable fish species, including those that are the target of the restoration effort.

Toxicants

Compounds toxic to fishes are occasionally used to remove undesirable fish species from water bodies. This approach has been applied in the Columbia River Basin, with the toxicant rotenone being used most commonly. This chemical is highly toxic to fishes, including the species that are to be restored. As a result, stocking of desired fishes into treated water bodies is generally required after chemical treatment.

Toxicant application is the measure most likely to achieve eradication of undesired fish species. Application of the fish toxicant antimycin to a stream tributary to Yellowstone Lake successfully removed brook trout (Gresswell 1991) and toxicants were successfully used to remove brook trout from streams in Crater Lake National Park (Buktenica 1997). However, even this sort of drastic measure may not kill all fish in a stream or lake. A section of Taylor's Outflow, a spring stream in the Flathead River watershed, was treated with rotenone in 1993 to remove brook and rainbow trout (Knotek et al. 1997). The section was then stocked with westslope cutthroat trout, the species native to the stream. Three years later the fish community at the treated site consisted of two species, westslope cutthroat trout and brook trout, with brook trout the predominant species. The failure to completely eradicate brook trout was attributed to ground water seeps entering the channel where a small number of brook trout were able to find refuge during the rotenone treatment. Chemical treatments may not achieve the desired level of control in systems where such refuge areas exist.

Rotenone is also toxic to non-target species, including desirable fishes and invertebrates. Application of fish toxicants to streams in the Umatilla and John Day watersheds may have contributed to the dramatic decline in Pacific Lamprey seen in these systems (Jackson et al. 1996). Zooplankton populations decline sharply after application of rotenone but generally recover to pre-treatment abundance within a few months (Melaas et al. 2001). Benthic macroinvertebrates are less sensitive to rotenone than zooplankton (Melaas et al. 2001) but short-term increases in invertebrate drift in streams have been observed during applications (Cerreto et al. 2003).

Electrofishing

Electrofishing to reduce populations of undesirable fishes is a technique that has been used primarily in streams. This method does not capture all fish. As a result, repeated treatment is typically required to maintain the non-native fishes at low abundance (Dunham et al. 2002). A study from southwestern Idaho illustrates this point (Meyer et al. 2006). Electrofishing was used to remove brook trout from a 7.8 km stream reach. The purpose of this effort was to reduce competitive pressure on native redband trout, enabling the population of this species to increase. Shocking was conducted each year for three years, removing an estimated 80% of the brook trout population each year. However, increasing brook trout mortality rates by electrofishing caused compensatory changes in other mortality factors. As a result, two years after removals stopped, age 0^+ brook trout populations had increased by 789%. Redband trout populations did not increase during or after the electrofishing treatments. This approach to controlling brook trout would likely require annual shocking but given the lack of response in the redband trout populations, the value of the effort would be questionable.

Electrofishing has the advantage over toxicants of not killing the species that are the target of a restoration effort; many will survive and can be returned to the stream after the project is completed. However, if electrofishing is required on a regular schedule in order to control population levels of undesirable species, the target species is very likely to suffer elevated mortality rates from repeated shocking.

Gill nets and trap nets are the most common types of nets used to reduce populations of undesirable fishes from ponds and lakes. Nets are not typically used in streams for this purpose, except as blocking nets, used in conjunction with electrofishing. The effectiveness of nets varies, depending on the target species and the characteristics of the water body being treated. In small lakes and ponds, nets can be quite effective. There are examples where aggressive fishing with gill nets appears to have completely removed the fish community from small, relatively shallow lakes (Knapp and Matthews 1998).

Nets

Nets have not proven as effective in large, deep lakes. Lake trout populations have become established in several large lakes in the Columbia River Basin including Lake Pend Oreille and Flathead Lake. This species has proven especially difficult to control due to their preference for deepwater habitats. There has been a recent effort to decrease lake trout populations in Lake Pend Oreille. The lake trout, in conjunction with a large population of introduced rainbow trout, are competing with native bull trout and are suspected of reducing kokanee populations to levels too low to support sport fishing.

Evaluation of large trap nets in Lake Pend Oreille indicated that effective control of lake trout was unlikely using only this technique as they could only be fished in locations where bottom morphology was appropriate for setting the nets, a relatively small proportion of the total lake trout habitat in the lake (Peterson and Maiolie 2005). Nine nets fished over a six-month period captured an estimated 17% of the total population.

Subsequently, more aggressive efforts have been implemented in Lake Pend Oreille to reduce the lake trout population (Hansen et al. 2007). In 2006, trap nets and gill nets were used. In addition, cash incentives were offered to anglers for the capture and removal of lake and rainbow trout from the lake. These efforts in concert removed an estimated 44% of the lake trout and 22% of the rainbow trout during 2006. Total annual mortality (fishing plus natural) for lake trout in Lake Pend Oreille in 2006 was estimated to be 58%, a rate thought to be high enough to preclude the species from maintaining itself at current population levels (Hansen et al. 2007). However, sustaining this level of mortality will require continued netting and sport angling targeted on this species.

Barriers

Barriers have been used widely in the Columbia Basin to protect headwater populations of native salmonids from introduced fishes. Barriers have been employed to isolate populations of westslope cutthroat, bull trout, and redband trout (Rieman et al. 1997; Thurow et al. 1997; Dunham et al. 2002). Generally, the purpose of these barriers is to restrict the access of introduced salmonids, including brook trout, brown trout (*Salmo trutta*) and rainbow trout (Fausch et al. 2006). A thorough review of the tradeoffs involved in the use of barriers to protect populations of native trout was recently published (Fausch et al. 2006). The reader is referred to this report for a comprehensive treatment of this subject.

Barriers that isolate headwater fish populations include road culverts, dams, water diversions, and waterfalls. Barriers erected expressly for the purpose of preventing upstream movement by non-native species may take many forms but perhaps the most common are rock-filled, wire gabions. Most manmade obstructions to fish passage were not installed originally to isolate trout populations, but the study of trout populations that have been isolated by these structures provides insights on how deliberately isolated populations would be likely to perform (Fausch et al. 2006).

Barriers have been used to isolate populations of native fish located above an area where a non-native species is invading. In a case such as this, the barrier is constructed and maintained to prevent movement of the non-native species into the area occupied by the native fish. In these situations no manipulation of the native fish community above the barrier is required. In many cases, however, the non-native fish must first be removed from the area above the chosen barrier position. As noted above, eradication of introduced fish is often quite difficult, and many barrier projects have suffered from a rapid increase in abundance of non-native species after population control measures have ceased. Meyer et al. (2006) used electrofishing to remove brook trout above barriers, attempting to isolate populations of native redband trout. They were successful at reducing populations of brook trout by over 80% during the three years that shocking was conducted. However, brook trout abundance increased rapidly after annual shocking was terminated and no increase of redband trout was seen either during or after removal operations.

Rebound of non-native fish populations also can occur when the barrier intended to prevent their upstream passage is not effective. Thompson and Rahel (1998) documented the passage of brook trout past a rock-filled gabion constructed to prevent upstream access by this species. Anglers often deliberately reintroduce non-native species above barriers. This response is precipitated by the perceived loss of fishing opportunity associated with removal of non-native fishes and the restrictive fishing regulations usually enacted to protect the native fish above the barrier (Fausch et al. 2006).

Even in cases where populations of introduced species have been successfully reduced and barriers effectively prevent re-invasion, the long-term prognosis of this approach has been mixed (Kruse et al. 2001). Novinger and Rahel (2003) evaluated an attempt to increase cutthroat trout populations in areas above barriers by reducing brook trout populations. Brook trout abundance was reduced 75-96%, relative to population levels in downstream-untreated areas, and the barriers were effective at preventing re-invasion by brook trout, but they saw no response by the cutthroat trout populations above the barriers. They suspected that the reason for a lack of response was that the small reaches isolated by the barriers lacked sufficient resources to support a large increase in the cutthroat population, even after reduction in competitive pressure from brook trout. They hypothesized that the large, deep pools used by cutthroat trout during winter were absent in the areas above the barriers. They argued that many cutthroat trout may have moved downstream, over the barriers, to locate such habitat and were then unable to return to the barrier-protected upstream reaches.

Isolation above barriers may present several challenges for long-term persistence of fish populations. Isolated populations suffer increased risk of extirpation due to reduced genetic diversity (Rieman and McIntyre 1993). This problem can be particularly acute when isolation is used in conjunction with an eradication effort. In such cases, often only a very small population of the species being enhanced may remain to re-populate the isolated reach. Isolated populations also may suffer increased susceptibility to catastrophic disturbance if the area they occupy is small enough that all habitats could be impacted by a single event (e.g., wildfire, landslide) (Dunham et al. 2002). As a result of genetic effects and susceptibility to catastrophic disturbance, the probability of extirpation of isolated trout populations increases with decreasing habitat area above a barrier. This is reflected in the observation from the Boise River that isolated stream reaches of about 5 km in length had a 50% probability of supporting bull trout, but isolated streams offering 9 km or more of habitat had an 80% probability (Rieman and McIntyre 1993).

Isolating a population above a barrier also usually leads to the loss of migratory life-history forms (Rieman et al. 1997). Bull and cutthroat trout often exhibit both resident and migratory life history forms within a single population. In these populations, the migratory form often supplies significant demographic support to the population as these fish are typically larger and have higher fecundity than the non-migratory fish (Dunham et al. 2002). The fact that bull trout are more likely to be found in Montana headwater streams where a healthy source population exists downstream (Rich et al. 2003) illustrates the importance of maintaining this life history form.

Isolation can be an effective protection technique for native salmonids in some situations. There are multiple factors that should be considered when determining whether or not isolation is a viable conservation alternative (Table 2). In general, barriers may be effective in situations where (1) the population does not exhibit a migratory life history form, (2) there is an imminent threat from an introduced fish, and (3) a sufficiently large area can be isolated above the barrier to minimize risks associated with loss of genetic diversity and catastrophic disturbance (Fausch et al. 2006). However, even when these criteria can be met, there may be alternatives to isolation (Dunham et al. 2002). There are some circumstances where native fish populations have been resistant to invasion by non-native species. This phenomenon has typically been observed in locations with relatively undisturbed, high-quality habitats (Fausch et al. 2001; Olsen and Belk 2005). In such cases, barriers may not be required to prevent expansion of introduced fishes.

Table 2. Considerations for using isolation to protect native trout populations from non-native trout invasions. If a majority of these constraints cannot be successfully addressed at a project location, it is unlikely that the population isolated above the barrier will persist. (Table modified from Table 3 in Fausch et al. 2006).

Consideration	Desired Condition
Loss of genetic variability	Breeding population is large enough to minimize loss of genetic variability through drift and inbreeding.
Resilience	Isolated habitat is large enough and of sufficient quality to compensate for lost fecundity and productivity due to loss of migratory life history.
Demographic stochasticity	Breeding population is of sufficient size to minimize the probability that chance demographic events may cause extirpation of the isolated population.
Environmental stochasticity	Size of the isolated habitat and size of the population are sufficient to minimize risk of extirpation due to common environmental fluctuations.
Catastrophes	Size and distribution of the habitat and size of the population is sufficient to ensure resilience in the face of rare, high-magnitude, environmental changes.
Human Impacts	Human activities in the watershed above the isolated habitat are not likely to cause significant habitat degradation or increase the frequency and magnitude of natural catastrophes to such an extent that survival of the isolated population is threatened.

Sport Fisheries

Introduced non-native fishes, such as walleye, channel catfish, and largemouth and smallmouth bass, have been shown to be, at times and places, significant predators on salmonids, as are the native northern pikeminnow (Rieman et al. 1991; Poe et al. 1991; Poe et al. 1994). While none of these non-native species were found to be either as abundant or as significant as predators on juvenile salmonids as the native northern pikeminnow, nevertheless, their combined effect on survival of juvenile salmonids during their outmigration deserves closer scrutiny. For example, during the ISRP's Anadromous Fish Evaluation Program Review (AFEP) (ISRP 2004), one of the AFEP proposals the ISRP reviewed was for evaluation of juvenile salmonid predation by smallmouth bass at The Dalles Dam. The sponsors reported that large numbers of smallmouth bass have been observed in the tailrace at The Dalles Dam, and they may be on the increase, which might explain low survival rates of juvenile salmonids observed at that project.

Smallmouth bass and channel catfish support significant sport fisheries in the lower Snake and Columbia rivers. Walleye are the subject of significant sport fisheries in the mid-Columbia, extending into the lower Columbia River. It seems somewhat contradictory that the Council has continued to support the project aimed at reduction in abundance of the native northern pikeminnow, while state agencies in Washington, Oregon, and Idaho have simultaneously adopted management policies that in some cases seem aimed at perpetuating or even enhancing populations of these introduced predators. For example, all three states have regulations in place that limit the daily catch of bass by recreational anglers.[12] In particular, Washington's Columbia River regulations seem to be designed to optimize the spawning capability and thus recruitment of bass, using the same type of regulations as in the sturgeon fishery. Similarly, Washington's regulations for the walleye fishery seem aimed at optimizing recruitment by protecting spawners. Walleye are not abundant in the Snake River, which explains Idaho's lack of regulation of their catch.

Non-native species are a problem outside the mainstem as well. In several lakes located in tributary systems, there have been introductions of *Mysis* shrimp that have been demonstrated to be competitors of kokanee (Spencer et al. 1991) and other salmonids, and the result has been reduction in kokanee abundance. Similarly, there have been introductions of lake trout, known to feed on kokanee and other small salmonids, and the result has been further reduction of kokanee abundance. Reviews of the kokanee measures funded by the Bonneville Power Administration in Flathead Lake indicated that the majority of hatchery planted kokanee were consumed by lake trout in a matter of weeks. One proposal reviewed by the ISRP in the Gorge and Intermountain Province estimated that 10-20% of hatchery planted kokanee were consumed by walleye within a few days. The Council has continued to receive proposals aimed at counteracting these adverse effects on kokanee, such as increased hatchery stocking of kokanee, and, in one case, managing lake-level elevation during the kokanee spawning and incubation period, with the intent of increasing recruitment of kokanee that might result from lakeshore spawning. The ISRP has continued to be skeptical of the likelihood of success of any of these measures, based on experience documented in the scientific literature, as well as in the progress reports of the projects themselves (see ISRP 2007). It needs to be recognized that the ecosystems of these lakes have been reorganized as a consequence of these introductions, and there is little or no likelihood of success of measures intended to reverse the shifts in the food web that have occurred.

Policy issues often arise wherever non-native species are present. For example, the presence of introduced lake trout in Flathead Lake makes unlikely the success of any effort to restore kokanee abundance to levels experienced before their introduction. According to the Council's 2000 Annual Implementation Work Plan, the sponsors stated that the kokanee program has failed and the focus of the program has shifted to rainbow trout and westslope cutthroat trout (NPCC 2000). Subsequently, the sponsors submitted a proposal for reduction of lake trout in Lake McDonald in Glacier National Park, a place

[12] Washington (2008) – Walleye, 16" to 22" size limit, daily limit five, only one over 22". Bass size limit only fish less than 12" or greater than 17, daily limit five, only 1 over 17". Channel catfish - daily limit five. Oregon (2008) – Walleye - no limit. Bass, maximum of 3 at 15", daily limit of five (six in Snake River). Channel catfish - no size or bag limits. Idaho (2008) – Walleye - no limits. Bass - daily limit five (six in Snake River), no more than three over 15" (no length limit in Snake River, below Hells Canyon Dam). Channel catfish - no size or bag limits.

where lake trout have been documented to have a detrimental impact on native bull trout populations (Fredenberg 2002).[13] However, the Council decided, as a policy matter, not to fund the project, as its connection with the concept of mitigating for impacts of the hydroelectric system was missing.

Non-native species and their management need to be taken into account in province and subbasin summaries, as well as in individual project proposals. The ISRP encountered this issue in the Gorge, Intermountain, and Mountain Columbia subbasins. Presence of non-native species is a limiting factor in both Flathead Lake and Lake Coeur d'Alene, and is a primary determinant of management options that can realistically be accomplished in those lakes. It no doubt is an issue in other subbasins and locations, though it may not have been brought to the forefront in those proposals and plans.

Obviously, the success of resident fish projects can be seriously affected by predation by non-native species. Introduction of northern pike into the Coeur d'Alene River and Lake system in 1972 has led to expansion of their range downstream into the Spokane River. In time, northern pike will no doubt extend their range into the Columbia River itself and, from there, into other tributaries (Wydoski and Whitney 2003). Note that the northern pikeminnow, the primary predator upon which control measures are focused in the Columbia River derives its name from this fish, the northern pike, one of the most effective predatory fish in freshwater.

Non-native Vegetation and Invertebrates

Efforts to control Eurasian milfoil include measures such as harvest, herbicide application, and biological control using grass carp or aquatic insects. Covering plants with an impermeable barrier such as plastic can be successful for limited areas.[14] Grass carp (*Ctenopharygodon idella*) is commonly used as a biological control organism for non-native vegetation and are found throughout the lower Columbia River (Sytsma 2004). There are concerns about the spread of this species, however, as it is also a non-native. Grass carp must be triploid to prevent reproduction, and should only be used in isolated lakes or ponds (Bonar *et al*. 1993). We note that grass carp have been found in the mainstem Columbia River Basin system, migrating upstream past dams (Loch and Bonar 1999). As a general rule, eradication of non-native vegetation is quite difficult, once the non-natives are firmly established, and managing the problem usually amounts to the repeated application of control measures.

[13] The ISAB removed an incorrect statement from our July 15, 2008 report, in the last paragraph on page 35 continuing on the top of page 36, that lake trout were first introduced into McDonald Lake in Glacier National Park and then spread to Flathead Lake. In fact, Spencer et al. (1991) documented that lake trout were introduced into Flathead Lake in 1905 and first appeared in McDonald Lake in 1959 (Fredenberg 2002).

[14] See: www.ecy.wa.gov/PROGRAMS/WQ/plants/weeds/aqua004.html

Future Concerns

What impact will climate change have on the spread and effects of non-native species?

Climate-induced changes to riverine environments are likely to have direct implications for invasive non-native species impacts and management (Rahel and Olden, 2008). Those species that have a higher temperature range tolerance will have an advantage over those species whose upper thermal limits are exceeded. Generally, the most common non-native/invasive species in the Columbia River Basin, primarily centrarchids and ictalurids, have greater tolerance limits for higher expected average water temperatures than native salmonids and other resident species.

Climate modeling of future water temperatures in the Columbia and Snake rivers predicts an increase of 1^{o} C or greater by 2040 (Hamlet and Lettenmaier 1999; Payne et al. 2004). The models also predict a winter precipitation increase of about 5% by 2040, with more falling as rain and less as snow, reducing winter snow accumulation, thus increasing winter to early spring flows and extending the low summer flow period (Payne et al. 2004). The construction of the hydrosystem has also altered mainstem seasonal water temperature patterns. Currently, warming of water in the reservoirs begins earlier in the spring and persists longer into the fall than has historically been the case (Quinn and Adams 1996).

These predicted increases in water temperature in Columbia and Snake River reservoirs and in the major tributaries of the Columbia during the major smolt emigration will probably increase consumption rates by and growth rates of predators, and therefore predation-related mortality. Summer emigrants, primarily subyearling fall Chinook, are particularly vulnerable. Juvenile salmonid consumption rates by the three major non-native predators (walleye, smallmouth bass, and channel catfish) in Columbia and lower Snake River reservoirs is highest in July and August, concurrent with high availability of subyearlings and high water temperatures (Poe et al. 1991, Vigg et al. 1991). The maximum daily consumption of juvenile salmonids by these non-native species increases significantly as a function of temperature (Vigg et al. 1991).

What impact will human population growth and development have on the spread and effects of non-native species?

Increased human population growth in more rural areas of the Columbia River Basin may lead to expanding fisheries of popular non-native species (i.e., large and smallmouth bass, northern pike, etc.) (ISAB 2007-3). This may occur by sports fishermen lobbying for stocking of those species or by illegal transport of fish among aquatic systems in the Columbia River Basin in various boat live-wells and other suitable containers. Expanding urban populations will also increase the accidental release of non-native species such as goldfish or koi (*Carassisus auratus*) and other fish favored by hobby aquarists.

What geographic locations within the Columbia River Basin are at highest risk to threats from non-native species?

The portions of the Basin blocked to anadromous fish passage, above Chief Joseph Dam in the mid-Columbia River and above Hells Canyon Dam in the Snake River, are those locations already dominated by non-native fish species and may be at highest risk from invasive non-native fish species. The lower Columbia River and estuary appear most susceptible to non-native invertebrates and plants, because of the importance of the shipping vector. The upper river may be most susceptible to introduction of non-native species from east of the Columbia River Basin watershed boundary, due to trailer transport of recreational boats from elsewhere.

However, there is very little direct evidence to confirm these predictions, therefore, research is needed in order to prepare to deal with these threats from non-native species. It would be particularly useful to map the predicted vulnerability of the landscape to non-native species introductions, establishment, and spread. These predictions could be used to target monitoring efforts and direct public outreach efforts.

If/when anadromous salmonids are re-introduced into currently blocked areas of the Columbia River Basin (via new fish passage technologies or mainstem dam removals) will the ecosystem dominated by non-native fish species prohibit their future restoration and survival?

As yet there are no studies in the literature that provide experimental evidence as to whether native anadromous salmonids can be successfully re-introduced above barriers to habitat dominated by non-native fish species.

CONCLUSIONS AND RECOMMENDATIONS REGARDING NON-NATIVE SPECIES IMPACTS

Conclusions

The overall results and conclusions of this review indicate that the potential impacts and risks to native salmonids and other native fishes from non-native species are significant, with most subbasins in the Columbia River Basin already dominated by non-native species of fishes. The major results for each section of the report are summarized below.

Non-Native Species Trends in the Columbia River Basin

The Pacific Northwest is home to 119 threatened or endangered species, most of them found within the Columbia River Basin. A large fraction of the threatened or endangered species are plants, but the majority of fauna listed under the Endangered Species Act are fishes, including Pacific salmon and steelhead. A 2007 survey indicated that non-natives constituted 46%, 54% and 60% of the resident fish species in Oregon, Washington, and Idaho, respectively. The rate of discovery of introduced non-native species of aquatic invertebrates in the lower Columbia River is also increasing, and over the past ten years, a new invertebrate species has been discovered about every five months. The increasing rate of new discovery is due both to the increasing frequency of introductions and to the number and type of surveys conducted. Non-native aquatic plants (i.e., macrophytes), such as Eurasian milfoil, have also become quite abundant and have altered littoral fish habitat in many mainstem reservoirs in the Columbia and Snake rivers.

In contrast to the increasing rate of invertebrate discovery, the rate of non-native fish discovery peaked in the 1950s and is now about one new non-native fish species every five years. This trend probably reflects a decline in intentional fish introductions by both individuals and by fish and game agencies. Nevertheless, non-natives introduced prior to the 1950s, such as American shad, common carp, brook trout, bluegill, walleye, and smallmouth and largemouth bass, are widespread and have come to dominate many fish communities throughout the Basin.

Economic and Cultural Context of Introduced Non-Native Species

Early introductions of non-native species into the Columbia River Basin were often motivated by the economic goal of increasing fish production through fish culture, to replace fish populations depleted by over-fishing and dam building. Another value associated with Euro-American settlement was the value of expansion. This was accompanied by the confident expectation that human actions could manipulate and improve upon nature, as they had for centuries in the practice of livestock husbandry. People valued the opportunity to develop new fisheries or manage the variability of natural ecosystems by engineering the production of eggs and habitat. Opportunities to expand non-native species were aggressively pursued in the late 1800s and early 1900s.

Over time, values supporting efforts to customize ecosystems have generally been supplanted by values respecting the integrity of natural ecosystems. However, currently, increased human population growth in rural areas of the Columbia River Basin have led to expanding fisheries of popular non-native species (i.e., large and smallmouth bass, northern pike, etc.). This has inevitably led to sports fishermen lobbying for stocking of those species, and has also probably contributed to illegal transport of fish among aquatic systems in the Columbia River Basin in various boat live-wells and other suitable containers. Expanding urban populations have led to an increase in the accidental release of non-native species such as goldfish or koi (*Carassisus auratus*) and other fish favored by hobby aquarists.

Non-Native Species Impacts on and Risks to Native Salmonids and Other Native Species

There is more information regarding the predatory effects of non-native fish species on native salmonids than there is regarding any other impact. One recent review concluded that predation was indeed the most well documented of all non-native impacts on salmon in the Pacific Northwest, and in some habitats fish and birds can consume up to 40% of emigrating juvenile salmon. The study also concluded that most predation studies have been performed at relatively small scales, such as individual stream reaches or single reservoirs and that they have often examined the impacts of one non-native species predator. The authors further suggested that because the cumulative impacts could be enormous, regional scale, multi-species research studies were needed to determine the true impacts of non-natives on native salmonids.

In addition to predation, non-native species pose a number of other significant impacts to natives species including *competition for food and habitat* (e.g., larval/juvenile American shad have reduced zooplankton species food base favored by subyearling Chinook); *food web alterations* (e.g., native resident fish communities in littoral habitats of Columbia River reservoirs are being replaced by non-native species); *interbreeding* (e.g., genetic introgression between cutthroat trout and brook trout); *disease transmission and parasites* (e.g., American shad as a carrier of the protozoan parasite of salmon). Native species are also significantly impacted by *non-native invertebrates* (e.g., quagga mussels which are close to invading the Columbia River Basin); and *non-native plants* (e.g., Eurasian milfoil which is widespread in Columbia River reservoirs and is altering littoral habitats).

Biological measures and their effectiveness

A variety of approaches have been employed in the Columbia River Basin to reduce the impact of introduced non-native fish species on bull trout, cutthroat trout, and redband trout. In streams, the primary targets of control efforts have been brook trout and rainbow trout. There have also been several instances in the Columbia Basin where lake trout introductions have had undesirable effects on native species and at least one effort is ongoing to reduce impacts from this species. Generally, the approaches that have been applied to control the impacts of these introduced species on native salmonids have involved either reducing or eradicating the non-native population, constructing obstacles to prevent access by introduced fish or employing both approaches (i.e., eradication followed by barrier construction).

The most common methods of population control include use of toxicants, electrofishing, netting, and targeted sport angling. These techniques all reduce populations of the target fishes, at least over the short-term. However, populations of the target species are rarely eradicated, especially in large lakes. As a result, control measures need to be applied on a regular basis to ensure populations of the introduced species do not recover to pre-treatment abundance. Most of these removal methods also have negative effects on aquatic habitats and desirable fish species, including those that are the target of the restoration effort.

Current Laws, Policies and Plans

After a long history of deliberate and accidental introductions of non-native species, current federal and state laws and regulations reflect a wide range of different approaches for preventing or reducing non-native species introductions, as well as recognition of the problems they may cause. Recent management plans in the Pacific Northwest have been developed by Invasive Species Councils in the states of Washington (2008), Oregon (2005), Idaho (2003), and Montana (2002). These are all solid plans based on ecosystem approaches with good preventative measures. If the actions recommended in these plans were translated into improved laws, regulations, education programs, and better coordination among various state and federal agencies, then the probability of successful prevention and control non-natives would be much greater. However, it will be critical to increase the funding in order to support these actions, or the plans will not be translated into reality.

Future Concerns

Two of the major future factors that will affect fish and wildlife populations in the Columbia River Basin are climate change and human population growth and development. Both are likely to effect the establishment and spread of non-native species with subsequent significant impacts on native species.

Climate-induced changes to riverine flow and thermal regimes are likely to have direct implications for invasive non-native species impacts and management. Those species that have a higher temperature range tolerance will have an advantage over those species whose upper thermal limits are exceeded. Generally, the most common invasive non-native species in the Columbia River Basin, primarily centrarchids (e.g., sunfishes such as bass) and ictalurids (e.g., catfish), have greater tolerance limits for higher expected average water temperatures than native salmonids and other resident species. A warming climate may also facilitate the establishment of new non-native species which previously were not able to maintaining self-sustaining populations.

Increased human population growth in more rural areas of the Columbia River Basin may lead to expanding fisheries of popular non-native species (i.e., large and smallmouth bass, northern pike, etc.). This may occur by sports fishermen lobbying for stocking of those species or by illegal transport of fish among aquatic systems in the Columbia River Basin in various boat live-wells and other suitable containers. Expanding urban populations will also increase the likelihood of accidental release of non-native species such as goldfish or koi (*Carassisus auratus*) and other fish favored by hobby aquarists.

Recommendations

The ISAB recommends that the Northwest Power and Conservation Council (Council) and the Fish and Wildlife agencies in the Basin elevate the issue of non-native species effects to a priority equivalent to that of habitat loss and degradation, climate change, and human population growth and development.

The ISAB also provides the following specific recommendations:

- **Exploratory Surveillance and Monitoring** – Exploratory surveillance and monitoring of fish, plant, and invertebrate populations needs to be increased for early detection of invasive non-native species and tracking of their distribution and abundance in the future. In addition to informing immediate management actions, this monitoring will provide information to evaluate the effectiveness of prevention and control measures. Early detection of rare non-native species is challenging and may sometimes require use of sophisticated sampling designs and estimation techniques. However, the cost of control after spread of undesirable species thoroughly justifies the effort.

- **Enforcement** – Federal, Regional, and State Policies and regulations regarding non-native species exist, but enforcement seems to be weak or non-existent. Improved enforcement of current regulations should be a high priority.

- **Fisheries Management** – Smallmouth bass and channel catfish support significant sport fisheries in the lower Snake and Columbia rivers. Walleye are the subject of significant sport fisheries in the mid-Columbia, extending into the lower Columbia River. State fisheries agencies in Washington, Oregon, and Idaho have simultaneously adopted management policies that in some cases seem aimed at perpetuating or even enhancing populations of these introduced predators. The ISAB recommends that the Council urge the state agencies to relax (or eliminate) fishing regulations that may be enhancing populations of non-native species (both predators and competitors), especially those that directly or indirectly interact with juvenile and adult salmonids.

- **Prevention** – Direct removal by physical (e.g., netting or electrofishing) or chemical (e.g., rotenone or antimycin) means have had very little success in eliminating or controlling non-native species, once they are well established. Therefore, prevention is the best hope for dealing with non-natives and certainly the most cost-effective.

- **Habitat Restoration –** One of the best strategies for protecting native species and minimizing the establishment and spread of non-native species is to maintain and restore habitats (including riparian habitats). When native species are provided with habitat for which they are best adapted, they have an improved chance of out-competing or persisting with non-native species. Restoring physical features (including natural flow and thermal regimes) may make native species more likely to persist in environments now occupied by non-natives.

- **Planning –** Planning for future actions to prevent, control, and minimize non-native species' impacts to native species and their ecosystems should be a high priority. The Council should encourage revisions in the Fish and Wildlife Program Subbasin Plans to include plans for addressing non-native species threats and impacts.

- **Education –** Public awareness of the threats that non-native invasive species pose to aquatic ecosystems and the native species therein is critical for curtailing the introduction and spread of new non-native species. A wide range of groups and educational actions can contribute to public awareness including public schools; watershed councils; television and radio public service announcements; billboards; sport fishing organizations; and other environmental organizations such as The Nature Conservancy.

- **Research –** Research needs are many, including (1) mapping the vulnerability of the landscape to non-native species introduction, establishment, and spread; (2) examining the impacts of non-native predators on native salmonids and other native species at regional scales and where many species co-occur; (3) determining the potential for transmission of diseases and parasites to native species, (4) improving understanding of the effects of competition between non-native and native species, and (5) exploring the potential synergistic interactions of climate change, land use, and non-native species spread.

Recommended Environmental Risk Assessment for Evaluating the Use of Non-native Fish in Resident Fish Substitution Projects

Background

In view of obvious historical and ecological connections between the practice of non-native introductions and subsequent alterations of the regional biota, it was also clear that another important issue to address in this review is the lack of a specific environmental risk assessment for the use of non-native fish species in resident fish substitution projects allowed in the Fish and Wildlife Program. The following paragraphs provide the background for this issue and a rationale for developing the environmental risk assessment.

At its October 2006 meeting, the ISAB reviewed and discussed a memo received from the ISRP that described several resident fish substitution issues that arose during the Fiscal Year 2007-09 project review. During the review, the ISRP examined a number of resident fish substitution proposals containing elements that appeared inconsistent with scientifically accepted conservation biology practices and which were also possibly inconsistent with the general guidelines of the Council's Fish and Wildlife Program.

The Council's Program recognizes that construction of Grand Coulee Dam on the Columbia River in 1941 and Brownlee Dam on the Snake River in 1959 completely blocked over 18,000 miles of streams that had been historically accessible to anadromous salmon. This blockage is believed to represent approximately 38% of 49,300 miles of stream habitat accessible before hydroelectric dam construction. The Council's Program mandates that anadromous fish losses due to the blocked areas need to be partly mitigated by assuring that populations of resident fish species remain healthy. Guidance for the biological objectives of that mitigation includes:

> *Restore native resident fish species (subspecies, stocks, and population) to near historic abundance throughout their historic ranges where original habitat conditions exist and where habitats can be feasibly restored.*

A part of that mitigation includes "Resident Fish Substitution," where non-native species are provided *in lieu* of extirpated anadromous species:[15]

> *Administer and increase opportunities for consumptive and non-consumptive resident fisheries for native,* ***introduced*** [emphasis added]*, wild, and hatchery*

[15] It is interesting to compare the Columbia River Basin's Fish and Wildlife Program's substitution policy with the federal Central Valley Project Improvement Act which calls for at least a doubling of naturally produced anadromous fish in California's Central Valley (Title 34. Public Law 102-575. Section 3406(b)(1)). Anadromous fish are defined to include not only native salmon, steelhead, and sturgeon but also non-native striped bass and American shad (Section 3403(a)).

> *reared stocks that are compatible with the continued persistence of native resident fish species and their restoration to near historic abundance (includes intensive fisheries within closed or isolated systems) (2000 Council Program).*

Further, the 2000 Program adopts an artificial production strategy to "*replace lost salmon and steelhead in blocked areas.*" These programs are to be executed consistent with the Council's Artificial Production Review policies that include:

> *Appropriate risk management needs to be maintained in using the tool of artificial propagation, and;*
>
> *Decisions on the use of artificial production need to be made in the context of deciding on fish and wildlife goals, objectives and strategies at the subbasin and province levels.*

The ISRP found that these broad Fish and Wildlife Program policies do not establish the specific limits (i.e., how much risk) or the methods (i.e., risk management protocols) to evaluate whether a proposed project is reasonably benign and likely to provide benefits, without undesirable consequences. Clear risk management criteria are needed for sponsors to follow when developing proposals for resident fish substitution projects and for the ISRP to use when reviewing such proposals. The ISAB agreed that this was an important issue and that they would pursue this assignment and work toward developing these criteria and guidelines.

The following section includes scientific guidelines, in the form of an environmental risk assessment, for evaluating the use of non-native fish in resident fish substitution projects.

ISAB Recommended Environmental Risk Assessment

The previous sections of this report have documented some of the numerous non-native species that have been introduced (intentionally or unintentionally) into the Pacific Northwest and beyond by agencies and anglers. Once introduced, many of the species have dispersed into new habitats and reproduced, resulting in established populations. A resident fish species substitution in most cases would not involve the introduction of a new species, but would more typically enhance non-native species already present in the Columbia River Basin and perceived to be of higher overall value (commercial, recreational, cultural, or aesthetic) than some other available native species in the basin.

The introduction or enhancement of non-native species is seldom a controlled research experiment, and it is difficult to reliably forecast the effects of such introductions or enhancements on native species. In the absence of clear knowledge of expected effects, which would most often require a lengthy research study, an alternative approach to evaluate a resident fish substitution project would be to complete an environmental risk assessment before initiation of the introduction or enhancement of a non-native species.

Such an assessment should be included as part of the review material for evaluation of non-native species substitution proposals.

The environmental risk assessment should be organized based on established risk assessment methodologies. Important references to consult include, but are not limited to: Ecological Risk Assessment (Suter 1993), the Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process (Risk Assessment and Management Committee 1996), the Generic Ecological Assessment Endpoints (GEAEs) for Ecological Risk Assessment (U.S. Environmental Protection Agency 2003); recent papers by Simberloff (2005), Stohlgren and Schnase (2006**)**, Hill and Zajicek (2007); and the American Fisheries Society Position on Introductions of Aquatic Species.[16]

Based on considerations from those reports, conclusions from our internal discussions, site visits to ongoing resident substitution projects, and discussions with sponsors of those projects, the ISAB recommends that the project proposal and the environmental risk assessment should address the 15 topics listed below. For topics that require a conclusion about the likelihood of an event occurring, likelihood should be classified as low, moderate, or high, much as has been commonly done in risk assessments (e.g., Aitkin et al. 2008). In addition, answers to the questions should include the evidence supporting the conclusions.

The ISAB understands that the Council, ISRP, and fish and wildlife managers would need to be involved in development of a final environmental risk assessment template and that this recommendation is a starting point and not an endpoint. The ISAB appreciates the efforts of the resident fish and wildlife managers to provide briefings on resident fish substitution issues, site visits to view affected habitats in the blocked areas of the Columbia River Basin, and constructive comments on a draft risk assessment approach.

The ISAB believes that the following 15 topics and associated questions ask for the documentation on rationale and risks needed to develop a thorough risk assessment and to conduct a scientific review of non-native substitution projects. The ISAB also believes that this risk assessment would fulfill many or most of the requirements and recommendations found in the federal and state laws, regulations, and management plans described above in the section of the report titled Non-Native Species Policies and Plans and in Appendix A.

1. Description of the proposed resident fish substitution project

a. Which species is/are proposed as a substitution species?
b. Which waters and drainages will be affected directly?
c. Have you included clear statements of the rationale(s) for proposing the resident fish substitution, including explicit considerations of the biological, socio-economic, and cultural benefits?

[16] www.fisheries.org/afs/docs/policy_15f.pdf

2. **Alternative species**

   a. Have native species been adequately considered for use, before the non-native substitution species has been selected?
   b. For all of the native species, describe explicitly, not just in general terms, the rationale(s) for their non-selection as viable species for reintroduction or enhancement, based on biological, socio-economic, and cultural considerations. Factors leading to the non-selection of native species as viable candidates for the proposed enhancement may include inadequate size, lack of commercial or other recreational value, or lack of primary historical, social, or cultural significance.

3. **Overview of subbasin** (subbasin plans may provide much of this information)

   a. Provide high quality maps or photos of the subbasin, showing main water bodies, as well as connectivity among waters within the subbasin and with water bodies of adjacent basins (upriver and downriver).
   b. Provide relevant limnological information (physical, chemical, or biological) related to the proposed resident fish substitution project.
   c. Provide a summary of all fish and key non-fish (e.g., listed, species of concern) aquatic species.
   d. Because of the problems associated with accidental dispersal, provide a history of flooding and other water overflows in the basin(s), both magnitude and frequency, that may be relevant to the proposed project.

4. **Distribution and abundance**

   a. What is the current distribution of the selected substitution species regionally, nationally, and within the affected river basins?
   b. What is the current abundance of the selected substitution species regionally, nationally, and within the affected river basins?

5. **Biology and life history**

What are the general attributes of the species proposed as the resident substitution species, with specific consideration of its:

   a. origin in North America and the state and region? (if known or if unknown, range outside the continent?)
   b. taxonomy? (including closest species relatives)
   c. growth?
   d. age-at-maturity and longevity?
   e. reproduction?
   f. diseases? (both wild and hatchery situations)
   g. genetics? (see also 7, below)

6. Ecological factors and relationships with other species

a. What are the ecological and habitat constraints (such as temperature, salinity, physical barriers such as dams, etc.) on growth, survival, reproduction, and dispersal?
b. What are the documented effects of the substitute species on each of the other native fish species with which it co-exists, nationally, regionally, and in the basin?
c. What are the documented effects of the substitute species on other aquatic taxa and aspects of the aquatic community nationally, regionally, and in the basin?
d. Based on the foregoing analyses, what are the possible ecological impacts of the substitute species on any native species within the basin?

7. Genetic effects

a. What is the likelihood of genetic effects (low, medium, high) from non-native species interbreeding with natives (e.g., bull trout and brook trout, hatchery rainbow trout and native redband or cutthroat trout)?

b. What sort of effects can be anticipated, given what is known about both the substitute and each of the native species with which it exchanges genes?

8. Escape and dispersal

a. What is the likelihood (low, moderate, high) of the species escaping from the body of water into which it is proposed for stocking or enhancement?
b. If the species escapes the area of stocking/enhancement, what is the likelihood (low, moderate, high) of it dispersing to other suitable habitats for that species?
c. What actions will be taken to discourage inadvertent or intentional release into other waters?

9. Reproduction and establishment potential

a. If the species escapes and disperses, what is the likelihood (low, moderate, high) of it reproducing?
b. If the species reproduces in other nearby subbasins or other bodies of water, what is the likelihood (low, moderate, high) of it becoming established (i.e., developing self-sustaining populations)?
c. Is sterilization of fish considered a desirable course of action for this species, or should fish with reproductive capability be used?
d. If sterilization techniques can be recommended to prevent the uncontrolled reproduction of the species, what is the likelihood (low, moderate, high) of success?

10. Effects on native species *outside* of the basin

a. If the substitute species escapes but does not reproduce, what are the short-term effects on any and all native species?
b. If the substitute species escapes and does reproduce, what are the short-term and potential long-term effects on native species?
c. Are there any other potential impacts (e.g., economic, cultural) outside of the basin?

11. **Potential effects of diseases and dispersal of other nuisance species**

a. What is the likelihood (low, moderate, high) of disease transmission to native species associated with rearing or stocking the species?
b. What is the likelihood (low, moderate, high) of unintentional dispersal of other species (e.g., exotic mussels, parasites) associated with rearing, stocking, and subsequent dispersal of the species proposed as a substitution species?

12. Potential for eradication or control of a resident fish substitution species

a. If the species is introduced or enhanced but subsequently becomes a nuisance species, what is the likelihood (low, moderate, high) that the substitute species can be eradicated or controlled?
b. If the species is introduced or enhanced, can the species later be significantly reduced in numbers? Describe the methodologies that would be used.

13. Actions of adjacent states

a. How do agencies in adjacent states and jurisdictions classify and manage the species proposed as a substitution species?
b. Describe the current management actions and regulations for the species in adjacent subbasins or other bodies of water.

14. Input from co-managers and other affected agencies

Other agencies and stakeholders should be provided with a copy of the Environmental Risk Assessment and be requested to comment on it. Their comments should be made available to the ISRP by being appended to the proposal when submitted.

a. Have you obtained statements and evaluations of your Environmental Risk Assessment from managers in all major adjacent and overlapping jurisdictions as part of your report?
b. Have those comments from relevant agencies included their willingness to provide you with any needed permits, if the proposed activity is within their jurisdiction?

c. Have any other stakeholders had a chance to review and comment on your Environmental Risk Assessment? Their comments should be appended to Environmental Risk Assessment.
d. Has there been any general public input? Their comments should be appended to the Environmental Risk Assessment.

15. Future monitoring

a. Describe the protocols for monitoring that you are proposing, as part of your requested project, to assess and monitor impacts of the substitution species on native species.
b. Describe clearly how the data collected will be interpreted to evaluate impacts to native species. For example, which metrics or ecological endpoints (e.g., abundance, production, reproductive success of native species, as defined and described in U. S. Environmental Protection Agency 2003) will you use to assess impacts to native species?
c. Also describe the monitoring and evaluation needed to determine success or needs for adjustments, perhaps tying in with the Early Detection, Rapid Assessment and Response (EDRR) program of the USGS (http://biology.usgs.gov/invasive)

Conclusions for Resident Fish Substitution Projects

By thoroughly addressing the questions above, project sponsors will have produced an adequate assessment of risk to native salmonids and other native species and developed monitoring and evaluation protocols sufficient to detect negative impacts to native species that result from substitution of non-native species.

Review of the Environmental Risk Assessment would be conducted by the ISRP as part of the Fish and Wildlife Program proposal review process, following the 15-point checklist recommended above. To meet scientific criteria, the proposal for funding would need to contain an acceptable Environmental Risk Assessment, including adequate monitoring and evaluation protocols for assessing impacts on native species.

For all resident fish substitution projects that have been approved and implemented, each annual and final report should include a detailed reporting of the results of all monitoring and evaluation that was implemented for assessing negative impacts to native species.

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Appendix A: Non-native Species Laws, Policies, and Plans

U.S. Federal Laws

Non-native invasive species populations span many geographic and jurisdictional boundaries across the United States, and the need to actively prevent and control the introductions and spread of non-natives has been partially addressed by passing federal laws. Following is an annotated list of Federal Laws that apply to the prevention and control of non-native species:

Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA; Title I of P. No.101-646, 16 U.S.C. 4701 et seq.) established a federal program to prevent the introduction and spread of introduced aquatic nuisance species. Five federal agencies comprise the Aquatic Nuisance Species Task Force to develop a program for protection, monitoring, control, and research. The Task Force reports to Congress.

Alien Species Prevention and Enforcement Act of 1992 makes it illegal to ship plants or animals that are covered under the Lacey Act or the Plant Protection Act through the U.S. mail.

National Invasive Species Act (NISA; P. No.104-332): The 1996 amendment of NANPCA mandates regulations to prevent the introduction and spread of aquatic nuisance species into the Great Lakes through ballast water and other vessel operations. The Act also required the U.S. Department of Transportation in coordination with the U.S. Coast Guard to do an analysis of the effectiveness of existing shore-side ballast water facilities used by tankers in the Columbia River estuary system, as well as other water bodies. NISA required a ballast water management program.

Plant Protection Act of 2000 consolidates and modernizes all major statutes pertaining to plant protection and quarantine (Federal Noxious Weed Act, Plant Quarantine Act) and permits APHIS to address all types of weed issues. It also authorized APHIS to take both emergency and extraordinary emergency actions to address incursions of noxious weeds.

Nutria Eradication and Control Act of 2003 authorizes the Secretary of the Interior to provide financial assistance to the State of Maryland and the State of Louisiana for a program to implement measures to eradicate or control nutria and restore marshland damaged by nutria.

Brown Tree Snake Control and Eradication Act of 2004 provides for the control and eradication of the brown tree snake on the island of Guam and the prevention of the introduction of the brown tree snake to other areas of the United States.

Also see *Executive Order 13112,* which established an interagency National Invasive Species Council (NISC) charged with developing a National Invasive Species Management Plan and provide national leadership regarding non-native invasive species.

See the section on Federal and State Coordination and Planning in the main body of this report.

Western U.S. Regional Policies and Programs

Following, are listed various western regional initiatives formed around the issue of non-native species, characterized as nuisances:

Columbia River Aquatic Nuisance Species Initiative (CRANSI): a joint endeavor of the Ports of Portland and Astoria, and Senator Ron Wyden, to address the need for a comprehensive approach to non-indigenous species in the lower Columbia River and an examination of how shipping traffic could transport non-indigenous species throughout the Columbia River Basin.

Pacific Ballast Water Group (PBWG): representing an effort by the shipping industry, state and federal agencies, environmental organizations, and others to develop a coordinated regional approach to ballast water management for prevention of invasive species introduction on the West Coast.

Pacific States Marine Fisheries Commission/Bonneville Power Administration Aquatic Nuisance Species (ANS) Program for the Columbia River Basin: development of a regional ANS prevention program for the Columbia River Basin, focused on Zebra mussels and mitten crabs. A program goal is to develop an ANS plan for the Columbia River Basin.

The Western Regional Panel (WRP) on Aquatic Nuisance Species: formed of representatives from Federal, State and local agencies and from private environmental and commercial interests under a provision in NISA. The goal is to help limit the introduction, spread, and impacts of aquatic nuisance species into western North America, through education and response planning.

Western Governors Association (WGA): developing a new program to address undesirable non-indigenous aquatic and terrestrial species in the West. Resolution 98-018, Undesirable Aquatic and Terrestrial Species, to develop and coordinate Western strategies and to support management actions to control and prevent the spread and introduction of undesirable species.

U.S. Army Corps of Engineers, Columbia River Basin, Northwestern Division (Portland, Seattle and Walla Walla Districts): coordination forum for state and federal agencies, tribes, and other interested parties in the Columbia River Basin.

U.S. Fish and Wildlife Service (USFWS) provides federal funding for implementation of state and regional ANS management plans. The 100th Meridian Initiative is designed to prevent the spread of zebra mussels and other ANS in the 100^{th} meridian jurisdictions and west, and monitor and control zebra mussels and other ANS if detected. The USFWS has also implemented a mitten crab management effort.

State Laws, Regulations, and Plans

Oregon

The State of Oregon's approach to managing non-native aquatic species through multiple authorities illustrates the current state philosophy. Historically, the state has long regulated the introduction, transport, and stocking of fishes through its administrative rule authority. Permits are required to transport, hold, or release live fish and are part of a larger framework of administrative rules restricting unauthorized establishment of any fishes (Hansen and Sytsma 2001). In 2002 the Oregon State Legislature created the Oregon Invasive Species Council (OISC) by passing statue ORS 561.685. The main objectives for the council were to coordinate state agencies to pursue protection measures against non-native species; aid in education efforts regarding the damage and costs caused by non-native species; and develop plans help prevent further impacts from non-native species. The OISC recently developed and finalized an Invasive Species Action Plan (2005) for the state.

Following is a list of Oregon State Administrative Rules that apply to the prevention and control of non-native species:

Fish Management Goals (OAR 635-007-0510): 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 635-007-0523): related to competition, predation and disease:

Wild Fish Management Policy (OAR 635-007-0525 through 635-007-0529): highest consideration to the protection and enhancement of wild fish stocks.

Management Plans (OAR 635-007-0515): set forth goals, objectives, and operating principles for management of species, waters, or areas. The Warm-water Fish Plan (1987) gives first priority to the protection of endemic salmonids.

Import or Transfer of Fish Restricted (OAR 635-007-0585): restriction based on disease history of the shipping station or watershed, current disease inspection report, or disease known to occur in the watershed to which fish would be shipped.

Permit Required to Transport, Hold or Release Fish (OAR 635-007-0600): to transport live fish into, within or out of state; hold any live fish in state waters; release or attempt to release any live fish into state waters.

Unlawful Import and Release (OAR 635-007-0615): fish in violation of rules or laws subject to seizure or destruction by ODFW.

Transport Release of Mosquito Fish (OAR 635-007-0620): county or district conducting a vector control program that includes, *Gambusia spp.*, must have a Fish Transport Permit.

Use of Fish for Bait (OAR 635-011-0140): unlawful to transport live fish between bodies of water. Live fish may not be used as bait in angling.

Washington

The State of Washington's approach to managing non-native aquatic species is similar to Oregon's, relying on administrative regulations and state laws (listed below). As in Oregon, Washington has also passed a bill in 2006 (ESSB 5385) that established the Washington Invasive Species Council, with objectives comparable to Oregon's invasive species council. The formal charge to Washington's council is "to facilitate a coordinated and strategic approach to prevent, detect, and respond to invasive species." The Washington council has recently developed a draft invasive species action plan (released for public comment in early June, 2008).

Washington State Laws that apply to prevention and control of non-native aquatic species include the following: *Prohibited Aquatic Animal Species (WSL Title 77.12.875); Ballast Water Management (WSL Title 77.120); Aquatic Noxious Weed Control (WSL Title 90.48.445); Aquatic Plant Management Program (WSL Title 90.48.447); Eurasian Water Milfoil-Pesticide 2,4-D Application (WSL Title 90.48.448).*

Washington State Regulations include: *Aquaculture Disease Control (WSR Title 220-77); Ballast Water Management and Control (WSR Title 220-77-090); Nonnative Aquatic Species (WSR Title 232-12-016); Deleterious Exotic Wildlife (WSR Title 232-12-017); Aquatic Nuisance Species (WSR Title 232-12-017A).*

Idaho

The State of Idaho was the first state in the Pacific Northwest to establish an Invasive Species Council in 2001 (by Executive Order No. 2001-11), but as yet, does not have an invasive species action/management plan. The council has, however, completed a detailed assessment of invasive species management in Idaho in 2003 and this document (NW Natural Resources Group, 2003) is to be used by the council to "Organize and streamline the process for identifying and controlling invasive species." Like Oregon and Washington, Idaho utilizes regulations and laws to help manage and protect against non-native species.

Idaho State Laws or Bills that apply to prevention or control of non-native aquatic species: *Animals – Importation or Possession of Deleterious Exotic Animals (ISL Title25-39); Idaho Invasive Species Act of 2003(HB212).*

Idaho State Regulations: *Rules Governing Deleterious Exotic Animals (ISR Title 2, 02.04.27); Non-Native Phytophagous Snails (ISR Title 2, 02.06.29).*

Montana

The State of Montana was the first state in the Pacific Northwest to establish an aquatic nuisance species management plan, 2002 (by the Montana Aquatic Nuisance Species Technical Committee).

A listing of Montana State Laws and Regulations related to non-native species is given below:

- **Montana Code Annotated 2005** - State Laws (http://data.opi.state.mt.us/bills/mca_toc/index.htm)
    - Local Government (Title 7)
        - General Provisions (Chapter 1)
            - Creation of New Boards (7-1-202)
        - Weed and Pest Control (Chapter 22)
    - Land Resources and Use (Title 76)
        - Timber Resources (Chapter 13)
            - Control of Forest Diseases and Insect Pests (Part 3)
    - Agriculture (Title 80)
        - Disease, Pest, and Weed Control (Chapter 7)
            - Weed Control (Part 7)
            - Noxious Weed Management Funding (Part 8)
            - Noxious Weed Seed Free Forage Act (Part 9)
    - Fish and Wildlife (Title 87)
        - Wildlife Protection (Chapter 5)
            - Importation, Introduction, and Transplantation of Wildlife (Part 7)

- **Administrative Rules of Montana** - State Regulations (http://www.mtrules.org/)
    - Agriculture (Title 4)
        - Noxious Weed Management (Chapter 5)