NOAA Technical Memorandum NMFS-NWFSC-53

Review of Potential Impacts of Atlantic Salmon Culture on Puget Sound Chinook Salmon and Hood Canal Summer-Run Chum Salmon Evolutionarily Significant Units

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Review of Potential Impacts of Atlantic Salmon Culture on Puget Sound Chinook Salmon and Hood Canal Summer-Run Chum Salmon Evolutionarily Significant Units

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EXECUTIVE SUMMARY

This document examines the potential of Atlantic salmon farming in Puget Sound to impose adverse impacts on the Puget Sound chinook salmon (*Oncorhynchus tshawytscha*) and Hood Canal summer-run chum salmon (*O. keta*) evolutionarily significant units (ESUs), both of which were listed as "threatened" under the federal Endangered Species Act (ESA) by the National Marine Fisheries Service (NMFS) in March 1999. The threatened status of these populations requires that all activities that may harm the fish or their critical habitat be limited such that they do not appreciably reduce the likelihood for recovery of the ESUs in the wild.

Many of the activities that may lead to the take of listed salmon in Puget Sound, including the artificial propagation of salmonids in hatcheries and marine enclosures, will have effects that are incidental to otherwise lawful activities. Among such activities is the private culture of Atlantic salmon. This document presents the best scientific and commercial information available to evaluate the possible effects of salmon farming on listed chinook and summer-run chum salmon populations, and will provide the scientific basis for federal regulatory agency direction for the appropriate management of the industry in Puget Sound.

Much of the available scientific information pertaining to salmon aquaculture was produced by NMFS in furtherance of its national mandate to advocate environmentally sustainable aquaculture through research, technology development, financial assistance, and regulatory programs. Locally, Washington State policies also recognize aquaculture as a legitimate and beneficial use of its coastal waters. By reason of NMFS' concomitant responsibilities to conserve Pacific salmon species, especially those listed under the ESA, the agency has also collected, analyzed, and published a significant amount of scientific information relevant to the specific issue of Atlantic salmon impacts on federally listed Pacific salmon. After conducting several scientific reviews of Washington's Atlantic salmon farming industry, including the present one, NMFS concluded that the operations can be managed to minimize risks to local salmon populations. In particular, NMFS found that Washington State regulation of the industry provides adequate protection to stocks of Pacific salmon listed under the ESA. Nonetheless, there are legitimate issues associated with hatchery-reared salmon and trout that end up in natural ecosystems, either by deliberate release or by escape from the rearing facility.

Concerns regarding the artificial propagation of salmon and trout in the Pacific Northwest have been expressed numerous times in recent years, focused primarily on Pacific salmon hatcheries. However, concerns about the potential adverse impacts of private trout and Atlantic salmon culture in Washington have been expressed as well. Uncertainty about genetic and ecological interactions and the transmission of disease among Atlantic and Pacific salmon are the most commonly voiced concerns.

It should be understood that this review does not intend to evaluate potential risks associated with Atlantic salmon farming anywhere in the world except Puget Sound, Washington. Also, social issues related to salmon farming in Puget Sound are not discussed. Much of the material presented here has been taken from previous NMFS evaluations of the risks of Atlantic salmon in Pacific coast states or from NMFS' ESA-related status reviews of West Coast salmonids.

The conclusions regarding the potential impacts of Atlantic salmon culture on the Puget Sound chinook salmon and Hood Canal summer-run chum salmon ESUs are based on three important assumptions. The first assumption is that the salmon farming industry in Puget Sound remains approximately the same size as currently or in the recent past. A significant expansion of the industry may increase risks and would require a reconsideration of some of the potential impacts discussed in this review. The second assumption is that salmon farms in Puget Sound continue to rear only Atlantic salmon. Should the local industry shift production to coho or chinook salmon or to steelhead (*O. mykiss*), the risks for hybridization, dilution of the gene pool, colonization, and competition for natural resources with wild salmonids will be greater than they are now with Atlantic salmon culture. Third, these conclusions assume that Atlantic salmon farmers in Washington continue to use only stocks presently in culture and that no new Atlantic salmon stocks are brought into the State.

Based on these assumptions, this review arrives at the following risk assessment conclusions: It finds no risk for one parameter, low risk for several parameters, little risk for other parameters, and no parameters for which the potential impacts from Atlantic salmon farms in Puget Sound are considered to be serious or even moderate.

The review finds no risk of adverse genetic interaction from transgenic salmon because there are currently no transgenic salmon being commercially cultured in Washington and there are no plans to do.

For several parameters, the risks associated with escaped Atlantic salmon are low, in particular:

- The expectation that Atlantic salmon will increase current disease incidence in wild and hatchery salmon is low.
- The risk that escaped Atlantic salmon will compete with wild salmon for food or habitat is low, considering their well-known inability to succeed away from their historic range.
- The risk that salmon farms will adversely impact Essential Fish Habitat is low, especially when compared to other commonly accepted activities that also occur in nearshore marine environments.

For other parameters, there appears to be little risk associated with escaped Atlantic salmon, in particular:

- There is little risk that escaped Atlantic salmon will hybridize with Pacific salmon.
- There is little risk that Atlantic salmon will colonize habitats in the Puget Sound chinook salmon and Hood Canal summer-run chum salmon ESUs.
- There is little risk that escaped Atlantic salmon will prey on Pacific salmon.
- There is little risk that existing stocks of Atlantic salmon will be a vector for the introduction of an exotic pathogen into Washington State.
- There is little risk that the development of antibiotic-resistant bacteria in net-pen salmon farms or Atlantic salmon freshwater hatcheries will impact native salmonids, as similar antibiotic resistance often observed in Pacific salmon hatcheries has not been shown to have a negative impact on wild salmon.

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The conclusions and recommendations in this document are those of the authors and do not necessarily reflect the opinions of the reviewers.

INTRODUCTION

In response to the depleted status of naturally produced chinook salmon (*Oncorhynchus tshawytscha*) and certain summer-run chum salmon (*O. keta*) in the Puget Sound region of Washington State, the National Marine Fisheries Service (NMFS) listed the populations as "threatened" under the U.S. Endangered Species Act (ESA) of 1973 in March 1999. The populations or evolutionarily significant units (ESUs) (Waples 1991) listed for protection under the provisions of the Act were the Puget Sound chinook salmon ESU and the Hood Canal summer-run chum salmon ESU. Subsequent to these listings, NMFS designated critical habitat necessary for the recovery of the populations to healthy levels. The Puget Sound chinook salmon ESU's critical habitat generally includes all freshwater areas accessible to anadromous salmon in the Puget Sound region, as well as the marine waters of Puget Sound. Critical habitat for the Hood Canal summer-run chum salmon ESU is encompassed within the area designated for chinook salmon.

Intent of Present Document

The ESA-listing status of these populations as threatened requires that all activities that may harm the fish or their critical habitat be limited such that they do not appreciably reduce the likelihood for the survival and recovery of the ESUs in the wild. In particular, Section 9 of the ESA and federal regulations pursuant to Section 4(d) of the ESA prohibit the direct or incidental "take" of endangered and threatened salmon species, respectively, without special exemption from NMFS. "Take" is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. "Harass" is defined as intentional or negligent actions that create the likelihood of injury to listed species to such an extent as to significantly disrupt normal behavior patterns which include, but are not limited to, breeding, feeding, or sheltering. "Harm" is defined to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing behavioral patterns, including breeding, feeding, or sheltering.

The majority of activities that may lead to the take of listed salmon in Puget Sound will have effects that are incidental in nature. Incidental takes are defined as takes that are incidental to, and not the purpose of, carrying out an otherwise lawful activity. NMFS evaluation and authorization for incidental takes of listed salmon may be provided through several avenues under the ESA. Section 7 of the ESA provides for the authorization of incidental takes associated with federal or federally funded actions through the completion of a consultation with NMFS to evaluate the effects of a proposed action. Successful completion of the consultation would lead to a determination by NMFS that the federal action does not jeopardize the continued existence of a listed population, or destroy or adversely modify its critical habitat. Non-federal entities may apply for permits from NMFS to incidentally take ESA-listed species under Section 10(a)(1)(B) of the ESA. A Section 10(a)(1)(B) permit shall be issued to a non-federal entity if NMFS finds:

1. The taking will be incidental.

2. The applicant will, to the maximum extent practicable, minimize and mitigate the impacts of such taking.
3. The applicant will ensure that adequate funding for a species "Conservation Plan," required for submittal with the take application, will be provided.
4. The taking will not appreciably reduce the likelihood of the survival and recovery of the species in the wild.
5. Any other measures that the Secretary of Commerce may require as being necessary or appropriate will be met.

Completed Section 7 consultations and Section 10 permits generally include measures, terms, and conditions required to limit or further minimize the incidental takes that may occur through the proposed action requiring authorization.

An additional means by which takes of recently listed threatened species, including Puget Sound chinook salmon and Hood Canal summer-run chum salmon, may be evaluated and authorized by NMFS is through the ESA Section 4(d) Rule issued for these species (50 Code of Federal Regulations 223.203 – 65 Federal Register 42422, July 10, 2000). Under the Rule, ESA Section 9 take prohibitions do not apply to actions that are in compliance with criteria specified in the Rule that insure consistency with ESA requirements, and that avoid or minimize the risk of take of listed threatened salmon. NMFS has identified 13 programs or subsets of activities in the Rule that are conducted in a way that contribute to conserving the listed ESUs, and where NMFS determines that added protection through federal regulation is not necessary or advisable for conservation of the ESU. Included in the 13 programs or "limits" is a category that limits application of take prohibitions to activity associated with salmonid artificial propagation programs, provided that such activity complies with certain criteria specified under the 4(d) Rule limit (50 CFR 223.203(b)(5)(i)).

Among the activities in the Puget Sound region that are now subject to federal prohibitions on the take of listed salmon and the need for NMFS evaluation and authorization of listed fish effects is the private Atlantic salmon (*Salmo salar*) aquaculture industry. The purpose of this review is to gather the best scientific and commercial information available to evaluate and determine the likely effects of Atlantic salmon aquaculture in the region on the survival and recovery of the listed chinook and summer-run chum salmon populations. It will also serve to indicate appropriate measures recommended by the NMFS Northwest Fisheries Science Center for minimizing risks of Atlantic salmon aquaculture to the listed salmon populations. This document will therefore provide the scientific basis for federal regulatory agency direction for the appropriate management of the industry in Puget Sound for listed salmon protection purposes. However, it is mainly intended to serve as the key resource for subsequent NMFS evaluation under the ESA of the specific, private Atlantic salmon aquaculture operations in the Puget Sound region for effects on listed fish. These site-specific NMFS evaluations will determine whether individual operations may be authorized for takes through the ESA Section 7 or Section 10 permit processes, or for limits on listed fish take prohibitions under the new ESA Section 4(d) Rule for the listed chinook and summer-run chum salmon populations.

Concerns Regarding Salmon Farming in Puget Sound

The artificial propagation of salmon and trout in the Pacific Northwest has come under increasing scrutiny in recent years. This is due to the recognition that hatchery-cultured salmon and trout have the potential to adversely impact natural populations (Busack and Currens 1995, ODFW 2000). Although the greater weight of attention has been focused on the large complex of federal, state, tribal, and cooperative Pacific salmon hatcheries in western states, concerns about the potential adverse impacts of private trout and Atlantic salmon culture in Washington have been expressed by some scientists and fisheries managers, as well as by some advocacy groups and the popular media (print and internet).

Uncertainty about genetic and ecological interactions and the transmission of disease among Atlantic and Pacific salmon are most commonly voiced. In testimony before the Washington State Pollution Control Hearings Board (PCHB 1997a), it was stated that Atlantic salmon had the potential for hybridization with Pacific salmon, based on a recent unpublished Canadian laboratory study, and that it was not impossible that the 369,000 Atlantic salmon which escaped into Puget Sound in 1997 would produce 10 million healthy smolts in local rivers (PCHB 1997b). The Marine Environmental Consortium, a coalition of Northwest environmental advocacy groups, considers escaped Atlantic salmon a serious threat to endangered species in Puget Sound, according to its spokesperson, Barbara Stenson (Le 1999). Assertions such as University of Victoria student John Volpe's that "native stocks will have to move aside to make room for a new exotic" have appeared in the popular press (Marsh 1999). Dale Kelly, executive director of the Alaska Troller's Association, declared that the impacts of escaped Atlantic salmon on Pacific salmon were frightening (Dobbyn 2001). Tom Geiger, outreach director of the Washington Environmental Council, said Atlantic salmon compete for food and shelter with native fish that are already struggling for survival (Morente 2001). The Alaska Department of Fish and Game has expressed concern that escaped Atlantic salmon from salmon farms in Washington State and British Columbia, Canada, will compete with wild salmon and spread diseases and parasites for which Pacific salmon have little resistance (ADF&G 1999). A letter a constituent sent to U.S. Senator Ted Stevens of Alaska read in part, "The continued introduction of Atlantic salmon to the marine habitat of British Columbia and Washington State will inevitably have negative biological impacts. These will include displacement, hybridization, and the introduction of alien...disease" (Gilbertsen 1997).

Scope of Literature Review

This paper reviews the potential risks from escapes of Atlantic salmon into the Puget Sound chinook salmon ESU and the Hood Canal summer-run chum salmon ESU, both of which are listed as threatened under the ESA. These hypothetical risks include the potential for escaped Atlantic salmon to interbreed with, displace, compete with, or prey upon listed Puget Sound chinook salmon or Hood Canal summer-run chum salmon. It is imperative to understand that this review pertains to potential impacts in just these two ESUs and is not intended to be an evaluation of potential biological risks associated with Atlantic salmon farming anywhere in the world except Puget Sound, Washington. Since regulatory and management policies, ecological factors, and biological and geophysical parameters are not uniform worldwide, potential adverse

biological impacts of artificially propagated Atlantic salmon on Pacific salmon in Puget Sound may not be the same as Atlantic salmon impacts observed in other parts of the world, especially in locations where Atlantic salmon are native. Social issues related to salmon farming in Puget Sound, such as the decline in consumer price of wild Pacific salmon due to free market competition from farmed salmon, are not addressed, as they do not pertain to potential risks for ESA-listed salmonids.

Specific sections of this paper review the literature concerning risks of hybridization between Atlantic and Pacific salmon, the colonization of aquatic environments by Atlantic salmon, and interactions of wild salmon and genetically altered transgenic salmon. A section concerning occurrence and transmission of waterborne salmon disease reviews the risk that cultured Atlantic salmon will introduce diseases into Puget Sound ecosystems. Information regarding genetic consequences and disease incidences associated with artificially propagated Pacific salmon are presented to provide a perspective against which to evaluate the potential adverse impacts of farmed Atlantic salmon for these same elements. The potential for adverse ecological impacts of escaped Atlantic salmon in the Pacific Northwest, specifically, competition for food and space, and predation, are then reviewed. That is followed by a summary, for comparative purposes, of known adverse ecological impacts associated with artificial propagation of Pacific salmon in the Pacific Northwest.

For additional perspective, a review of impacts of other nonindigenous fish species in the Pacific Northwest is given, followed by a comparison of the number of artificially propagated Atlantic and Pacific salmon found in natural environments (by escape or release) on the West Coast of North America. Reviews of previous evaluations of the potential adverse impacts of escaped Atlantic salmon in Puget Sound are then presented. These include the findings of the PCHB and a perspective on escaped Atlantic salmon from the Washington Department of Fish and Wildlife (WDFW). In addition, a brief review of the potential impact of salmon farms on Essential Fish Habitat (EFH) is provided. The volume of solid waste discharged from salmon farms onto EFH and the amount of solid waste discharged from fish processing plants onto EFH are presented to provide a comparison of the amount of nearshore wastes produced by two different methods of fish production. The scale of marina development in Puget Sound is examined for comparison to an activity which uses similar nearshore habitat and also has the potential for environmental impacts on salmon EFH. Pertinent excerpts from the Artificial Propagation of Fish and Shellfish section of the EFH Provision of the Magnuson-Steven Fisheries Conservation and Management Act are presented. Finally, a list of managing agencies and specific regulations pertaining to private and public aquaculture in Puget Sound is presented to show current government oversight of salmon farming.

Previous Investigations of Salmon Farming in the Pacific Northwest

Much of the material presented here has been taken from previous NMFS evaluations of the risks of Atlantic salmon in Pacific coast states or from NMFS' ESA-related status reviews of West Coast salmonids. These evaluations include: *The Net-Pen Salmon Farming Industry in the Pacific Northwest*, by the Resource Enhancement and Utilization Technologies Division of the Northwest Fisheries Science Center (Nash 2001), and oral and written testimony (oral by Conrad

Mahnken, written by William Waknitz, both of the Northwest Fisheries Science Center's Manchester Research Station) before the Washington State Senate on September 16, 1999. In addition, material from recent salmon farming reviews by the PCHB and WDFW is included in the present review.

ORIGIN OF ATLANTIC SALMON STOCKS IN PUGET SOUND

Beginning in 1971, scientists from the NMFS Northwest Fisheries Science Center tested the feasibility of rearing New England stocks of Atlantic salmon in seawater net-pens in Puget Sound to provide 3.5 million eyed eggs annually for restoring depleted runs in southern New England as part of a cooperative effort between the U. S. Fish and Wildlife Service (USFWS) and NMFS (Mighell 1981, Harrell et al. 1984). Between 1971 and 1983, NMFS received eggs from many North American stocks, including the Grand Cascapedia River in Quebec (via Oregon State), and the Penobscot, Union, St. John, and Connecticut rivers in the United States.

Prior to the transfer of eggs from New England to Washington, all Atlantic salmon eggs sent to the NMFS Manchester Research Station were examined according to the Code of Federal Regulations (50 CFR) and certified by federal pathologists to be free of bacterial and viral pathogens. However, few eggs were ever sent back to New England due to the reluctance of East Coast fisheries managers to accept eggs from Atlantic salmon which had been grown in waters inhabited by Pacific salmon and thereby exposed to indigenous Puget Sound salmon diseases. A panel of New England state and federal fisheries officials meeting at Newton Corner, Massachusetts, in March 1984 determined that the risk of introducing Pacific salmon diseases to New England Atlantic salmon populations due to raising Atlantic salmon in the proximity of Pacific salmon in Puget Sound was great and had rendered the eggs unfit for transfer back to the East Coast.

As a result of this decision, millions of Atlantic salmon eggs originally meant for New England restoration programs were available for distribution to salmon farmers in Washington. These eggs proved to be a boon to the local industry as, by this time, it was clear that Atlantic salmon grown in Puget Sound salmon farms were superior to the coho salmon (*O. kisutch*) originally used by local salmon farmers in all aspects of culture, including survival to hatch, growth rate in freshwater and seawater enclosures, size at harvest, and contrary to East Coast opinion, resistance to infectious diseases (Mighell 1981, Waknitz 1981, Amos and Appleby 1999).

In Washington now about 67.5 total hectares (ha) are leased by companies for commercial salmon net-pens, although not all the leased area is being used (WDNR 2001). The leased area extends to the perimeter of the anchoring system, so the actual area covered by floating structures is much less. The 10 commercial sites currently operational in Puget Sound have a total of 53 ha under lease from the State (ranging in size from 0.8 to 9.7 ha per site), with a total of 8.7 ha permitted for internal pen structures for all Puget Sound salmon farms combined (range 1,951 m^2 to 15,793m^2) (K. Bright[1]).

[1] K. Bright, Washington Fish Growers Association, 10420 173rd Ave. SW, Rochester, WA 98579. Pers. commun., February 12, 2001.

POTENTIAL GENETIC IMPACTS OF ATLANTIC SALMON CULTURE IN THE PUGET SOUND CHINOOK AND HOOD CANAL SUMMER-RUN CHUM SALMON ESUs

Potential Genetic Interactions of Artificially Propagated Pacific and Atlantic Salmon

A major concern with artificial propagation of salmonids in hatcheries, which includes the farming of Pacific salmonids and Atlantic salmon, is the potential genetic effects of released fish (hatcheries) and inadvertent escapees (farming) on native salmonids. For the salmon farming industry in British Columbia, where both Pacific and Atlantic salmon are extensively farmed, a recent study listed three major areas of concern (EAO 1997):

- Hybridization between Atlantic and Pacific salmon
- Genetic dilution and alteration of the wild salmonid gene pool
- Interactions between wild salmon and genetically altered transgenic salmon

These concerns are both geographically and species specific. For private aquaculture in Puget Sound net-pens, the concerns expressed by citizen groups and agencies have been primarily associated with farmed Atlantic salmon, as Pacific salmon, with rare exception, are not cultured by private enterprises.

Hybridization between Atlantic and Pacific Salmon

Potential Genetic Compatibility

No genetic compatibility between Atlantic salmon (genus *Salmo*) and wild Pacific salmon (genus *Oncorhynchus*) has been reported in the Pacific Northwest or elsewhere. Similarly, under controlled and protected laboratory conditions, where survival of hybrid offspring should be optimized, genetically viable hybrids between Atlantic and Pacific salmonid species have been impossible to produce. Refstie and Gjedrem (1975), Sutterlin et al. (1977), and Blanc and Chevassus (1979, 1982) found that crosses between Atlantic salmon and rainbow trout (*O. mykiss*) failed to produce any viable progeny. A similar lack of survival was observed in attempted hybridization of Atlantic salmon and coho salmon (Chevassus 1979) and Atlantic salmon and pink salmon (*O. gorbuscha*) (Loginova and Krasnoperova 1982). Gray et al. (1993) attempted to produce diploid and triploid hybrids by crossing Atlantic salmon with chum and coho salmon and rainbow trout. All embryos died in early developmental stages, leading to the conclusion that hybridization of Atlantic salmon with Pacific salmon species was unlikely to happen.

Recently, two pilot studies from British Columbia have provided more data regarding the lack of genetic compatibility between Atlantic and Pacific salmon (R. Devlin, Department of Fisheries and Oceans Canada, reported in Alverson and Ruggerone 1997). In the first study using a small number of eggs, crosses with Atlantic salmon produced a few hybrids with pink

salmon, but no hybrids with coho, chum, chinook, sockeye salmon (*O. nerka*), and rainbow trout (Table 1). In the same experiment, by contrast, the interspecific crosses between *Oncorhynchus* species produced hybrids with survivals to hatch ranging from 10 to 90% in 15 of the 42 crosses, with each species of Pacific salmon readily producing hybrids with between 2 and 5 other Pacific salmon species, confirming previous observations of this genus (Foerster 1935, Seeb et al. 1988). It should be noted that because of dissimilar spawning times between Atlantic salmon (fall spawning) and steelhead (spring spawning) (*O. mykiss*), this particular cross was performed using cryopreserved Atlantic salmon sperm.

In the second study using a larger number of eggs, and involving crosses between Atlantic salmon and rainbow and steelhead trout, coho, chum, chinook, and pink salmon, a few hybrids were also produced (Table 2). It should be noted that because of dissimilar spawning times between Atlantic salmon (fall spawning) and cutthroat trout (winter spawning) (*O. clarki*), this particular cross was performed using cryopreserved Atlantic salmon sperm. Approximately 6.1% of the steelhead x Atlantic salmon, and 0.02% of the pink salmon x Atlantic salmon hybrids survived to the hatching stage. Surviving progeny exhibited deformities such as curvature of the spine and none of the survivors showed any signs of maturity after four years (Noakes et al. 2000). The results pertaining to survival to the hatching stage were presented as evidence of hybridization potential between Atlantic salmon and Pacific salmon in hearings before the PCHB (PCHB 96-257-266, and 97-110, 1998). However, the PCHB found that evidence of hybridization was not supported by this study, and there was no reasonable potential for hybridization between escaped Atlantic salmon and native Pacific salmon in Puget Sound based on current knowledge and behavior (PCHB 1998). No concerns about these studies' evidence of hybridization potential resulting from the introduction of hatchery stocks of Pacific salmonids into natural habitats were addressed to the PCHB or voiced in the popular press, despite the readily produced hybrids in Pacific salmon compared to the low percentage of survival to hatch observed between the Atlantic salmon x pink salmon cross (Table 1).

The few Atlantic x steelhead hybrids produced resulted from experiments conducted *in vitro*, and actual Atlantic/steelhead hybridization would probably not happen under natural conditions (no cryopreservation) in Washington State. The Atlantic salmon stocks used in Washington begin spawning in early October and have finished spawning by the end of November (Waknitz unpubl. data). Wild steelhead in western Washington spawn from March through June (Freymond and Foley 1985). Therefore, there is virtually no opportunity for Atlantic salmon to spawn with native steelhead outside the laboratory.

Atlantic salmon x Pacific salmon hybrids have not been observed in other regions of North or South America or New Zealand. In eastern North America, non-native rainbow trout have been successfully introduced into 12 states or provinces within the natural range of Atlantic salmon (MacCrimmon 1971). No naturally produced hybrids have been reported in the 30 to 100 years subsequent to this occurrence, even though many adult Atlantic salmon are examined at weirs and traps sometime during their upstream migration (NMFS/USFWS 1999). Similarly, no hybrids between Atlantic salmon and brown trout (*Salmo trutta*), rainbow trout or brook trout (*Salvelinus fontinalis*) have been reported in South America or New Zealand, where all four of these species are not native to those locations (MacCrimmon 1971, Lever 1996).

Table 1. Percent survival to hatch from various Atlantic salmon x Pacific salmon crosses, or interspecific Pacific salmon x Pacific salmon crosses, using a small number of eggs (less than 500). (Data from EAO 1997.) Intraspecific crosses (nonhybrids) are in bold.

Female: / **Male:**	Atlantic	Sockeye	Chum	Pink	Coho	Chinook	Rainbow trout
Atlantic	**64.1**	0.0	0.0	0.0	0.0	0.0	0.0
Sockeye	0.0	**88.4**	90.9	16.9	0.0	0.3	0.0
Chum	0.0	61.9	**94.9**	85.7	0.0	0.0	0.0
Pink	5.5	77.7	54.2	**83.9**	14.9	93.2	15.8
Coho	0.0	82.9	0.0	1.5	**73.3**	0.0	0.7
Chinook	0.0	43.2	35.3	64.3	52.3	**94.3**	10.6
Rainbow trout	0.0	0.0	0.0	0.0	0.0	0.0	**54.6**

Table 2. Percent survival to hatch from various Atlantic salmon x Pacific salmon crosses, using a large number of eggs (more than 2,000). (Data from EAO 1997.) Crosses not attempted are represented by a blank cell.

Female: / **Male:**	Atlantic	Sockeye	Chum	Steelhead	Pink	Coho	Chinook	Cutthroat	Rainbow Trout
Atlantic		0.012	0.12	6.07	0.018	0.00	0.012	0.00	0.098
Sockeye	0.00								
Chum	0.014								
Steelhead	0.0012								
Pink	0.36								
Coho	0.014								
Chinook	0.023								
Cutthroat	0.00								
Rainbow	0.0017								

No natural hybrids between Atlantic salmon and Pacific salmonids have been reported in Europe, despite the fact that introduced rainbow/steelhead trout, brook trout, coho salmon, and pink salmon have all established naturalized populations to some degree within the native range of Atlantic salmon on the European continent (MacCrimmon and Campbell 1969, MacCrimmon 1971, Berg 1977, Lever 1996).

Potential Contribution from Precocious Male Atlantic Salmon

It has been suggested that spawning escaped Atlantic salmon may produce precocious male Atlantic salmon which will attempt to breed with Pacific salmon. It was hypothesized that, while not actually capable of producing hybrids, these precocious males might produce genetic disturbances by interfering with wild salmonid breeding behavior, and by beating Pacific salmon males to the eggs in the redd, produce nonviable eggs that would reduce the number of juvenile salmonids available for recruitment in depressed populations (Group Participants 2001). Although it is possible that this could happen in some locations, the risk of this scenario occurring in Puget Sound tributaries is low for a number of reasons.

First, salmon farmers in Puget Sound use Atlantic salmon derived from stocks provided to them by NMFS in the mid-1980s, primarily Penobscot River and Grand Cascapedia River strains. The Penobscot River hatchery strain is known to have a remarkably low incidence of early maturity, either after 1 or 2 years in freshwater (precocious male parr), or at 2 or 3 years of age (1 year at sea), known as grilse (Ritter et al. 1986). Since age at maturity is a genetically inherited trait which can then be influenced by changes in environmental conditions (Randle et al. 1986), the Penobscot River Atlantic salmon strain now used in Puget Sound salmon farms begins with an especially low potential for adverse impacts from precocious males, assuming that naturally spawned juvenile male Atlantic salmon ever become numerous in Puget Sound tributaries.

Second, smoltification and early male maturity are mutually exclusive events (Thorpe 1986), and precocious parr Atlantic salmon do not survive transfer to full strength seawater (Waknitz unpubl. data), due primarily to the fact that they have invested their metabolic resources in producing gametes instead of acquiring the ability to osmoregulate in seawater. Therefore, precocious parr are directly selected against in Puget Sound domesticated Atlantic salmon populations every generation at the time of transfer to seawater, where they are eliminated from that particular brood.

Third, protocols common to salmon farming also directly, if inadvertently, select against the production of precocious male Atlantic salmon in local salmon farms. To reduce freshwater rearing costs, local salmon farmers cull juveniles which do not smolt at 1 year of age. This serves to select against early maturity because 1-year-old smolts are known to produce fewer precocious parr and grilse than 2-year-old smolts (Ritter et al. 1986). Furthermore, Atlantic salmon that mature as grilse after only 1 year in seawater are not retained for broodstock by growers in Puget Sound because fish that never grow to a large size are not as profitable as those that do. Grilse are known to produce more precocious parr than older Atlantic salmon (Ritter et al. 1986).

Fourth, it may not be a cause for concern that low population abundance in some Pacific salmon stocks might create conditions favorable to hybridization by male Atlantic salmon parr, if any are ever produced in Puget Sound tributaries. In a study of wild Atlantic salmon and brown trout in Newfoundland, McGowan and Davidson (1992) found that it was unlikely that a disparity in species abundance was a principal cause of interspecific hybridization by Atlantic salmon.

Therefore, the unusually low incidence of early maturity in the Atlantic salmon strain from the Penobscot River, which Ritter et al. (1986) noted as "striking" compared to the much higher incidences of early maturity observed in nearby Canadian populations in Quebec and New Brunswick, has been further reduced by generations of directed selection by Puget Sound salmon farmers against this particular life-history type. Similarly, no precocious parr were observed in several generations of the Grand Cascapedia River population held at the NMFS Manchester Research Station between 1971 and 1983 prior to this stock being made available to the public (Mighell 1981, Waknitz unpubl. data).

Hybridization between Atlantic Salmon and Brown Trout

While viable hybrids between Atlantic salmon and the Pacific salmonid species are difficult to produce in the laboratory and have not been observed in natural environments, hybrids between Atlantic salmon and a congeneric species, the brown trout, are relatively successful. Viable Atlantic salmon x brown trout hybrids in the laboratory have been reported by Suzuki and Fukuda (1971), Refstie and Gjedrem (1975), and Blanc and Chevassus (1982).

Successful hybridization under natural conditions has been reported in many European countries where brown trout are native, and also in North America where the brown trout has been introduced (Verspoor and Hammar 1991). The frequency of natural Atlantic salmon x brown trout hybrids in Europe and North America ranges from 0.1 to 13.2% of juveniles in river systems (Jordan and Verspoor 1993) and appears to be increasing relative to pre-aquaculture levels in Europe (Hindar et al. 1998). McGowan and Davidson (1992) cite the breakdown in pre-reproductive isolating mechanisms in Newfoundland (abundance of mature Atlantic salmon parr) as the principal mechanism for such natural hybridization between wild brown trout and wild Atlantic salmon. Hindar et al. (1998) reported that although a disproportionate number of hybrids were the product of pairings involving Atlantic salmon females, there was no evidence that escaped farmed Atlantic salmon females produced more hybrids than wild females. Youngson et al. (1993), on the other hand, had previously reported that escaped females in western and northern Scotland rivers hybridized with brown trout more frequently. Wilkins et al. (1993) found that male hybrids were fertile, and when back-crossed with female Atlantic salmon, produced about 1% diploid progeny. Galbreath and Thorgaard (1995) reported that back-crosses between male diploid, male triploid, and female diploid Atlantic salmon x brown trout hybrids and both parental species produced either nonviable or sterile progeny.

Brown trout have established naturalized populations in many locations in the Columbia River basin (Wydoski and Whitney 1979, WDFW 2002) and in about a dozen rivers and lakes on Vancouver Island (Idyll 1942, Lever 1996, Wightman et al. 1998, BC.com 2001). Brown trout in the mid-Columbia River region above Bonneville Dam and below Grand Coulee Dam are so large they are commonly mistaken for adult chinook salmon (Shangle 2001). However, no

reports of hybridization between introduced brown trout and native Pacific salmon in these areas were found in this literature review, despite the fact that many of these brown trout populations have been naturalized in these locations for over half a century, during which time local native and hatchery populations of salmonids have been subject to frequent observations. No scientific or media reports expressing apprehension about brown trout x Pacific salmon hybrids were found in the process of this review, suggesting that hybrids resulting from escaped Atlantic salmon are viewed as a threat to wild Pacific salmon in the Pacific Northwest, while the same hypothetical threats that could also be associated with brown trout have either been accepted or not recognized.

The propensity of Atlantic salmon to produce successful hybrids with brown trout and not with Pacific salmonids may be related to the phylogenetic distance between the two groups. Neave (1958) postulated that the putative ancestors of the *Salmo* group migrated to the Pacific 600,000 to 1,000,000 years ago, were subsequently isolated by land bridges, and evolved to the ancestral Oncorhynchid form. The ancestral form subsequently developed to form the separate *Oncorhynchus* species (Simon 1963). McKay et al. (1996), based on DNA sequence analysis of growth hormone type-2 and mitochondrial NADH dehydrogenase subunit 3 gene, estimated that, at a minimum, the major divergence between the genus *Salmo* and the genus *Oncorhynchus* occurred 18 million years ago, while speciation within the genus *Oncorhynchus* began about 10 million years ago.

Hybridization among Pacific Salmon

Attesting to their phylogenetic similarity, interspecific hybrids within the Oncorhynchids are relatively successful, as noted above. Foerster (1935) was among the first to report successful hybrids between controlled matings of sockeye, chum, pink and chinook salmon. Two-year-old chum salmon x pink salmon hybrids released from a hatchery in Puget Sound returned at a higher rate than pure pink salmon (Simon and Noble 1968). However, as Simon and Noble (1968) observed: "The fact that hybrids can be produced artificially is of little consequence to natural circumstances unless: (a) fertility of the hybrids is evident, and; (b) the same crosses occur in nature." These requirements were met in crosses of chum and pink salmon in British Columbia, where natural hybrids have been observed (Hunter 1949). On the whole, however, reports of natural hybrids among anadromous salmonids have been limited. Bartley et al. (1990) reported on natural hybridization between chinook and coho salmon in a northern California river, and Rosenfield (1998) reported a natural pink x chinook salmon hybrid from the St. Mary's River in Michigan. The situation for non-anadromous salmonids is very different. Hybridization between introduced rainbow trout and native cutthroat trout appears to be almost ubiquitous throughout the interior part of western North America, and has been enormously detrimental to the latter species (Gresswell 1988, Behnke 1992).

Genetic Dilution and Alteration of the Wild Salmon Gene Pool

Adverse genetic and ecological effects on wild Atlantic salmon populations due to releases or escapes of artificially propagated Atlantic salmon from public hatcheries and private net-pens have been reported in Norway, Scotland, Ireland, and the Canadian Maritime Provinces.

For wild, native Atlantic salmon, these include a reduction in their genetic diversity and capacity to evolve, a result of dilution of genetic diversity by interbreeding with artificially propagated fish, and direct competition for food and space (Einum and Fleming 1997, Gross 1998).

Such adverse effects happened in Europe and eastern North America because both the cultured and wild fish were Atlantic salmon. However, Atlantic salmon escaping into the Puget Sound and Hood Canal ESUs for chinook and summer-run chum salmon will not have conspecific or congeneric wild individuals with which to interact. In the Pacific Northwest region, releases of artificially propagated Pacific salmon, not the escape of Atlantic salmon, have been shown to produce impacts on native Pacific salmon that are analogous to those found between artificially propagated and wild Atlantic salmon in Europe and eastern North America.

Adverse genetic and ecological interactions on local wild Pacific salmon populations from artificially propagated Pacific salmon have been well-documented by Weitkamp et al. (1995), Busby et al. (1996), Hard et al. (1996), EAO (1997), Gustafson et al. (1997), Johnson et al. (1997, 1999), and Myers et al. (1998a) in reviews of this large body of literature. Over the last 100 years, no detrimental genetic effects related to escaped or planted Atlantic salmon have been reported in Puget Sound or western North America.

Potential Impact of Transgenic Atlantic Salmon

As with other agricultural sectors, there is considerable interest within the fish farming and fish enhancement sectors to improve growth or survival of fish or shellfish through genomic or chromosomal manipulations. For example, triploid (treated to produce 3 instead of 2 chromosome copies) California-strain rainbow trout were planted in about 75 lakes in Washington this year to provide anglers with opportunities for large fish (WDFW 2002). The use of triploids in fish farming is considered to be a low risk endeavor in Washington, and has been suggested as one of the means to avoid genetic interactions, remote as they are, between Atlantic salmon and native salmonids (PCHB 1998). However, in recent years the role of transgenics (descendants of genetically engineered parents whereby introduced DNA has been incorporated and inherited) in traditional farming has been a controversial topic. The potential risk is thought to be that transgenic fish, should they escape from fish farms, may reproduce successfully with wild or other transgenic fish and produce offspring that may eventually adapt to their local environments. This is a topic that will receive considerable debate in the years to come. There is no evidence in the literature that transgenic fish have been raised or are currently being raised in Puget Sound waters, and at present there are no plans to raise them in the future (P. Granger[2]). The formally adopted position of the Washington Fish Growers Association is as follows: "Transgenic fish (as defined by actual transfer of genes from one species to another species) are not used in commercial production in Washington State today and should not be used here or elsewhere in the future unless they are proven healthy and nutritious, safe for human

[2] P. Granger, Washington Fish Growers Association, 10420 173rd Ave. SW, Rochester, WA 98579. Pers. commun., February 12, 2001.

consumption and of minimal risk to the environment. This would mean approval by appropriate state and federal agencies" (D. Swecker[3]).

[3] D. Swecker, Washington Fish Growers Association, 10420 173rd Ave. SW, Rochester, WA 98579. Pers. commun., March 4, 2002.

POTENTIAL FOR COLONIZATION OF PUGET SOUND CHINOOK AND HOOD CANAL SUMMER-RUN CHUM SALMON ESUs BY ATLANTIC SALMON

Success of Atlantic Salmon Introductions Worldwide

Worldwide, there have been several hundred attempts to establish Atlantic salmon outside their native range, and with two exceptions in barren habitat, these have inevitably failed (MacCrimmon and Gots 1979, Lever 1996). On the other hand, there are many reports regarding other non-native species that eventually became established after first experiencing numerous failures, especially introductions involving plants and invertebrates (Williamson 1996). However, most Atlantic salmon introductions have been well-matched to habitat (northern and mountainous states or southern provinces) with optimal environmental conditions for the salmon, have included large numbers over many years, and still have failed. Thus, it is the total number of failed introductions over the last century that is the basis of the risk assessment presented below.

Success of Atlantic Salmon Introductions in the United States

In the past century, there have been numerous attempts in the United States and elsewhere to establish Atlantic salmon outside their native range. At least 170 attempts occurred in 34 different states where Atlantic salmon were not native, including Washington, Oregon, and California (MacCrimmon and Gots 1979). None of these efforts was successful. No reproduction by Atlantic salmon was verified after introductions in the waters of these states (MacCrimmon and Gots 1979, Alverson and Ruggerone 1997, Dill and Cordone 1997).

Success of Atlantic Salmon Introductions in the Pacific Northwest

The initial transfer of Atlantic salmon to Washington occurred in 1904 (MacCrimmon and Gots 1979). Attempts to introduce this species, as well as plantings for recreational purposes, continued until about 1991 (Coleman and Rasch 1981, Amos and Appleby 1999). Occasional releases of Atlantic salmon into high mountain lakes in Washington have since been made. Sea-run and landlocked strains (originally from NMFS) were used, but neither life-history form succeeded in establishing self-perpetuating populations.

Several Atlantic salmon farmers in Washington rear juveniles in the Chehalis River basin prior to transfer to seawater in Puget Sound. Since the mid-1980s, escaped Atlantic salmon smolts have been captured in traps designed to monitor the out-migration of juvenile Pacific salmon (Seiler et al. 1995). However, as of 1998, no returning adult Atlantic salmon have been encountered at adult salmon traps on several tributaries of the Chehalis River system, or been caught in tribal gill-net fisheries, which capture about 10% of all upstream migrating adults in

the main stem of the Chehalis River (D. Seiler[4]). If 20 adult Atlantic salmon were returning to the Chehalis River in a given year, a 10% level of sampling would give an 88% percent chance of observing at least one Atlantic salmon if it returned at the same time as the tribal fisheries in the summer through early fall (R. Kope[5]). Therefore, the probability of not capturing an adult Atlantic salmon if they were numerous enough to have a hypothetical negative impact in the Chehalis River is small.

Between 1905 and 1934, the government of British Columbia released 7.5 million juvenile Atlantic salmon into local waters, primarily on the east coast of Vancouver Island and the lower Fraser River (MacCrimmon and Gots 1979, Alverson and Ruggerone 1997). These releases were not successful in establishing Atlantic salmon populations in the province (Carl et al. 1959, Hart 1973), although some natural reproduction may have occurred in the Cowichan River, as specimens thought to have resulted from the planting of Atlantic salmon were taken until May 1926 (Dymond 1932). The Department of Fisheries and Oceans Canada (DFO Canada) currently is carrying out a long term monitoring study, known as the Atlantic Salmon Watch, examining catches and sightings of Atlantic salmon to determine if self-sustaining populations are becoming established (Thomson and Candy 1998). Recently Volpe et al. (2000) reported that feral Atlantic salmon had successfully produced offspring in British Columbia. Locations in British Columbia where juvenile Atlantic salmon of both naturally produced (feral) and hatchery (escapees) origin have been captured are presented in Table 3.

In addition to the total failure of fisheries managers to establish populations of anadromous Atlantic salmon outside their native range, it appears that it is extremely difficult to reintroduce Atlantic salmon to their native rivers in North America. In the last 100 years, Atlantic salmon populations in New England have declined precipitously, despite widespread introductions of locally derived hatchery fish, primarily from the Penobscot River (Moring et al. 1995), a stock now used in net-pen farms in Puget Sound. Due to continued declines in abundance, Atlantic salmon in Maine have recently been listed as an endangered species under the ESA (USDOI and USDOC 2000). Emery (1985) and Crawford (2001) noted that in historic Atlantic salmon habitat in Lake Ontario, attempts to reestablish Atlantic salmon populations have not been successful. However, introduced Pacific salmonids have succeeded in establishing self-reproducing populations throughout the Great Lakes (Brown 1975), although it appears that many populations of introduced salmon and trout in the Great Lakes would face an immediate risk of local extinction without continued supplemental stocking (Crawford 2001). USFWS (1982) reported that Pacific salmon and trout, as well as brown trout from Europe, were prevalent in Canadian and United States tributaries of Lake Ontario, a system where Atlantic salmon were once a common species. Coho salmon were observed spawning in 48 different streams, kokanee (sockeye salmon life-history form) in 4 streams, chinook salmon in 52 streams, rainbow trout/steelhead in 62 streams, and brown trout in 25 streams. Atlantic salmon were not observed in any tributary of Lake Ontario in this 1982 study, having been extirpated from the Lake Ontario system by 1904.

Lever (1996) reported that, worldwide, no self-sustaining populations of anadromous Atlantic salmon have been established outside the natural range of this species, although

[4] D. Seiler, WDFW, 600 Capitol Way N, Olympia, WA 98501. Pers. commun., September 1, 1999.
[5] R. Kope, NMFS, 2725 Montlake Blvd. E, Seattle, WA 98112. Pers. commun., October 16, 2001.

Table 3. Number of juvenile Atlantic salmon observed in British Columbia freshwater areas, 1996-2001. Suspected naturally produced juveniles in bold. (Data from A. Thomson, DFO Canada, Pacific Biological Station, Nanaimo, BC V9R 5K6. Pers. commun., April 16, 2001.) It is possible that the three fish observed in the Adam R. in 1999 could have been brown trout (D. Noakes, DFO Canada, Pacific Biological Station, Nanaimo, BC V9R 5K6. Pers. commun., February 2, 2002).

River or lake	1996	1997	1998	1999	2000	2001
Adam R.				**3**		
Amor de Cosmos R.				**113**	**8**	
Carnation Creek		1	3		1	
Georgie Lake	41	21	86	30		
Keogh R.			1	2		
Lois Lake	13					
Pye R.		1				
Stamp R.						3
Tsitika R.			**24**	**2**	**3**	

landlocked populations appear to have become established in the Southern Hemisphere in Argentina and in the mountains of New Zealand. Reproduction by Atlantic salmon was observed subsequent to introductions in Chile and Australia, but these transfers failed to create self-sustaining populations.

Possible Reasons for the Failure of Atlantic Salmon Introductions

Primitive Hatchery Methods

The failure of early introductions of Atlantic salmon to produce self-sustaining populations could have been due to the rather primitive hatchery methods used in the early 1900s (Volpe 2001). However, the same primitive methods that failed to establish Atlantic salmon anywhere in North America proved to be remarkably successful in establishing European brown trout, brook trout, and rainbow trout almost everywhere in the earliest days of fish culture, often on the first attempt (Lever 1996, Dill and Cordone 1997). With these particular salmonids, the success or failure of introduction appears to be associated with attributes inherent to each species, not with the hatchery methods employed.

Pristine Habitats and Healthy Pacific Salmon Populations

It has also been suggested (by University of Victoria student John Volpe) that the earlier attempts to establish Atlantic salmon in the Pacific Northwest failed because salmonid habitats had not yet been damaged and local salmonid populations were abundant, thereby preventing Atlantic salmon from finding an available niche to colonize (Glavin 2001). However, brown trout, brook trout, California-strain rainbow trout, lake trout (*Salvelinus namaychus*), and several dozen non-salmonid species all successfully colonized habitats throughout Washington and the rest of North America during this early period (Wydoski and Whitney 1979), indicating that the limited availability of suitable niches and the presence of abundant salmon populations were not exclusionary factors for colonization by non-native fish, including Atlantic salmon, early in the 20th century. Moreover, attempts to establish Atlantic salmon populations in the Pacific Northwest were conducted under a variety of climatic conditions, variations of which have been show to dramatically influence the ocean survival of Pacific salmon (Beamish and Bouillon 1993, Beamish et al. 1997, Noakes et al. 2000). Climatic conditions during the early part of the 20th century were favorable for salmon survival as evidenced by high abundance of salmon in the Pacific Ocean during this period (Beamish et al. 1997, Noakes et al. 2000). Most of the introductions of Atlantic salmon into the Pacific Northwest occurred concurrent with this episode of favorable ocean conditions, but colonization failed to take place.

Incompatible Biological Characteristics of Introduced Atlantic Salmon

The failure of Atlantic salmon to colonize new habitat has also been attributed to other factors, including the inability to navigate in new environments, and to introductions that were made in small batches of less than several hundred thousands of individuals (Lever 1996, Dill and Cordone 1997). Atlantic salmon may also have “prohibitively stringent reproductive

requirements, including very particular stream substrate qualities" (Crawford 2001). The experience in Washington and elsewhere in the world suggests that the failure of Atlantic salmon to establish populations after introductions is linked to incompatible biological characteristics of Atlantic salmon and not with the availability of suitable habitat or absence of potential competitors or predators. In California, attempts to establish Atlantic salmon populations have been discontinued because the expectation of successful introductions is "so remote that it does not warrant the effort or expense of an attempt" (Dill and Cordone 1997). In a review of the ecological and genetic effects of salmonid introductions in North America, Krueger and May (1991) observed that, with the notable exception of pink salmon inadvertently introduced into the Great Lakes, successful introductions from the accidental release or escape of salmonids has rarely occurred, unlike the frequent success observed with some intentionally introduced salmonid species such as chinook and coho salmon, and rainbow, brook, and brown trout.

As noted above, the success of introduced salmonids in the Great Lakes may be due for the most part to the relatively large numbers of artificially propagated salmonids introduced into the Great Lakes each year. For example, between 1966 and 1998, 4 million Atlantic salmon, 336 million chinook salmon, 81 million brown trout, 148 million coho salmon, and 174 million rainbow trout have been planted in all the Great Lakes combined (Crawford 2001). Atlantic salmon may have failed to succeed in the Great Lakes because of the low numbers of artificially propagated Atlantic salmon introduced compared to the much larger number of artificially propagated Pacific salmon and trout juveniles present in the Great Lakes (M. Gross[6]). In addition, competitive interactions with coho and chinook salmon and rainbow and brown trout may limit the successful restoration of Atlantic salmon to Lake Ontario (Crawford 2001).

Atlantic salmon are virtually the only non-native salmonid not successfully introduced to Washington, with the exception of Arctic char (*Salvelinus alpinus*) and Masu salmon (*Oncorhynchus masou*) (Wydoski and Whitney 1979). Even so, Barbara Stenson, spokesperson of the Marine Environmental Consortium, views escaped Atlantic salmon colonizing habitats throughout the Puget Sound Basin at great detriment to Pacific salmon as an inevitable outcome of salmon farming (Le 1999).

The risk of anadromous Atlantic salmon establishing self-perpetuating populations anywhere outside their home range has been shown to be extremely remote, given that substantial and repeated efforts over the last 100 years have not produced a successful self-reproducing anadromous population anywhere in the world. In Oregon, the hatchery-supported fishery for Atlantic salmon in Hosmer Lake represents the only successful fishery produced in approximately eight lakes stocked with this species (Dill and Cordone 1997). In the Pacific Northwest, there have been no reports of self-sustaining populations resulting from deliberate or accidental Atlantic salmon introductions, compared to the plethora of other non-native species which have readily established themselves in the region.

[6] M. Gross, University of Toronto, 25 Harbord St., Suite 503, Toronto, ON M5S 3G5. Pers. commun., February 24, 2002.

POTENTIAL FOR DISEASE TRANSMISSION OR ADVERSE DISEASE IMPACTS BETWEEN ATLANTIC SALMON AND PACIFIC SALMON IN WASHINGTON

The occurrence and treatment of diseases is an unavoidable consequence of animal husbandry. This is no less true for aquatic husbandry, public and private, than for terrestrial farming. This section will discuss salmon diseases commonly observed in the Pacific Northwest and whether net-pen rearing of Atlantic salmon has a potential for adverse disease impacts comparable to disease risks associated with the artificial propagation of Pacific salmon in public hatcheries, which in turn appears to have a low risk for federally protected Pacific salmon in Puget Sound and Hood Canal.

Diseases of Salmon and Trout in Hatcheries

Freshwater salmonid diseases observed in Pacific salmon hatcheries in the Pacific Northwest include furunculosis, bacterial gill disease, bacterial kidney disease, botulism, enteric redmouth disease, cold water disease, columnaris, infectious hematopoietic necrosis, infectious pancreatic necrosis, viral hemorrhagic septicemia, erythrocytic inclusion body syndrome, and a number of parasitic infections, such as gyrodactylus, nanophyetus, costia, trichodina, ceratomyxosis, proliferative kidney disease, whirling disease, and ichthyophonis. These diseases are described in manuals by Wood (1979), Leitritz and Lewis (1980), Foott and Walker (1992), and Kent and Poppe (1998).

The frequency of occurrence of these pathogens in hatcheries appears to vary geographically. For example, between 1988 and 1993, a greater percentage of Alaska hatcheries tested positive for infectious hematopoietic necrosis, viral hemorrhagic septicemia, furunculosis, and ceratomyxosis than hatcheries located in other western states, whereas hatcheries in Alaska tested positive at the lowest rate for several other salmonid pathogens (PNWFHPC 1993) (Table 4).

In the Pacific Northwest, hatchery diseases associated with the freshwater phase of salmon culture can also occur in natural seawater environments after salmon are released from hatcheries or transferred to net-pens for further rearing. Other pathogens, such as *Vibrio anguillarum* and various parasites, are unique to the marine environment and are normally encountered by wild and hatchery-reared salmonids only after they leave rivers for the sea (Wood 1979, Harrell et al. 1985, 1986, Kent and Poppe 1998). Salmonid diseases observed in salmon and trout reared in public and private net-pens in seawater in the Pacific Northwest include; vibriosis, furunculosis, bacterial kidney disease, enteric redmouth disease, myxobacterial disease, infectious hematopoietic necrosis, infectious pancreatic necrosis, viral hemorrhagic septicemia, erythrocytic inclusion body syndrome, rosette agent, and a number of parasitic infections (Kent and Poppe 1998).

Table 4. Facilities (% in state or agency) testing positive for various salmonid diseases (July 1988-June 1993). (Data from PNWFHPC 1993.)

State or agency	IHN	IPN	VHS	EIBS	BKD	FUR	ERM	CWD	PKD	MC	CS	ICH
AK	47.3	0.0	1.2	0.0	75.2	42.5	10.9	27.5	NS[a]	NS[a]	50.0	0.0
CA	24.2	0.0	0.0	0.0	31.2	2.2	23.0	19.4	27.9	12.0	12.8	56.3
ID	20.2	8.7	0.0	15.5	48.4	1.8	12.3	23.6	4.3	15.6	20.4	20.7
MT	0.0	0.0	0.0	0.0	5.6	2.5	0.8	4.2	7.7	0.0	0.0	0.0
OR	18.1	0.3	0.0	24.6	53.1	35.9	17.8	84.8	0.0	2.9	33.3	26.2
WA	11.5	0.7	0.1	34.2	52.6	20.1	17.0	60.3	3.5	0.0	11.9	24.4
USFWS	37.5	1.0	0.0	27.2	84.9	23.7	20.0	34.9	0.0	0.6	30.6	24.0
NWIFC[b]	2.9	0.0	0.6	NS[a]	51.5	14.0	18.1	39.9	56.3	0.0	0.0	15.0
Average	20.2	1.3	0.2	14.5	50.3	17.8	15.0	36.8	12.5	4.4	18.8	20.8

[a]NS = Not surveyed
[b]Northwest Indian Fisheries Commission

Key:

Viral Diseases
IHN Infectious hematopoietic necrosis
IPN Infectious pancreatic necrosis
VHS Viral hemorrhagic septicemia
EIBS Erythrocytic inclusion body syndrome

Bacterial Diseases
BKD Bacterial kidney disease
FUR Furunculosis
ERM Enteric redmouth disease
CWD Coldwater disease

Parasites
PKD Proliferative kidney disease
MC Whirling disease
CS Ceratomyxa
ICH Ichthyopthirius

Salmon, like other animals, can carry pathogenic organisms without themselves being infected. For example, numerous bacterial species were observed in tissues of chinook salmon which had returned from the ocean to a hatchery in the lower Columbia River Basin, although the fish displayed no clinical signs of disease. Some of the bacteria observed were *Listeria* sp., *Aeromonas hydrophila*, *Enterobacter agglomerans*, *Enterobacter cloacae*, *Staphylococcus aureus*, *Pseudomonas* sp., *Pasteurella* sp., *Vibrio parahaemolyticus*, *V. extorquens*, *V. fluvialis*, *Hafnia alvei*, and *Serratia liquefaciens* (Sauter et al. 1987). Several of these organisms are known to be infectious to humans. However, the fact that such bacteria were found in hatchery salmon does not mean they posed a risk to humans, as the bacteria were present only at background levels.

Disease Therapy

Fish diseases and subsequent antibiotic therapy have been normal occurrences at state, federal, and tribal Pacific salmon hatcheries since the 1940s (WDF 1950, 1953, PNWFHPC 1993). An examination of the disease histories of Puget Sound area Pacific salmon and trout hatcheries (data from 45 hatcheries) during the 1980s showed that, on average, each hatchery experienced disease outbreaks from about 4 different pathogenic organisms during this period, frequently on an annual basis (PNWFHPC 1988a-d).

Cumulatively, salmon hatcheries in the Pacific Northwest (Alaska, Washington, Oregon, and Idaho), including those located in Puget Sound, experience hundreds of disease outbreaks every year (Wood 1979, PNWFHPC 1988a-d). It is not uncommon for a hatchery to experience different diseases in a relatively short period. For example, Michak and Rodgers (1989) reported that between 1983 and 1986 the WDFW Cowlitz Hatchery experienced *Costia* sp. infections on 11 different occasions, bacterial hemorrhagic septicemia 4 times, cold water disease 9 times, bacterial kidney disease 8 times, and furunculosis 1 time. Disease outbreaks have been observed in hatchery salmon reared in saltwater in Washington since the first attempts at seawater rearing in the 1950s (WDF 1954, PNWFHPC 1998).

Concerns Regarding Treatment of Diseases in Salmon Rearing Facilities

Alexandra Morton (1997), director of Raincoast Research, Peter Knutson, commissioner of the Puget Sound Gillnetters Association, Arthur Whitely, board member of the Marine Environmental Consortium (Carrel 1998), and others (Meloy 2000) have recently expressed concerns that the use of chemotherapeutics in fish culture will have negative impacts on wild salmonids and their environment. However, the occurrence of fish diseases at public hatcheries or private salmon farms and their treatment with chemotherapeutics have not been shown to have deleterious effects on wild salmonids or their habitat. For example, it is a recommended procedure to bath freshly spawned eggs in an iodophor solution at state, tribal, federal, and private hatcheries in the Pacific Northwest (ADF&G 1983, IHOT 1995-1998, NWIFC/WDFW 1998). However, this procedure has not been shown to be harmful to wild salmonids in the Pacific Northwest. In a study at several Atlantic salmon net-pen farms in Puget Sound, it was found that the use of antibacterial compounds in fish food had no inhibitory effect on important

sediment biogeochemical processes such as bacterial densities, oxygen and ammonia fluxes, or interstitial ammonium and sulfate levels (Weston et al. 1994).

Chemotherapeutants Registered for Use in the United States

Diseases in public and private trout and salmon hatcheries in western states are normally treated with a variety of antibiotics and chemical baths, including oxytetracycline, Romet-30®, formalin, iodophores and several others (Wood 1979; PNWFHPC 1988a-d, IHOT1995-1998, PNWFHPC 1998). Drug therapy in federal, state, and tribal hatcheries in Washington, Oregon, Idaho, California, and Alaska is conducted in accordance with U.S. Food and Drug Administration (FDA) guidelines (Nash 2001, K. Amos[7]). As a result of drug therapy, antibiotic-resistant strains of bacterial fish pathogens have been observed in Pacific salmon hatcheries in the Pacific Northwest for over 40 years (WDF 1954, Wood 1979, PNWFHPC 1993).

Only three therapeutants (formalin, oxytetracycline, and Romet-30®) and one anesthetic (MS-222) are currently approved by the federal government for use with food fish in public and private artificial propagation facilities for salmon, trout, and catfish (Schnick 1992). However, the use of antibiotics in the United States is far more restrictive than in some countries. For example, Weston (1996) observed that 26 different antibacterial preparations were approved for use in Japan. This compares currently with 3 in Canada (EAO 1997) and 2 in the United States (Schnick 1992).

Amount of Antibiotics Used in Fish Culture Facilities

Given that Pacific salmon hatcheries rear thousands of metric tons (t) of fish each year, the amount of antibiotics used to treat bacterial salmon diseases in hatcheries is not inconsequential, sometimes amounting to hundreds of tons of medicated feed each year. Michak et al. (1990) stated that the Washington Department of Fisheries (WDF, now WDFW) hatcheries located in the Columbia River Basin used about 200 t of feed containing antibiotics. Since WDF hatcheries in the Columbia River Basin represented only about 25% of the number of all salmon and trout hatcheries (albeit many of the largest facilities are in the Columbia River Basin) in Washington State at that time (Myers et al. 1998a), it is reasonable to estimate that the total amount of medicated feed used by the public hatchery system in the State was about 450 t in 1990.

Actual or estimated annual amounts of medicated feed used in private fish culture of Atlantic salmon in seawater and rainbow trout in freshwater are not available at this time for the United States or Puget Sound. However, the amount of drugs used elsewhere in salmon farming has declined greatly, mostly as a result of improved husbandry practices, including development of effective vaccines for common fish diseases. EAO (1997) noted that salmon farmers in Norway used a total of 48.7 t of antibacterial drugs in 1987, and the figure had fallen to 6 t by 1993. In 1998 it was only 0.7 t (Intrafish 2000). To put the amount of antibiotics currently used in Norway into perspective, it took about two level teaspoons (approximately 7 g) of antibiotic to

[7] K. Amos, WDFW, 600 Capitol Way N, Olympia, WA 98501. Pers. commun., May 30, 2001.

produce a metric ton of farmed salmon in Norway in 1996 (Noakes et al. 2000). Less than that is required today. During the same 12-year period, the production of salmon in Norway increased from 50,000 t to 400,000 t and the quality of product was considerably improved (ODIN 2001). A similar pattern of reduced drug use has occurred in British Columbia (EAO 1997). Although the amount of antibiotics used in Puget Sound Atlantic salmon farms has not been summarized, with just a few salmon farms in Puget Sound, the annual use of antibiotics in the net-pen farms would be relatively small compared to the amount used in other countries.

Disease Interactions between Hatchery and Wild Salmon and Trout

Transmissions of Disease from Hatchery to Wild Salmon

Documented examples of disease transmission between wild and artificially propagated fish are not common, yet have been known to occur (Brackett 1991). For example, the planting of infected Atlantic salmon smolts from two Norwegian federal salmon hatcheries into rivers in Norway was responsible for the introduction of the freshwater parasite *Gyrodactylus salaris*, which caused the extirpation of Atlantic salmon in many river systems (Johnsen and Jensen 1986, 1988). The viral disease infectious hematopoietic necrosis, ubiquitous in Alaska, British Columbia, and Washington sockeye salmon populations (Meyer et al. 1983), was introduced to Japan from a shipment of infected sockeye salmon eggs from a hatchery in Alaska and subsequently caused epizootic mortality in Japanese chum salmon and in two species of landlocked salmon which occur only in Japan (McDaniel et al. 1994). In these two cases, the indigenous salmonids in Norway and Japan were exposed to novel pathogens to which they had little or no immunity. In Washington, where no new stocks of Atlantic salmon have been introduced since 1991, the pathogens found in cultured salmonids are the same as those known to occur in wild salmon (Amos and Appleby 1999).

Recently, significantly higher infestation rates by the copepod parasite *Lepeophtherius salmonis* was found on wild salmonids in Irish bays containing *L. salmonis*-infected farmed salmon than in bays where infected farmed salmon were not present (Tully et al. 1999). It appears that salmon farms in Ireland acted as a biomagnifier for this particular organism. Sea lice have also been observed on salmon from farms in British Columbia (Kent and Poppe 1998). However, *L. salmonis* has not been reported to be a significant problem in marine net-pens in Puget Sound (K. Amos[8]). For example, since 1969, rainbow and cutthroat trout, and coho, chum, chinook, sockeye, pink, and Atlantic salmon have been grown in government and private net-pens in Clam Bay, Washington. *L. salmonis*, although commonly observed on captive fish in the net-pens, has not been a serious problem at the NMFS Manchester Research Station (L. Harrell[9]), despite the fact that the fish in the pens experienced a high rearing density (number of fish per unit space) relative to densities experienced by free-swimming fish. High rearing density is thought to be primarily responsible for the greater incidences of fish diseases observed in hatchery salmon versus wild salmon (Wood 1979, Leitritz and Lewis 1980, Foott and Walker 1992, Kent and Poppe 1998).

[8] K. Amos, NMFS, 510 Desmond Dr. SW, Lacey, WA 98503. Pers. commun., March 27, 2002.
[9] L. Harrell, NMFS, P.O. Box 130, Manchester, WA 98353. Pers. commun., March 27, 2002.

Diseases of Atlantic Salmon in the Pacific Northwest

Alexandra Morton, director of Raincoast Research (PSGA 2000), and Peter Knutson, commissioner of the Puget Sound Gillnetters Association (Carrel 1998), asserted that Atlantic salmon in the Pacific Northwest are more likely to carry diseases than hatchery stocks of Pacific salmon, but these statements were not accompanied by a review of the scientific literature. Salmonids, including Atlantic salmon, can only carry diseases to which they have been exposed. The New England Atlantic salmon stocks used by Washington growers were certified by federal pathologists to be disease-free prior to shipment from East Coast hatcheries between 1980 and 1986 and have been reared exclusively in the Pacific Northwest for many generations. Their diseases, if any, would be no different than the diseases found in nearby Pacific salmon hatcheries. In addition, Washington regulations require that all broodstocks of hatchery salmon, including Atlantic salmon broodstocks, must be examined for pathogens each year (Washington Administrative Code 220-77; Revised Code of Washington 75.58). Nonindigenous salmon diseases transmitted into the Pacific Northwest by the North American hatchery stocks of Atlantic salmon used in Washington have never been observed in the yearly sampling of these stocks since the mid-1970s.

Potential for Disease Transmission from Atlantic Salmon to Pacific Salmon

Pacific salmonids do not appear to be put to any increase in disease incidence when continually exposed to water in which Atlantic salmon have been reared. For example, Rocky Ford Creek, near Ephrata in eastern Washington, is considered to be one of the premier trout streams in the State (Northwest Fishing Holes 2001), yet the entire flow in this stream consists of effluent from an Atlantic salmon hatchery and smolt production facility (J. Parsons[10]). There are no reports of diseased trout in this stream in either the scientific literature or in the many media reports on the fine fishing in this stream.

There is no evidence that hatchery-reared Atlantic salmon have introduced or spread nonindigenous diseases to native fishes in Washington (Amos and Appleby 1999). By law, privately owned Atlantic salmon populations in Washington are examined for diseases every year (WAC 220-77-030), and no exotic pathogens have been reported. With Pacific salmonids, Griffiths (1983) observed that outbreaks of serious contagious diseases were normally associated with the intensive culture of fish in a hatchery environment. Documentation of disease introductions in North America from the stocking or escape of artificially propagated salmonids has been uncommon (Krueger and May 1991).

The Scale of Artificial Propagation of Salmon in the Pacific Northwest and Disease Transmission Potential

Based solely on the enormous number of hatchery-reared salmonids released into rivers and lakes in the Pacific Northwest, the potential for transmission of disease to wild stocks from hatchery-reared Pacific salmon and trout would be greater than that of accidentally escaped farmed Atlantic salmon and rainbow trout in Washington State, although this statement is not

[10] J. Parsons, Troutlodge, Inc., P.O. Box 1290, Sumner, WA 98390. Pers. commun., March 12, 1999.

meant to suggest that the risk from Pacific salmon hatcheries is severe or even moderate. However, escaped farmed Atlantic salmon and rainbow trout constitute a miniscule percentage of all artificially propagated salmon which end up in natural waters in the area. Furthermore, hatchery Pacific salmon occupying the marine waters of Washington each year have not been shown to impose adverse disease impacts on wild salmonids. Peter Knutson (Carrel 1998) described escaped Atlantic salmon as "smart bombs, delivering disease right into the bedrooms of wild salmon" in the Pacific Northwest, but this declaration has not been supported by the scientific literature.

Mahnken et al. (1998) reported that since 1980 the number of Pacific salmon released from several hundred federal, state, tribal, and cooperative hatcheries on the West Coast was about 2 billion fish annually, which is about 30,000 to 40,000 times more than the number of Atlantic salmon that may have escaped from net-pens since 1980 (Table 5).

On a smaller scale, the number of Pacific salmon released from saltwater net-pens in Puget Sound is much greater than the number of Atlantic salmon that escape from salmon farms. For example, NRC (1995, 1996) reported that coho salmon were released annually from 18 different marine net-pen sites, chinook salmon from 13 different sites, and chum salmon from 10 different sites in Puget Sound between Olympia and Bellingham. The number of fish released from these marine sites averaged about 10 million annually between 1980 and 1992. Currently, however, only about half that number are being released, due to dramatic changes in hatchery practices meant to protect wild salmonids in Puget Sound and Hood Canal (NWIFC 2001, WDFW 2000). These hatchery fish had sometimes been exposed to various salmonid pathogens before transfer to or while in seawater, including bacterial kidney disease, vibriosis, and furunculosis. Infections in these fish were often treated with antibiotics (PNWFHPC 1988a-d). Adverse disease impacts on wild salmonids were not reported during the rearing period or after they were released, nor were any media reports seen expressing concern that these fish may have been treated with antibiotics sometime prior to release into public waters.

Disease Control Policies in Washington and the United States

In Washington all public and private growers of salmon, including Atlantic salmon hatchery operators, are required to adhere to strict disease control polices that regulate all phases of fish culture, from egg take to harvest and release (NWIFC/WDF 1991, NWIFC/WDFW1998). Each year at spawning time, adult salmon at public and private hatcheries must be sampled for viral, bacterial, and parasitic organisms. If any of several reportable organisms are detected in fish at a hatchery or have been detected within the past five years, transfer of eggs or fish from that facility is prohibited, thereby significantly reducing the risk of diseases transfer from one location to another.

The movement of fish and eggs across state or international borders is regulated by the USFWS under Title 50 of the CFR, which has stipulations and controls in accord with state regulations (50 CFR 16.13). For the case in point, all Atlantic salmon stocks distributed to local growers by NMFS were certified by federal pathologists before transfer from New England, and have been annually certified since then under Washington guidelines and procedures.

Table 5. Number (in millions) of salmon released or escaped by species and location along the West Coast of North America, 1980-1995. (Data from Amos and Appleby 1999, Mahnken et al. 1998, Thomson and McKinnell 1993, 1994, 1995, 1996, 1997, Thomson and Candy 1998.)

State or region	Atlantic	Sockeye	Chum	Steelhead	Pink	Coho	Chinook
Alaska	0.0	978	3,885	2	8,610	193	98
BC, Canada	~0.4	3,930	2,870	17	533	300	721
Pacific Northwest	~0.6	52	1,081	359	21	1,726	4,320
Total No.	~1.0	4,960	7,836	377	9,164	2,219	5,139
Total %	0.0003	16.7	26.4	1.2	30.9	7.5	17.3

POTENTIAL ECOLOGICAL IMPACTS OF ATLANTIC SALMON IN THE PACIFIC NORTHWEST

Impacts of Cultured Atlantic Salmon on Wild Atlantic Salmon

In areas where Atlantic salmon are indigenous, such as Scandinavia, Great Britain, and eastern North America, adverse genetic and ecological impacts for natural populations of Atlantic salmon have been reported following programmed releases or unintentional escapes of artificially propagated Atlantic salmon from public hatcheries and private net-pens (Hearn and Kynard 1986, Beall et al. 1989, Jones and Stanfield 1993, Heggberget et al. 1993, Gross 1998). The impacts included reductions in the genetic diversity and capacity to evolve in wild Atlantic salmon, introduction of genetic maladaptations as a result of interbreeding with artificially propagated Atlantic salmon, and competition for food and space between wild and hatchery stocks of Atlantic salmon.

These particular adverse effects occurred because the artificially propagated and wild salmonid species were both Atlantic salmon. Escaped Atlantic salmon on the Pacific coast of North America do not have conspecific or congeneric wild individuals with which to interact. However, adverse ecological effects may still occur between different species. For example, introductions of hatchery coho salmon juveniles in western Washington appear to have had a negative impact on the abundance of wild cutthroat trout in some streams (Johnson et al. 1999). Actual negative ecological consequences for Pacific salmon and trout related to the deliberate or unintentional introduction of Atlantic salmon into their habitats have not been reported. In the Pacific Northwest region, introductions and transfers of hatchery stocks of Pacific salmon, rather than escapes of Atlantic salmon, have much greater potential to produce impacts on native Pacific salmon analogous to those found between propagated and wild Atlantic salmon in Europe and eastern North America.

Impacts of Cultured Pacific Salmon on Wild Pacific Salmon

Many adverse genetic and ecological interactions on local wild salmon populations resulting from plants of artificially propagated Pacific salmonids have been documented in the Pacific Northwest (Campton and Johnston 1985, Nicholson et al. 1986, Leider et al. 1987, Behnke 1992, WDF et al. 1993, Kostow 1995). These adverse impacts in part include introgressive hybridization, competition for food and rearing space, decreased effective population size, decreased reproductive success, and reductions in intraspecific diversity. Recently, significant changes in management strategies by resource agencies have been initiated to reduce or eliminate adverse impacts from traditional hatchery programs, such as stock transfer guidelines used by WDFW for the last decade (WDF 1991a). No reports of detrimental impacts in the Puget Sound or Hood Canal ESUs related to deliberate or accidental Atlantic salmon introductions have been found.

Ecological Interactions between Atlantic Salmon and Pacific Salmon

Behavioral Interactions

Gibson (1981) reported that in laboratory studies in New England, introduced Pacific steelhead juveniles were more aggressive than Atlantic salmon. In turn, Atlantic salmon fry appeared to be more aggressive than coho salmon fry when introduced into open pools, although it was recognized that open pools are not the preferred habitat of coho salmon fry. In a similar experiment, Beall et al. (1989) reported that the survival of Atlantic salmon was reduced in the presence of older coho salmon fry.

In trials of interspecific combative behavior in a small river in New England, Hearn and Kynard (1986) observed that rainbow trout juveniles initiated three to four times more aggressive encounters than did Atlantic salmon, and concluded that it would take very large numbers of Atlantic salmon juveniles to displace or even disrupt rainbow trout. Jones and Stanfield (1993), in a study conducted in a Lake Ontario tributary once inhabited by Atlantic salmon, reported that their attempts to reintroduce hatchery strains of Atlantic salmon were significantly impaired in the presence of naturalized Pacific salmon juveniles, compared with reintroduction in stream sections where Pacific salmon juveniles had been removed. Volpe et al. (2001) observed that in an artificial environment, territory was successfully defended by the initial resident, whether that was an Atlantic salmon or a steelhead, which had been reared to achieve a standardized size prior to the study. It was speculated that the potentially greater size-at-age of naturally produced Atlantic salmon (Volpe et al. 2000) might give them a greater advantage.

Predation by Atlantic Salmon

In a study on farmed fish in British Columbia by Black et al. (1992), stomach analyses revealed that less than 1% of farmed salmon in net-pens (in this case coho and chinook salmon) contained the remains of fish. Since 1992 Canadian government scientists have examined the stomach contents of escaped Atlantic salmon recovered in the open waters of British Columbia as part of the Atlantic Salmon Watch Program in the province. Fish remains of any sort were rarely observed, and to date, the remains of just a few Pacific salmon (chum salmon) have been observed, in this case, in the stomach of a hatchery Atlantic salmon juvenile in Carnation Creek, British Columbia (Thomson and McKinnell 1993, 1994, 1995, 1996, 1997, Thomson and Candy 1998; A. Thomson[11]). That only a few juvenile salmonids have been observed in the stomachs of escaped Atlantic salmon (over 1,000 stomachs examined in British Columbia and Alaska) indicates that these fish have a very low propensity to prey on juvenile salmonids, compared to Pacific salmon. For example, Fresh (1997) compiled information showing that about 50% of chum salmon juveniles are consumed by various predators, including other salmon, during their short period of migration from freshwater to marine environments. In the Chignik Lakes of Alaska, Ruggerone and Rodgers (1992) observed that juvenile coho salmon ate almost 60% of the sockeye salmon fry population. Fresh (1997) indicated that 33 fish species, 13 bird species, and 16 marine mammal species are predators of juvenile and adult Pacific salmon. Tynan (1981)

[11] A. Thomson, DFO Canada, Pacific Biological Station, Nanaimo, BC V9R 5K6. Pers. commun., December 27, 2001.

examined the stomachs of 93 coho salmon post-smolts captured after release from a net-pen near Squaxin Island, in South Puget Sound, and reported that only 3 stomachs contained fish remains, which were identified as smelt (*Hypomesus pretiosus*).

At the NMFS Manchester Research Station in Puget Sound, many species of forage fish have been observed seeking refuge from predators in net-pens containing adult Atlantic salmon. Among the species observed are known prey of salmonids, such as herring (*Clupea pallasi*), smelt, sand lance (*Ammodytes hexapterus*), shiner perch (*Cymatogaster aggregata*), and tube snouts (*Aulorhynchus flavidus*). These prey species voluntarily enter the net-pens through the mesh and then grow too large to exit. Alverson and Ruggerone (1997) noted that many thousands of these small fish had been observed in Atlantic salmon net-pens, and eventually had to be removed by hand.

Buckley (1999) observed that cannibalism and predation by chinook salmon on other salmonids was uncommon in Puget Sound waters. It is difficult to imagine that escaped Atlantic salmon, conditioned to a diet of artificial feed pellets and trained to be fed by humans, could have greater predation impacts on juvenile native salmonids than the impacts observed with free-swimming Puget Sound chinook and coho salmon.

Predation by Introduced Brown Trout

In the Cowichan River in British Columbia, non-native brown trout became established soon after the first introduction in 1932. Idyll (1942) observed that native salmon, trout, and their eggs, were a significant dietary component of young Cowichan River brown trout, and were the primary food item of large brown trout, as they were found to be elsewhere (Krueger and May 1991). Recent evaluations by Wightman et al. (1998) of steelhead populations on the east coast of Vancouver Island showed that the Cowichan River was one of only two rivers (out of 27 evaluated) with a relatively healthy steelhead population. Therefore, the successful colonization of the Cowichan River by a highly piscivorous species such as the brown trout has apparently had little or no adverse impact on steelhead abundance for more than 60 years, whereas attempts to establish Atlantic salmon in the Cowichan River Basin were failures. No media reports deploring the establishment of predatory brown trout in the Cowichan River were found in this review. On the contrary, the fact that large brown trout established in the Cowichan River compete with and prey on native salmon and trout was described, simply, as “browns will be browns” (Marsh 2000). Self-sustaining populations of predacious brown trout do not appear to be a cause for concern for citizens in the Pacific Northwest. However, the presence of a small number of Atlantic salmon juveniles in Vancouver Island streams has been viewed with alarm. These concerns can be summarized by statements such as John Volpe’s that “steelhead will likely suffer most” from the presence of Atlantic salmon in these streams (Marsh 1999); Barbara Stenson’s that “the possibility of farmed salmon interbreeding with Pacific salmon has been confirmed in laboratory tests” (1998); and that of Jim Fulton, executive director of the David Suzuki Foundation, that successful Atlantic salmon reproduction will be “the wave of death” for native salmon stocks (Howard 1999).

Ecological Interactions between Cultured Pacific Salmon and Wild Pacific Salmon

Adverse genetic and ecological effects from artificially propagated Pacific salmon have been documented by Weitkamp et al. (1995), Busby et al. (1996), Hard et al. (1996), Gustafson et al. (1997), Johnson et al. (1997, 1999), and Myers et al. (1998a) in coast-wide status reviews of Pacific salmonids conducted by NMFS in fulfillment of its responsibilities under ESA. The reviews contained information from the scientific literature that documented known adverse ecological impacts sometimes associated with the artificial propagation and release of Pacific salmon on the West Coast. In recent years, however, concerned management agencies have eliminated or modified many of the policies that contributed to these adverse effects. Nevertheless, examining known adverse impacts of Pacific salmon hatchery programs offers an effective demonstration that, by comparison, the ecological and genetic risks associated with Atlantic salmon farming are very small for federally listed chinook and summer-run chum salmon, as well as for other species, in Puget Sound and Hood Canal. The following paragraphs provide a brief review, by species, of adverse effects of artificial propagation that occurred before some of the Pacific salmon hatchery strategies that contributed to these effects were modified or eliminated.

Chinook Salmon

About 1.77 billion hatchery chinook salmon have been released into Puget Sound and its tributaries between 1953 and 1993, which is about 84 million per year, with the stock from the Green River Hatchery being the dominant stock as far back as 1907 (Myers et al. 1998a). Concerns that this strategy may have eroded genetic diversity were raised by Myers et al. (1998a). As recently as 1995, 20 hatcheries and 10 marine net-pen sites throughout Puget Sound regularly released Green River-stock chinook salmon, although most marine releases of chinook salmon in Puget Sound have been terminated (NWIFC 2001). Busack and Marshall (1995) reported that the extensive use of this stock had an undoubted impact on among-stock diversity within WDFW's South Puget Sound, Hood Canal, and Snohomish summer/fall chinook salmon genetic diversity unit (GDU), and may also have impacted GDUs elsewhere in Puget Sound and the Strait of Juan de Fuca. A GDU is defined as: "a group of genetically similar stocks that is genetically distinct from other such groups. The stocks typically exhibit similar life histories and occupy ecologically, geographically, and geologically similar habitats. A GDU may consist of a single stock" (Busack and Marshall 1995). Generally, GDUs delineate stocks at a finer scale than the NMFS criteria for ESUs. For example, the single NMFS ESU for Puget Sound chinook salmon includes 6 WDFW GDUs (Busack and Marshall 1995).

Rogue River chinook salmon have recently been released on the Oregon side of the Lower Columbia River to produce a south-migrating stock to avoid interception in commercial fisheries in British Columbia and southeast Alaska. Consequently, chinook salmon exhibiting Rogue River fall chinook salmon genetic markers were subsequently observed in about 13% of naturally produced chinook salmon juveniles in several lower Columbia River tributaries (Marshall 1997). In addition, most of the naturally spawning spring chinook salmon in Lower Columbia River tributaries were already hatchery strays (Marshall et al. 1995). Adverse impacts

resulting from the introduction of artificially propagated fish into native populations of chinook salmon were identified as a primary concern by the NMFS Biological Review Team(BRT) for ESA Status Review during the recent review of the status of West Coast chinook salmon populations (Myers et al. 1998a). There is no evidence of similar adverse effects on chinook salmon resulting from escaped Atlantic salmon in Washington or elsewhere within the original and naturalized (introduced) range of chinook salmon.

Chum Salmon

Johnson et al. (1997) reported that five hatchery stocks and several wild populations of chum salmon outside Hood Canal that were enhanced with eggs from Hood Canal hatcheries for several years subsequently exhibited genetic profiles more similar to those in Hood Canal hatchery populations than to populations in nearby streams that did not receive Hood Canal hatchery stock. Analyses of genetic profiles were consistent with the hypothesis that egg transfers between hatcheries and out-plantings of Hood Canal stock fry had genetically influenced the receiving populations. As a result, such transfers were terminated because of the potential jeopardy to wild gene pools through interbreeding (Phelps et al. 1995).

Steelhead Trout

Hatchery stocks of steelhead have been widely distributed. Few native steelhead stocks exist in the contiguous United States that have not had some influence from hatchery operations. For example, the summer steelhead program at the Nimbus Hatchery in Central Valley, California, was established with fish from a distant coastal tributary hatchery, which was itself earlier established with Lower Columbia River summer steelhead (Busby et al. 1996).

Howell et al. (1985) reported that over 90% of the "wild" steelhead spawning in the Cowlitz River originated in a hatchery, and some of these fish exhibited genetic characteristics (chromosome number) of Puget Sound steelhead due to previous transfers of Puget Sound stock to the Cowlitz Hatchery. Chilcote (1997) reported that since 1980 the percentage of non-native hatchery steelhead (from upper Columbia River and Snake River hatcheries) spawning in the Deschutes River had increased to over 70% of the run, while the percentage of native, wild steelhead spawning in the Deschutes River decreased to less than 15%. Phelps et al. (1997) postulated that introductions of non-native steelhead stocks in Washington, primarily Chambers Creek winter steelhead and Wells and Skamania summer steelhead, may have changed the genetic characteristics of some Puget Sound and eastern Washington steelhead populations sufficiently so that the original genetic relationships between stocks may have been obscured. Leider et al. (1987) concluded that the genetic fitness of the wild Kalama River population had been compromised by maladaptive gene flow from excess hatchery escapement. By comparison, no adverse effects on steelhead have been reported as a result of escapes of Atlantic salmon in Washington or elsewhere within the original and naturalized (introduced) range of steelhead.

Coho Salmon

Weitkamp et al. (1995) noted that it was extremely difficult for the NMFS BRT for ESA Status Review to identify any remaining natural populations of coho salmon in the Lower

Columbia River below Bonneville Dam, due in large part to persistent and extensive hatchery programs. A recent survey by NRC (1999) of coho salmon spawning habitat in the Lower Columbia River estimated that about 97% of recovered spawned-out carcasses originated from hatchery releases. Hatchery fish were observed in high percentages in streams up to 45 miles from the nearest hatchery. In many streams, wild coho salmon were not observed at all. In an earlier survey in Hood Canal, over 50% of all spawning coho salmon in streams within a 10-mile radius of a net-pen release site were fish originally released from the net-pen as juveniles 18 months earlier (NRC 1997).

Kostow (1995) stated that hatchery programs in Oregon may have contributed to the decline of wild coho salmon by supporting harvest rates in mixed-stock fisheries that were excessive for sustained wild fish production, and by reducing the fitness of wild populations through interbreeding between hatchery and wild fish. Furthermore, hatchery fish may have reduced survival of wild coho salmon juveniles in Oregon through increased competition for food in streams and estuaries, attraction of predators during mass migrations, and initiation of disease problems.

Weitkamp et al. (1995) also reported that artificial propagation of coho salmon appeared to have had substantial impact on native coho salmon populations to the point where it was difficult for the NMFS BRT for ESA Status Review to identify self-sustaining native stocks in Puget Sound, as over half the returning spawners originated in hatcheries. Spawn timing had been advanced by selective breeding to allow hatcheries to meet their quotas for eggs by early November. Fish arriving at the hatchery with the later part of the run (which would be coincidental with the spawn time of the majority of wild or native fish) were not propagated. As a result of such practices, segments of hatchery coho salmon populations which historically returned as late as January through March have disappeared from many river systems, resulting in a significant loss of life-history diversity (Flagg et al. 1995). Regarding speculation that small pockets of self-sustaining wild coho salmon populations that have had no hatchery influence might remain in any tributary in Washington State, WDF (1991b) stated: “To assume there are, given the record, would seem to be a most notable defiance of the odds.” There is no documented evidence of similar adverse effects on coho salmon resulting from escaped Atlantic salmon.

Pacific Trout

Long-term introductions of rainbow trout into western streams originally inhabited only by cutthroat trout have resulted in widespread extinction of native cutthroat trout through introgressive hybridization (Leary et al. 1995). Most of the rainbow trout released into Pacific Northwest lakes are derived from California strains, which have a different number of chromosomes than the rainbow trout native to many Puget Sound watersheds (Busby et al. 1996). Genetic analysis has shown the California-strain rainbow trout to be dramatically different than local strains (Busby et al. 1996). Hybridization between introduced brook trout and native bull trout (*Salvelinus confluentus*) is widespread in the western United States and usually produces sterile hybrids (Behnke 1992). Behnke (1992) noted that introduced brown trout had commonly replaced interior subspecies of cutthroat trout in large streams throughout

the same region, and introduced brook trout were the most common trout to be found in some small streams.

The situation regarding attempts to establish Atlantic salmon populations west of the Mississippi River is much different. In summary, MacCrimmon and Gots (1979) described frequent attempts (all failures) to introduce Atlantic salmon to western states, many of which occurred in the same river systems and at the same time as the successful trout introductions noted above. Since MacCrimmon and Gots (1979), no recent introductions, accidental or not, have succeeded and, most importantly, no known adverse impacts on Puget Sound trout by Atlantic salmon have been reported in the literature.

ADVERSE IMPACTS OF NONINDIGENOUS FISH INTRODUCTIONS

In contrast to the situation with Atlantic salmon, as many as 50 species of non-native fish are successfully established in the western United States (Table 6). Some adverse impacts associated with the establishment of these species are discussed below.

ODFW/NMFS (1998) documented that many introduced non-native species were harmful to native salmon. For example, walleye (*Stizostedion vitreum*), bass, perch (*Perca flavescens*), sunfish (*Lepomis* sp.), brown trout, and brook trout, among others, are well-known predators or competitors of native salmon and trout and all have now been successfully established in Northwest waters. Beamesderfer and Nigro (1988) and Beamesderfer and Ward (1994) estimated that walleye and smallmouth bass (*Micropterus dolomieu*) introduced into the Columbia River consumed an average of 400,000 and 230,000 juvenile salmonids, respectively, each year in the John Day Reservoir. Daily et al. (1999) reported that juvenile salmonids from 7 ESUs currently listed as threatened or endangered under ESA must migrate through the John Day Reservoir.

In some coastal lakes in Oregon, the summer rearing of coho salmon fry no longer occurs due to predation by introduced largemouth bass (*Micropterus salmoides*) (Daily et al. 1999). Tabor et al. (2000) observed that introduced largemouth and smallmouth bass eat out-migrating salmon, including juvenile chinook salmon, as they pass through the Lake Washington Ship Canal in Seattle, Washington. From April through July, juvenile chinook salmon constituted about 50% of the stomach contents of smallmouth bass in the Ship Canal. As many as 100,000 juvenile chinook salmon, some of which are hatchery fish, may be consumed in the Ship Canal during the 90 day out-migration period, which may pose a significant threat to juvenile chinook salmon migrating from the Lake Washington system (City of Bellevue 2002). By comparison, there is no documented literature which shows that escaped Atlantic salmon are a significant predator of juvenile native salmonids in the Pacific Northwest. Of the over 1,000 feral Atlantic salmon examined to date in Alaska and British Columbia, only one was found to have consumed a Pacific salmon juvenile (see Predation by Atlantic Salmon subsection above).

Table 6. Status of non-native fish introductions in the Pacific Northwest and their behavior relative to Pacific salmonids. (Data after Behnke 1992, Lever 1996, Daily et al. 1999, WDFW 1999, Wydoski and Whitney 1979, Dill and Cordone 1997.)

Non-native species	Naturalized in Washington	Naturalized in Oregon	Naturalized in California	Predator	Competitor	Hybridize
Atlantic salmon						
Non-native rainbow	X	X	X	X	X	X
Non-native cutthroat	X	X	X	X	X	X
Lahotan cutthroat	X					X
Westslope cutthroat	X		X		X	X
Brown trout	X	X	X	X	X	X
Brook trout	X	X	X	X	X	X
Lake trout	X	X	X	X		X
American shad	X	X	X		X	
Threadfin shad			X			
Lake whitefish	X					
Arctic grayling	X		X			
Grass pickerel	X			X		
Northern pike	X		X	X		
Striped bass		X	X	X		
White bass			X			
Common carp	X	X	X		X	
Grass carp	X		X			
Tench	X		X			
Brown bullhead	X	X	X	X	X	
Black bullhead	X	X	X	X	X	
Yellow bullhead	X	X	X	X	X	
Flathead catfish	X		X	X	X	
Blue catfish	X			X	X	
Channel catfish	X	X	X	X	X	
White catfish		X	X	X	X	
Largemouth bass	X	X	X	X	X	
Smallmouth bass	X	X	X	X	X	
Warmouth bass	X	X	X	X	X	
Rock bass	X			X	X	
Redeye bass			X			
Northern spotted bass			X			
Alabama spotted bass			X			
Black crappie	X	X	X	X	X	
White crappie	X	X	X	X	X	
Green sunfish	X	X	X	X	X	
Bluegill	X	X	X	X	X	
Pumpkinseed	X	X	X	X	X	
Redear sunfish			X			
Bigscale logperch			X			
Yellow perch	X	X	X	X	X	
Walleye	X	X	X	X	X	

MANAGEMENT OF NONINDIGENOUS FISH IN WASHINGTON

In 1997 and 1999, in response to the escape of a large number of net-pen Atlantic salmon, WDFW suspended fishing regulations concerning size and bag limits for these fish. Licensed anglers fishing in open management zones were permitted to keep all the Atlantic salmon they could catch, of whatever size (WDFW 1997, 1999, 2002). The suspension of fishing regulations for an introduced, non-native species in waters inhabited by native salmonids is a management strategy that has been used before in Washington. For example, freshwater angling regulations for non-native brook trout were recently relaxed to increase harvest of this species, and regulations for non-native shad (*Alosa sapidissima*), perch, crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), and carp (*Cyprinus carpio*) have long since been dismissed entirely. Harvest policies of this type would likely reduce, but not eliminate, known impacts of non-native species on listed salmonids in the two Puget Sound ESUs that are the subject of this review. However, regulations currently applied to some non-native species (see next paragraph), such as those that encourage their sustained natural reproduction, may not reduce but actually increase the impacts of non-native species on listed salmonids.

Catch limits and closed seasons for non-native salmonids (such as brown trout, lake trout, landlocked Atlantic salmon, California-strain rainbow trout, and grayling) in watersheds within the Puget Sound and Hood Canal ESUs for chinook salmon and summer-run chum have given these species many of the same statutory protections given to native salmonids. Several non-native warm-water species known to prey on salmonid juveniles in Washington (such as smallmouth and largemouth bass, walleye, and channel catfish [*Ictalurus punctatus*]) are currently managed for sustained natural reproduction through regulations that limit the take of large individuals, which have the greatest reproductive potential (WDFW 2002). Although walleye and channel catfish are found primarily in the Columbia River, largemouth and smallmouth bass populations in dozens of Puget Sound area tributary systems are regulated to insure their continued survival. As shown in this review, Atlantic salmon have far less potential for adverse impacts on Puget Sound chinook salmon and Hood Canal summer-run chum salmon than the non-native species noted here. Extending management policies currently applied to escaped Atlantic salmon (no catch or size limits) to all non-native fish in Puget Sound would be the most effective method to decrease adverse impacts by nonindigenous fish on listed native Puget Sound salmonids. However, this is probably not feasible due to the tremendous economic and social value of non-native game fish species in local sport fisheries. Zook (1998) estimated that recreational angling for non-native game fish, including California-strain rainbow trout, contributed about $735 million annually to the economy in Washington State.

SCALE OF ARTIFICIAL PROPAGATION OF PACIFIC SALMON IN THE PACIFIC NORTHWEST

Virtually all opinions about the negative biological impacts of escaped Atlantic salmon on native salmon in the Pacific Northwest are hypothetical, and have not been observed or documented in this region. They appear to be strongly associated with the belief that artificially propagated salmon, including Atlantic salmon, are bigger, stronger, and more vigorous than wild Pacific salmon. Although this opinion has been generally disproved, many studies and reviews, among them WDF et al. (1993) and NMFS' ESA-related status reviews (Weitkamp et al. 1995, Busby et al. 1996, Hard et al. 1996, Gustafson et al. 1997, Johnson et al. 1997, 1999, Myers et al. 1998a), have shown that adverse impacts from hatchery stocks of Pacific salmon can occur if and when hatchery fish comprise a significant portion of the total population. Therefore, it will be instructive to compare the numbers of artificially propagated Pacific salmon released each year to the number of Atlantic salmon estimated to escape each year. Such comparison will provide a perspective for evaluating which species or types of culture actually present the greatest risks to wild Pacific salmon, keeping in mind that recent changes in hatcheries strategies in the Pacific Northwest have been initiated to reduce or eliminate impacts sometimes associated with releases of artificially propagated Pacific salmon.

Number of Artificially Propagated Pacific Salmon Released Each Year

Mahnken et al. (1998) reported that several billion Pacific salmon were released from freshwater hatcheries and marine net-pens in North America each year, with most of these fish (about 1.4 billion per year) released from hatcheries in Alaska (McNair 1997, 1998, 1999) (see Table 5), although Washington, Oregon, Idaho, and California have more salmon hatcheries.

Pacific salmon are released from hatcheries with the understanding that to survive, they must compete for food and habitat in common with native wild salmon. Until recently the capacity of the ocean pastures were thought to be limitless. However, recent investigations by Heard (1998), Cooney and Brodeur (1998), and Beamish et al. (2000), among others, show that food availability in the ocean fluctuates over time and might be limiting salmon abundance. Bisbal and McConnaha (1998) proposed that fishery managers planning to release large numbers of fish from hatcheries should take these fluctuations into account. Given the enormous numbers of Pacific salmonids released each year into Pacific Ocean ecosystems, including Puget Sound, the relatively few domesticated Atlantic salmon that escape could never pose a corresponding competitive threat to native Pacific salmon for forage or habitat.

Survival of Artificially Propagated Pacific Salmon

The success of a hatchery or net-pen facility, which in large part determines the degree to which hatchery fish potentially impact wild fish, is largely influenced by how well fish survive in

the wild after release. Some hatchery programs are very successful at producing fish. Johnson et al. (1997) noted that hatcheries in Alaska, through extremely efficient early rearing strategies, produced prodigious numbers of adult chum and pink salmon, two species which normally have juvenile to adult survival rates of less than 0.5%. The Hidden Falls Hatchery in southeast Alaska has frequently experienced survivals of 3–8% with chum salmon (Bachen 1994), resulting in this single facility producing more than 22% of all the chum salmon, wild and hatchery, caught in the fisheries of southeast Alaska (Johnson et al. 1997). McNair (1998) reported that 93.6% of all pink salmon caught in Prince William Sound in 1997 were artificially propagated, and that for all salmon harvested in common property fisheries throughout Alaska that year, 22% of the coho salmon, 30% of the pink salmon, and 65% of the chum salmon originated in hatcheries. Overall, hatcheries contributed 26% of all salmon harvested in Alaska in 1997 (McNair 1998). This percentage increased to 34% in 2000 (McNair 2001). In Washington, WDFW (2000) estimated that hatcheries provide about 75% of all coho and chinook salmon harvested, as well as 88% of all steelhead harvested. Since West Coast hatcheries put enough artificially propagated salmon into the natural environments to produce a significant proportion of the harvest in Alaska and the overwhelming proportion of the harvest in Washington, including all ESUs in Puget Sound and Hood Canal, it is not possible that the competition for natural resources from present levels of escaped Atlantic salmon could be noticeable. Therefore, expressions of concern regarding competition for food from relatively small numbers of escaped Atlantic salmon (Carrel 1998, ADF&G 1999, 2002, PSGA 2000, Suzuki 2001) appear to be focused on the wrong species. The potential for adverse impacts on wild Pacific salmon through competition for natural resources is clearly greater from the enormous number of hatchery Pacific salmon in natural environments than from the relatively small number of domesticated Atlantic salmon that occasionally escape.

Comparison of Numbers of Artificially Propagated Atlantic Salmon and Pacific Salmon in the Pacific Northwest

The majority of Atlantic salmon escapes in Washington have occurred in Puget Sound. However, the number of escaped fish is extremely low compared with the number of Pacific salmon intentionally introduced into the Puget Sound and Hood Canal ESUs for chinook and summer-run chum salmon. The total number of hatchery chinook, coho, and chum salmon released into Puget Sound tributaries by various fisheries agencies between 1980 and 1992 exceeded 2.2 billion fish (NRC 1995, 1996). Although data are not yet available through the year 2001, it is predictably over 3 billion by now. For illustrative purposes, if all the Atlantic salmon which have escaped into Puget Sound since 1980 (assume 1 million) were represented on a bar graph by a bar about 3 cm high, the total number of Pacific salmon released into Puget Sound and its river basins since 1980 would be depicted on the same graph by a bar about 76 m high. Comparison with the 13.5 billion hatchery fish released into Alaskan waters since 1990 (McKean 1991, McNair 1995, 1996, 1997, 1998, 1999, 2000, 2001, Holland and McKean 1992, McNair and Holland 1993, 1994) is even more dramatic, and would require a bar almost 400 m high.

The adverse ecological and genetic interactions sometimes associated with abundant releases of hatchery-reared Pacific salmon are well-documented and clearly present a greater risk for native salmonids in Puget Sound and Hood Canal than escaped Atlantic salmon, although this

is not meant to imply that the risk from hatchery stocks of Pacific salmon is severe under present, modified hatchery policies. However, no evidence in the literature pertaining to Atlantic salmon introductions was found that suggests that current levels of production would pose a manifest threat to the Puget Sound chinook salmon ESU or the Hood Canal summer-run chum salmon ESU.

POTENTIAL IMPACT OF SUCCESSFULLY REPRODUCING ATLANTIC SALMON IN PUGET SOUND

Number of Naturally Produced Juvenile Atlantic Salmon that Would Approximate Impacts from Pacific Salmon Hatchery Programs in Puget Sound

It would take a very large number of successfully spawning, escaped Atlantic salmon to produce enough progeny to approach the number of hatchery Pacific salmon juveniles introduced into streams in the Puget Sound ESU. For example, NRC (1995, 1996) reported that about 18 million pre-smolt coho salmon were released into Puget Sound tributaries each year between 1980 and 1992. Since then, the number of unsmolted coho salmon has been reduced by over half, due to changes in hatchery strategies (FPC 1999). Nonetheless, to survive in freshwater habitats, artificially propagated salmon fry planted into local rivers compete with native salmon for food and rearing space for up to 18 months. Using typical wild coho salmon life-history data (ODFW 1982), such as egg to smolt survival levels of 10% and a fecundity of 4,000 eggs per female, it would take about 46,000 mature, successful Atlantic salmon spawners (1:1 female:male ratio) to produce enough fry to equal the numbers of artificially propagated nonmigrant hatchery coho salmon planted in Puget Sound rivers every year. However, the likelihood of such an outcome is remote, given the well-documented negligible ability of introduced Atlantic salmon to prosper in habitats outside their native range.

Number of Naturally Produced Juvenile Atlantic Salmon that Would Approximate Impacts from Pacific Salmon Hatchery Programs in the Green River

On a more local scale, FPC (1999) reported that about 7,500,000 hatchery coho salmon fry were planted in the Green River between 1993 and 1996. To produce an equal number of Atlantic salmon juveniles, it would be necessary for over 9,000 mature Atlantic salmon adults to escape and spawn successfully in the Green River each year. However, Thomson and Candy (1998) reported fewer than 20 mature Atlantic salmon in all Washington river systems during 1997, although few streams were surveyed completely. As Puget Sound region stocks of farmed Atlantic salmon continue to be domesticated, there is little chance they will suddenly outperform native salmon in their natal streams. Best management practices for net-pen salmon farming continue to stress the importance of preventing escapes (BCSFA 1999), but any potential adverse impacts associated with escaped Atlantic salmon cannot begin to approach the potential impacts of fish released from Pacific salmon hatchery programs, even when recent beneficial changes in hatchery strategies are considered.

Number of Juvenile Atlantic Salmon Observed in the Pacific Northwest

Fewer than 25 naturally spawned juvenile Atlantic salmon were recovered during counts of salmon juveniles in the Tsitika River in British Columbia in 1998 (A. Thomson[12]). Although scale analysis confirmed that these fish were the progeny of naturally spawning adult Atlantic salmon (Volpe et al. 2000), it is not known whether these were first, second, or greater generation wild Atlantic salmon. During the same Tsitika River survey, Noakes (1999) noted that more than 10,000 juvenile Pacific salmonids were observed in the river. Therefore, the juvenile Atlantic salmon made up less than 1% of the juvenile salmonids in the river in 1998. Since 1998, 5 more juvenile Atlantic salmon have been observed in the Tsitika River (A. Thomson[12]). Over 90% of all naturally produced Atlantic salmon juveniles discovered to date were found in 1998 and 1999. Interestingly, naturally produced Atlantic salmon juveniles were never observed in the same streams in which juvenile Atlantic salmon hatchery escapees were found (Table 3).

It is possible that Atlantic salmon have been successfully spawning in the Pacific Northwest for the past 20 years and that this behavior has just recently been observed. Conversely, Atlantic salmon could be periodically introduced into local environments every so often via escaping adults without successfully colonizing new habitat, although naturally produced offspring may have been occasionally produced. In any event, no naturally produced Atlantic salmon have been observed in Washington rivers to date, although surveys specifically designed to find juvenile Atlantic salmon have not been conducted here, unlike the situation in British Columbia.

[12] A. Thomson, DFO Canada, Pacific Biological Station, Nanaimo, BC V9R 5K6. Pers. commun., April 16, 2001.

OTHER EVALUATIONS OF POTENTIAL RISKS FROM CULTURED ATLANTIC SALMON IN PUGET SOUND CHINOOK SALMON AND HOOD CANAL SUMMER-RUN CHUM SALMON ESUs

Washington State Pollution Control Hearings Board

In 1996, a consortium of organizations brought suit before the PCHB against the Washington State Department of Ecology (WDOE), WDFW, and Atlantic salmon farmers in Puget Sound. The suit (PCHB Nos. 96-257 through 96-268) challenged the issuance of National Pollutant Discharge Elimination System (NPDES) permits to the salmon farmers. The basis of the suit by the appellants was a series of allegations regarding conflict with other resources and perceived unacceptable environmental risks associated with the culture of Atlantic salmon, the effects of waste on the water column and benthic environment, and damage to other resources, including fish and shellfish.

Following months of testimony by experts, on May 27, 1997, the PCHB denied partial summary judgment to the appellants because of a genuine issue of material fact as to whether escaped Atlantic salmon "shall cause or tend to cause pollution" under State law, and whether they constitute "a manmade change to the biological integrity of State water" under federal law (PCHB 1997b). The PCHB found that, "the Permittees' facilities do not create unresolved conflicts with alternative uses of Puget Sound resources as contemplated by RCW 43.32C.030(2)(e). The existence of commercial salmon farms as permitted does not preclude other beneficial uses in Puget Sound, such as shellfish harvesting, commercial or sport fishing, navigation, or recreational boating. Likewise, the existence of the salmon farms does not operate to the exclusion of available resources, such as native salmon runs, sediment and water quality, or marine mammals. In short, salmon farming in Puget Sound does not present the citizens of the State of Washington with an 'either/or' choice with respect to other beneficial uses and important resources."

The Board issued its Final Order on the matter on November 30, 1998, (PCHB 1998) and found: "no evidence that Permittees' facilities have impacts that effectively exclude other beneficial uses of available resources of Puget Sound. The escapement of Atlantic salmon from Permittees' facilities absent large regular releases in the future does not pose an unacceptable risk to native Pacific salmon in terms of competition, predation, disease transmission, hybridization, or colonization." This decision by the PCHB was not substantially different from that of the authors of the *British Columbia Salmon Aquaculture Review* (EAO 1997), who concluded that salmon aquaculture as currently practiced in British Columbia did not pose unacceptable risks to the environment.

Washington Department of Fish and Wildlife Atlantic Salmon Management Perspective

Some fishery managers have expressed concerns that escaped Atlantic salmon may impact native fish stocks through "competition, predation, disease transfer, hybridization, and colonization" (summarized by Amos and Appleby 1999). In a review of the potential for adverse impacts on Pacific salmon from farmed Atlantic salmon, WDFW found there was no evidence that Atlantic salmon competed well against native species, or that they would prey on native species. Furthermore, WDFW recognized that diseases of Atlantic salmon in Puget Sound were the same as diseases of Pacific salmon, that the risk of Atlantic salmon hybridizing with native salmonids was low, and that colonization was an unlikely event (Amos and Appleby 1999).

NMFS Biological Status Reviews of West Coast Pacific Salmon Stocks

Since 1991 NMFS has published 15 biological status reviews as part of its obligation under ESA. These reviews are individual scientific compilations of the current status of all anadromous salmonid populations on the West Coast of the United States, excluding Alaska. These are generally regarded as the most complete scientific reviews of Pacific salmon abundance ever published. They form the basis for NMFS actions concerning ESA listing determinations, as well as the scientific basis for NMFS testimony for litigation and courtroom challenges to proposed and implemented listings under ESA.

In these reviews, teams of experienced Pacific salmon scientists, known as the NMFS BRTs for ESA Status Reviews, have identified many factors that have adverse effects on salmonids of the West Coast (Weitkamp et al. 1995, Busby et al. 1996, Hard et al. 1996, Gustafson et al. 1997, Johnson et al. 1997, 1999, Myers et al. 1998a). The potential biological impacts of artificially propagated Pacific salmon have consistently been identified as one of several primary factors impacting wild salmonids (Hard et al. 1992, Waples 1991). However, Atlantic salmon farms have not been identified as causing adverse effects on Pacific salmon in any of the status reviews conducted to date, which cover 55 separate ESUs for Pacific salmon species, nor have Atlantic salmon been suggested as a factor for decline of Puget Sound chinook salmon or Hood Canal summer-run chum salmon (NMFS 1996, 1998).

POTENTIAL IMPACTS OF SALMON FARMS IN PUGET SOUND ON ESSENTIAL FISH HABITAT

In addition to concerns about adverse impacts to native salmonids resulting from escapes of Atlantic salmon, conjecture has been raised that organic input to the EFH and over-water structures associated with salmon farming will have a significant negative effect on nearshore estuarine and marine habitats used by juvenile salmon in the Puget Sound chinook salmon ESU (Eglick 1990, McMather 1990). (There are no commercial salmon farms in the Hood Canal summer-run chum salmon ESU.) Apprehension about potential water column impacts, such as reduced dissolved oxygen (DO) levels and the stimulation of phytoplankton blooms, are most commonly expressed, as well as concerns about accumulation of organic and inorganic material and chemotherapeutants in the sediments under and in the vicinity of the salmon farms. These issues have been extensively evaluated over the last 15 years in Puget Sound and elsewhere. Therefore, only a brief review of the pertinent findings will be presented here.

Water Column Impacts

Dissolved nitrogen added to the water column by salmon farms is essentially not measurable more than 9 m away from the perimeter of the farm. Correspondingly, there was no measurable effect on phytoplankton production near salmon farms, even in countries with substantial development of salmon farms (Pease 1977, Weston 1986, Rensel 1988, Parametrix 1990). Salmon farms in Puget Sound had little to no effect on levels of DO in the water column immediately adjacent to the farms (Weston 1986, Brooks 1995).

Clam Bay, Washington, location of the NMFS Manchester Research Station since 1969, and also the location of one of the largest salmon farms in the world since 1972, may be used as an example of the type of effects on EFH water quality that can be expected from a well-sited, large fish farm. In 1979 the U.S. Environmental Protection Agency (EPA) Region X Water Quality Laboratory was constructed on the shore of Clam Bay next to the NMFS Manchester Research Station. During most of the 1980s, this laboratory used oyster larvae bioassays to determine the level of pollution in water samples taken from other areas in the Pacific Northwest. The EPA laboratory used water pumped from Clam Bay as the clean, control baseline water against which oyster larvae survival in polluted water was compared. The laboratory drew the control water less than 200 m from the salmon farm. If the salmon farm had adversely effected the ambient water quality, the EPA investigations would have been severely compromised. However, there are no reports that they were compromised. During the same period, a study investigating the best places in Puget Sound for mussel culture found that Clam Bay was a poor site for mussel culture as the waters there were “clear, deep blue,” and that “large blooms of phytoplankton to support fast growth are rarely found” (Skidmore and Chew 1985). The NMFS Manchester Research Station was involved in a plethora of important scientific studies with salmon during this period, all of which required the use of high quality seawater. Concurrent with the EPA and NMFS work and the mussel study, the commercial salmon farm in Clam Bay reared about 3 million fish per year. Claims that salmon farms will adversely affect EFH by polluting the water or stimulating blooms of phytoplankton have not been verified by numerous

scientific investigations conducted in Clam Bay during a period of intense salmon farming. It should be noted that the salmon farm site in Clam Bay does not meet current Washington State siting criteria, which require specific depths and tidal flows for salmon farm location (WDOE 1986). Because the salmon farm was in existence before siting criteria were developed, it was allowed to remain at its present site. However, the Clam Bay situation can be used to demonstrate that the salmon farm siting criteria used in Puget Sound since 1986 adequately protects the environment occupied by ESA-listed chinook and summer-run chum salmon.

Comparison to Benthic Impacts of Other Activities in the Pacific Northwest

Sewage Treatment Plants

Since the area beneath salmon farms is organically enriched by uneaten fish food and by fish feces, salmon farms have often been likened to sewage treatment plants (McMather 1990, Ellis 1996). However, this simile is not accurate, at least for salmon farms in Puget Sound, for several reasons. First, the organically enriched area beneath a salmon farm (Weston 1986, Mahnken 1993, Brooks 2000) is far less extensive than the area impacted by a sewage treatment plant (Brown et al. 1987, Taylor et al. 1998). Second, waste from a salmon farm does not contain the metals and industrial hydrocarbons associated with sewage wastes. Third, the time required for biological remediation at a fish farm site ranges from about five months to several years (Mahnken 1993, Brooks 2000), whereas the period for full remediation at a sewage outfall can easily be at least 10 years (Rosenberg 1976, Pearson and Rosenberg 1978, Shillabeer and Tapp 1989). And finally, demersal fish bearing tumors and lesions have not been observed nearby or associated with salmon farms in Puget Sound, unlike the situation near sewage treatment plants and other contaminated areas of Puget Sound, where diseased and cancerous fish are commonly observed (Myers et al. 1998b).

Fish Processing Plants

It has been estimated that salmon farms in Puget Sound produce about 0.7 kg of solid waste for each kg of fish produced (Weston 1986). At current levels of production, about 7300 t (P. Granger[2]), all Puget Sound salmon farms produce a cumulative total of about 5000 t of solid organic waste per year. By comparison, seafood processing plants discharge substantially more organic material onto the benthos. For example, individual seafood processing plants at numerous locations, mostly in Alaska, discharge 20,000 to 30,000 t of organic material per year into nearshore waters (NMFS 2001a). The waste pile at one plant was estimated to be 200 m in diameter and 7 m deep, and at another location, the waste pile covered 4.5 ha to a depth of 1 m (NMFS 2001a). The negative effects on the environment from large waste piles such as these would certainly be enormous compared to impacts associated with the relatively small amount of solid waste produced by Puget Sound salmon farms. However, NMFS (2001a) found that the discharges from seafood processing plants in Alaska "appear to be localized and would not be expected to adversely affect threatened or endangered species under NMFS jurisdiction."

Similarly, the markedly smaller organic discharges from Puget Sound salmon farms do not seem likely to adversely affect threatened salmonids in Puget Sound.

SCALE AND IMPACTS OF SIMILAR ACTIVITIES IN PUGET SOUND

Scale of Salmon Farms and Other Aquaculture

Salmon Farms

In 1986 there were 9 sites in Puget Sound where coho salmon or Atlantic salmon were raised commercially in net-pen facilities (Weston 1986). In addition, at that time there were 5 major and 8 minor noncommercial net-pen facilities used by WDFW, tribes, or sportsmen's clubs for delayed release of coho and chinook salmon. By 1990 there were 13 commercial sites, each limited to a total surface area of less than 0.8 ha (WDF 1990a). WRAC (1999) reported 6 companies with leases to sites in Washington in 1997. These included Domsea Farms Inc. (5 sites), Global Aqua USA Inc. (3 sites), Moore-Clark Co. (USA) Inc. (3 sites and a hatchery), Scan Am Farms (3 sites), Sea Farm Washington (3 sites), and British Petroleum (1 site).

In the last five years, there has been considerable restructuring in the salmon aquaculture industry worldwide, with some companies consolidating their position through merger or purchase of smaller companies. Consequently, much of the global industry is now dominated by a few international companies, although individual farms may still operate under the name of the registered leaseholder. In Washington 4 different companies now hold the leases to 12 licensed net-pen production sites, of which 9 licensed sites are in production. These are:

- Cypress Island Inc., which has 3 leases by Cypress Island outside Anacortes and 1 lease in Skagit Bay, and under Northwest Farms, 3 leases in Rich Passage, 1 in Port Angeles Harbor (formed by combining 2 previous leases), and 1 by Hartstene Island currently not in use.
- Sunpoint Systems, which has 1 lease in Rich Passage.
- Jamestown S'Klallum Tribe, which has 1 lease in Discovery Bay, but not in use.
- Ocean Spar Technologies, a sea-cage manufacturing company, which has 1 lease by Whiskey Creek near Port Angeles for research and development trials, but not in use.

In the State of Washington, statistics provided by the Washington State Department of Natural Resources (WDNR 2001) indicate there are 67.5 ha currently leased by companies for commercial salmon net-pens, a further 15.7 ha currently leased by the State, tribes, and private enterprises for net-pens used for the delayed release of native salmon, and 0.2 ha for herring net-pens. All these sites have a different limit for the water surface area leased (for anchorage and navigational protection) and the internal surface area for the net-pens in production. The 9 commercial sites currently operational in Puget Sound have a total of 53 ha under lease from the State (ranging from 0.8 to 9.7 ha in size), with a total of 8.7 ha permitted for internal pen structures for all Puget Sound salmon farms combined (range 1,951 m^2 to 15,793 m^2) (K. Bright[1]).

Oyster Farms

By comparison, other activities in Washington, such as other types of aquaculture and marinas, use habitats similar to those used by salmon farms in Puget Sound, but require substantially more space. For example, 585 ha of State-owned aquatic lands are leased for oyster farming, primarily in Willapa Bay (WDNR 2001).

Scale and Impacts of Marinas in Puget Sound

Scale of Marina Development

The surface area of Puget Sound covered by salmon farms is insignificant compared to the surface area covered by marinas. The total surface area actually covered by floating structures for all salmon farms in Puget Sound combined, about 8.7 ha of State-owned aquatic lands (WDNR 2001), is much less than the total surface area occupied by several of the larger marinas located on State-owned aquatic lands. All the above-water structures at salmon farms in Puget Sound would fit several times over inside each of several large Seattle-area marinas such as the Elliott Bay Marina, Shilshole Bay Marina, or Fisherman's Terminal (Port of Seattle 2001, Serdar and Cubbage 1996). The Shilshole Bay Marina alone covers 32.1 ha between the shoreline and breakwater, with about 3 ha of this area covered by over-water structures such as floats and vessels (T. Wheeler[13]). In addition, marinas are much more numerous than salmon farms in Puget Sound. Goodwin and Farrel (1991) published a directory of marinas and moorage facilities in the State and listed 379 facilities, about 150 of which were located in the marine waters of Puget Sound. Kitsap County, where most of the salmon farms in Puget Sound are located, had 26 facilities and more than 2,900 wet moorage slips. The 20 facilities in Kitsap County that completed the survey data offered a total of more than 6.4 km of float space to moor commercial and recreational boats. Because most marinas are adjacent to the shore and required some dredging to accommodate vessels, marinas have probably eliminated some areas which previously had been important nearshore habitat for juvenile chinook and summer-run chum salmon in Puget Sound, primarily eel grass beds (Healey 1991). By contrast, sites permitted for salmon farms are restricted to deeper waters to minimize impacts on benthic communities (WDOE 1986). Many marinas are protected by breakwaters which may inhibit free flow of water and may impede passage of nearshore migrating juvenile chinook and summer-run chum salmon, whereas free-flowing water is essential at a salmon farm.

Environmental Impacts of Marinas

Based upon past studies of marinas for WDF, Cardwell et al. (1980) considered reduced DO and increased water temperature the greatest potential threat to aquatic organisms in Puget Sound marinas. Potential threats such as fecal coliform bacterial contamination of shellfish, the leaching of antifouling paints, and the introduction of hydrocarbons via the exhausts of outboard motors were also identified (PSWQAT 2001, Cardwell et al. 1980). Subsequently, Cardwell and Koons (1981) documented several water quality perturbations within marinas and moorage

[13] T. Wheeler, Port of Seattle, P.O. Box 1209, Seattle, WA 98111. Pers. commun., November 6, 2001.

facilities in Puget Sound. Pollutant inputs included runoff from parking lots and storm drains, hydrocarbons from outboard motor exhaust, heavy metals from antifouling paints, and biocides such as creosote and pentachlorophenol in wood piling and docks. Indirect effects resulted from nocturnal reductions in DO due to respiration from blooms of phytoplankton and diurnal elevations in water temperature due to solar radiation. By contrast, salmon farms sited under current WDOE guidelines only slightly reduce DO, do not increase water temperature (Brooks 2000), and cold-blooded animals such as salmon do not produce fecal coliform bacteria (Geldreich and Clarke 1966). Although some salmon farms in Puget Sound use tarred nets similar to those used by commercial salmon fishermen, use of chemical antifoulants is restricted to the same compounds used on the hulls of the commercial and recreational salmon fleets. Most, if not all salmon farms in Puget Sound are constructed of either plastic or metal, while concrete and wood, sometimes treated, is the material of choice in most marinas. Since floating wooden structures associated with marinas cover much more surface acreage than salmon farms in Puget Sound, marinas would therefore constitute the primary source of wood preservation chemicals entering the marine environments of Puget Sound from floating structures.

An examination of sediments in and near a marina in Port Townsend, Washington, found that concentrations of copper, lead, zinc, butylated tins, polyaromatic hydrocarbons, and total organic carbon were elevated compared to sediments outside the marina. The zone of influence from the marina was observed to extend for a distance of about 150 m from the entrance (Crecelius et al. 1990), a somewhat greater distance than the zone of impact typically observed at Puget Sound fish farms (Capone et al. 1994).

In a similar study, also conducted in Port Townsend, concentration of metals in sediments under an Atlantic salmon farm were similar to those found at a control site at Point Wilson in the Strait of Juan de Fuca. However, for selenium, beryllium, silver, arsenic, lead, copper, and zinc, the concentrations of metals under the salmon pens were less than those found near a local marina (same marina as above) in Port Townsend (Johnson 1988). Another study in Puget Sound found that several marinas violated Washington State water temperature and oxygen concentrations standards, primarily due to poor flushing (Cardwell et al. 1980). Unlike marinas, which may introduce elevated levels of toxic chemicals to the environment, the primary impact from salmon farms consists of organic enrichment and, in some cases, short-term inputs of antibiotic residues, which also may occur at public fish-culture facilities. Since marinas occupy at least 100 times the total nearshore acreage of salmon farms in Puget Sound, they clearly are a greater source of pollutants introduced to EFH. However, although marinas are a significantly greater source of toxic chemicals than Atlantic salmon farms in Puget Sound, Crecelius et al. (1990) concluded that if the toxic input from all marinas in Puget Sound were similar to the marina in Port Townsend mentioned above, the total environmental impact would be very small: the annual influx of metals and other contaminants from marinas would be less than a 1% addition to the total input to the main Puget Sound Basin from other sources. Since the total inputs of chemical pollution to Puget Sound from salmon farms are much less than inputs from marinas, it is unlikely that the environmental impacts of salmon farms are equal to or greater than the small overall impacts noted for marinas.

ESSENTIAL FISH HABITAT AND THE MAGNUSON-STEVENS ACT

The potential impacts of public and private fish and shellfish on EFH have been addressed in Section 3.2.3, Appendix A, of the Essential Fish Habitat Provision of the amended Magnuson-Stevens Fishery Conservation and Management Act (Public Law 94-265). It is the responsibility of NMFS and the eight regional Fishery Management Councils, under authority of the Secretary of Commerce, to: describe and identify EFH in each fishery management plan, minimize to the extent practicable the adverse effects of fishing on EFH, and identify other potentially deleterious actions to encourage the conservation and enhancement of EFH. The potential adverse impacts to EFH on the West Coast can be found on the Pacific States Marine Fisheries Commission's Web site at: www.psmfc.org/efh.html.

Primary recommendations in Section 3.2.3, Appendix A, to minimize adverse fish culture impacts include following established guidelines and policies regarding disease prevention and the use of chemotherapeutics, and the use of stocks in hatcheries and salmon farms that will have little or no impact on native salmon. The farming of Atlantic salmon in Puget Sound currently adheres to the EFH guidelines.

REGULATORY STRUCTURE FOR COMMERCIAL AQUACULTURE ENTERPRISES IN WASHINGTON AND PUGET SOUND

Most of the extensive body of scientific information pertaining to salmon farming published in the last several decades has already been integrated into the regulatory processes of Washington State. This information has been incorporated into State regulations relating to farm fish escapes, antibiotic residues in sediments, accumulation of organic wastes on the seabed, importation of non-native and non-local species, and disease management. These and other important regulations and documents pertaining to private salmon farming include:

- Final programmatic Environmental Impact Statement for fish culture in floating net-pens (WDF 1990b)
- Recommended interim guidelines for the management of salmon net-pen culture in Puget Sound (WDOE 1986)
- Environmental effects of floating mariculture in Puget Sound (Weston 1986)
- Environment fate and effects of aquacultural antibacterials in Puget Sound (Weston et al. 1994)
- Disease control policies of Washington (NWIFC/WDF 1991)
- Disease control policies of the United States (USFWS 1984)
- Fish health manual of the WDFW (1996)
- Marine finfish aquaculture escape prevention reporting and recapture plan (WAC 220-76-100 to WAC 220-76-160)

The policies and regulations (and their enforcement) for aquaculture introductions in Washington State and British Columbia were reviewed and summarized in detail by Elston (1997) in a study of pathways and management of marine nonindigenous species into the shared waters of British Columbia and Washington. Shellfish and finfish aquaculture had been identified as one of six potential pathways for nonindigenous species introductions for the study, and in his final report to the Puget Sound Water Quality Authority, the EPA, and the DFO Canada, he stated that the adequacy of information available to assess the relative risks of introductions through aquaculture was good, because for more than a decade, Washington State and British Columbia have had in place state/provincial and federal procedures specific to aquaculture. He noted that intentional introduction of fish and shellfish species was now far more restricted than in the past, and that technology could assist further in reducing the risk from exotic species introductions by, for example, culturing only strains of sterile organisms. Elston (1997) concluded that the risk of introductions from aquaculture was well-defined, the industry was highly regulated, and active processes were underway for continuous review of aquaculture activities as they involved nonindigenous species.

Agencies Regulating Salmon Farming in Washington

State of Washington Agencies

Traditionally, the policy of the State of Washington has been supportive of aquaculture. The State was one of the first to recognize that aquaculture was a form of agriculture and enacted legislation in 1985 that designated the Washington State Department of Agriculture (WSDA) as the lead agency, with WDF (now WDFW) responsible for regulations pertaining to disease control and prevention. Recently, Second Substitute House Bill 1499 gives WDFW the authority to require all fish farms in Washington to prevent, report, and recapture escaped fish. The current policy of the State fosters the commercial and recreational use of the aquatic environment for production of food, fiber, income, and public enjoyment from State-owned aquatic lands, and identifies aquaculture among legitimate uses. In its policy implementation manual for the use of the State's aquatic resources (WDNR 2000), shellfish and finfish aquaculture is specifically designated as an aquatic land use of State-wide value. The WDNR generally encourages this use and it takes precedence over other water-dependent uses that have only local interest values. While commenting on the possible environmental impact on aquaculture by surrounding activities and vice versa in a discussion on net-pens and floating rafts, the manual states again that aquaculture remains a favored use of State-owned aquatic lands. WDNR (1999) recently published a technical report on the potential for offshore finfish aquaculture in the State.

Amos and Appleby (1999) summarized the roles and responsibilities of the regulatory authorities in the State of Washington with regard to the management of salmon farming in State waters, and particularly Atlantic salmon farming. Their summary forms the basis of the following overview of the regulatory structure for commercial farms producing either Pacific or Atlantic salmon.

Washington Department of Fish and Wildlife

WDFW has management and regulatory authority over all free-ranging fish in the State. The authority of WDFW over commercial fish culture in State waters is restricted to disease control, prevention of escapes, and protection of wildlife in general. Within this authority:

- The Fin Fish Import and Transfer Permit (WAC 220-77-030) assures that diseases, pests, and predators are not introduced or transferred. In addition, under a legal settlement, WDFW is required to kill and conduct biological examination of any Atlantic salmon encountered by agency staff.
- Regulation of Marine Fin Fish Aquaculture (WAC 220-76-110 to WAC 220-76-160) gives WDFW authority over fish that have escaped from a salmon farm.
- Hydraulic Project Approval (RCW 75.20.100, WAC 220-120), or HPA, assures that all construction projects ensure protection of wildlife and habitats. However, the authority of WDFW to require HPAs of aquaculture workers at their sites is not clear.

Washington State Department of Ecology

WDFW, in association with WDOE and WDNR, provides guidance to State and local agencies siting farms to avoid adverse impacts on the environment. In association with WSDA, it develops disease control regulations with regard to human health and safety.

WDOE has regulatory authority over discharges of pollutants into State waters for the protection, preservation, and enhancement of the environment. Within this authority:

- The National Pollution Discharge Elimination System Permit (40 CFR 122.21), or NPDES, assures compliance with state and federal water quality laws.
- The Water Discharge Permit (RCW 90.48) assures that discharges and wastes do not adversely affect water quality and standards.

Under the Clean Water Act and the Water Pollution Control Act, WDOE can take regulatory action against net-pen operators who allow Atlantic salmon to escape. This follows the determination by the PCHB that escaped Atlantic salmon are "pollutants," primarily because they escaped from a point source (PCHB 1998), the fish themselves constituted biological material, and are a species not native to Puget Sound. The PCHB also adjudicates appeals over permits issued by WDOE. In association with WDFW and WDNR, WDOE provides guidance to State and local agencies on siting farms to avoid adverse impacts on the environment.

Washington State Department of Natural Resources

WDNR has regulatory authority over State-owned aquatic lands, including all bedlands of Puget Sound, navigable rivers, lakes, and other waters. The authority also extends over lands covered and exposed by the tide, and most shores of navigable lakes and other fresh waters. Within this authority, the Aquatic Lands Lease (RCW 79.90-79.96), or ALL, assures that all uses of the land and the proposed facilities are as specified. WDNR, in association with WDFW and WDOE, provides guidance to State and local agencies on siting farms to avoid adverse impacts on the environment.

Washington State Department of Agriculture

WSDA is responsible for assuring the safety of the State's food supply, providing protection from diseases and pests, and facilitating movement of agriculture products in domestic and international markets. With WDFW it jointly develops disease control regulations with regard to human health and safety.

Local counties in Washington State act as lead agencies for applying the environmental policies of the State and the management of their respective county shorelines. Among relevant authorities:

- The State Environmental Policy Act (RCW 43.21C, WAC 197-11), or SEPA, assures consideration of social and environmental impacts of proposed actions.
- The Shoreline Management Act (RCW 90.58), or SMA, assures appropriate and orderly development of State shorelines, management of their uses, and preservation of their natural character.

Federal Agencies

A number of federal agencies (NMFS, U.S. Army Corps of Engineers, USFWS, U.S. Coast Guard, and EPA), together with respective State agencies (WDFW, WDOE, WDNR, WSDA), have management and regulatory authority over the use of all waters by the public.

NMFS administers the ESA for anadromous salmonids, including authorizing Section 10 Exception Permits, which assures protection of public interests, including navigation, water safety, and water quality. In collaboration with USFWS and WDNR, NMFS permits the use of predator control methods (nonlethal) for birds and mammals in accordance with permit restrictions.

The FDA is responsible for the protection of consumers by enforcing the Federal Food, Drug, and Cosmetic Act, and several related public health laws. It is also responsible for the safety of feed and drugs for pets and farm animals. Salmon and trout farmers are restricted to the use and conditions of veterinary medicines, drugs, growth enhancers, and other chemical supplements licensed by the FDA.

The Treaty Tribes of the State of Washington co-manage fisheries resources in the State with WDFW and have input into finfish culture regulations in common with WDFW.

The Regulatory Structure for Public and Tribal Hatcheries in Washington

Public and tribal hatcheries producing Pacific salmon (and other fish) in Washington State must conform to the same general directives that regulate commercial hatcheries and farms (see WDFW subsection above). These regulations, as described, are concerned with protection of the environment or the health and safety of other plants and animals, including human consumers. However, since 1994 when a number of Pacific salmonid species in the region were listed for protection under the ESA, there have been some differences in regulations for public and tribal hatcheries that rear federally listed salmonids. Generally, the production of listed salmon populations in public and tribal hatcheries is now restricted to recovery purposes only, and not to provide fish for subsequent commercial or recreational harvest.

As part of this approach, NMFS (2001b) has been working with management agencies in the region to develop Hatchery and Genetic Management Plans. The HGMP procedure provides a thorough description of each hatchery operation, including the facilities used, methods employed to propagate and release fish, and measures of performance. There are also sections dealing with the status of listed stocks that may be affected by the plan, anticipated listed-fish "take" levels, and a description of measures to minimize risk to listed fish. However, once the HGMP is completed, accepted, and followed, hatchery managers are assured that their activities are all in compliance with ESA and no further permitting is required.

CONCLUSIONS REGARDING POTENTIAL IMPACTS OF ATLANTIC SALMON CULTURE IN PUGET SOUND

These conclusions regarding the potential impacts of Atlantic salmon culture on the Puget Sound chinook salmon and Hood Canal summer-run chum salmon ESUs are based on three important assumptions. The first assumption is that the salmon farming industry in Puget Sound remains approximately the same size as currently or in the recent past. A significant expansion of the industry may increase risks and would require a reconsideration of some of the potential impacts discussed in this review. The second assumption is that salmon farms in Puget Sound continue to rear only Atlantic salmon. Should the local industry shift production to coho or chinook salmon or to steelhead, the risks for hybridization, dilution of the gene pool, colonization, and competition for natural resources with wild salmonids will be greater than they are now with Atlantic salmon culture. Third, these conclusions assume that Atlantic salmon farmers in Washington continue to use only stocks presently in culture and that no new Atlantic salmon stocks are brought into the State.

Based on these assumptions, this review draws the following risk assessment conclusions: It finds no risk for one parameter, low risk for several parameters, little risk for other parameters, and no parameters for which the potential impacts from Atlantic salmon farms in Puget Sound are considered to be serious or even moderate. In particular:

1. There is little risk that Atlantic salmon which escape from net-pen farms will hybridize with Pacific salmon or dilute the native gene pool. Atlantic salmon x Pacific salmon hybrids are not observed in nature, whether for introduced Atlantic salmon in western North America or for North American salmonids introduced to Europe and the other continents. By comparison, successful interspecific and intraspecific hybridization between North American salmonids has been regularly recorded.

2. At present, there is no risk of adverse genetic interaction between transgenic farm fish and wild salmon in Puget Sound, as there are no transgenic salmon being commercially cultured in Washington and no plans to raise them here in the future.

3. There is little risk that Atlantic salmon will colonize habitats in the Puget Sound chinook salmon and Hood Canal summer-run chum salmon ESUs. Atlantic salmon of various sizes occasionally escape into the waters of Puget Sound. Deliberate releases of Atlantic salmon have failed to establish local self-sustaining populations anywhere in the Northern Hemisphere outside their native range. Monitoring programs in British Columbia find naturally produced juveniles from time to time, but naturally produced adults have not been observed.

4. There is a low risk that the presence of salmon farms will increase the incidences of disease among wild fish. The specific diseases and their prevalence in Atlantic salmon stocks cultured in net-pens in Puget Sound are no different than those of the more numerous cultured stocks of Pacific salmon in hatcheries, which in turn have not been shown to have a high risk for infecting wild salmonids. All Pacific and Atlantic salmon stocks currently cultured in Washington are inspected annually for bacterial and viral pathogens, and the movement of fish from place to place is regulated by permit.

5. There is little risk that existing stocks of Atlantic salmon will be a vector for the introduction of an exotic pathogen into Washington State. Movements of fish into and within Pacific Northwest states are well-regulated, including the requirement for disease-free certification. No Atlantic salmon stocks have been transferred into Washington State since 1991.

6. There is little risk that the development of antibiotic-resistant bacteria in net-pen salmon farms or Atlantic salmon freshwater hatcheries will impact native salmonids. All drugs used in Atlantic and Pacific salmon hatcheries are safe and efficacious and approved by the FDA. Drug resistant bacteria have been commonly observed in fish culture facilities in Washington State for over 40 years and no resulting adverse impacts on wild salmonids have been reported.

7. There is little risk that escaped Atlantic salmon or their progeny will become an introduced non-native species that will be a predator of indigenous species. Analyses of the stomachs of recovered farm Atlantic salmon and of the few naturally produced juveniles caught in the wild have shown that only a few juvenile Pacific salmon have been eaten by Atlantic salmon. Other introduced non-native species are credited with consuming hundreds of thousands of juvenile salmon in, for example, one reservoir of the Columbia River. These non-native predators have been deliberately or accidentally introduced and are now managed for sustained natural reproduction to enhance recreational fisheries and contribute to sport fishing revenues.

8. The risk that escaped Atlantic salmon or their progeny will compete with native salmonids for natural forage is low. Few prey items of any sort have been found in the stomach contents of escaped Atlantic salmon of any size. The few natural prey items any escaped fish might consume is negligible compared with the food requirements of the tens of millions of hatchery-reared juvenile Pacific salmon released each year into Puget Sound and its tributaries.

9. The risk of adverse impact to EFH is low because the salmon farming industry is well-regulated at local, state, and federal levels. Salmon farming impacts on EFH are no more harmful than impacts from marinas, which cover much more nearshore acreage in Puget Sound, and are less than impacts from Pacific Northwest seafood processing facilities.

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