Evaluating Alaska's Ocean-Ranching Salmon Hatcheries: *Biologic and Management Issues*

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EXECUTIVE SUMMARY

This review of the biologic and management issues surrounding ocean-ranching hatcheries summarizes both the documented and theoretical threats that these facilities pose to Alaska's wild salmon. It focuses on North Pacific Rim hatchery production and examines the topics of genetics, straying, ecological interactions between wild and hatchery fish, fish-culture practices, biological concerns associated with managing mixed wild and hatchery stock fisheries, questions of the ocean's carrying capacity, and global climatic regime shifts together with associated management implications.

Alaska's ocean-ranching salmon hatcheries operate amidst considerable uncertainty. Perhaps the most striking feature uncovered by this review was the many gaps in the scientific data from which one could fairly draw conclusions of the effects hatcheries may or may not have on wild salmon. Alaska has been successful in augmenting salmon harvest with hatchery-produced fish, but whether or not salmon biodiversity has been adequately protected in the process is unanswered. Data necessary to evaluate interactions between hatchery and wild salmon populations have not, in most cases, been collected. Better data are needed to bring consensus among scientists and managers on how to figure uncertainties into the management equations, such as ocean carrying capacity and genetic risk to wild fish from hatchery straying.

After more than 30 years of debate about the impact of hatchery fish on the genetic diversity of wild salmon populations, there is still no definitive answer to this concern (even given the increase in the body of knowledge). While it may be easy to identify potential risks that hatcheries pose for natural populations, it is not so easy to predict whether deleterious effects have occurred or how serious the consequences may be. However, the documented high incidence of straying of hatchery fish (especially pink and chum salmon in Prince William Sound and Southeast Alaska, respectively) suggests that large-scale ocean ranching has the potential to severely disrupt the extensive population genetic structure that exists among wild salmon populations—a structure that many biologists believe correlates to adaptive traits. To date, there is insufficient data from genetic studies monitoring wild stocks proximal to hatcheries to resolve such issues. But, if such impacts are of a significant magnitude, the operations of certain hatcheries may not be in line with the State of Alaska's Sustainable Salmon Fisheries, Finfish Genetics, and Salmon Escapement Goal Policies nor with its wild-stock priority.

The need to conserve genetic information is fundamental to salmon biodiversity. Both commercial fishing and hatchery production can adversely affect genetic diversity. Alaska's Finfish Genetics Policy recommends designation of hydrologic basins or geographic areas as gene preserves—perpetual repositories of genetic information for all plant and animal species inhabiting such areas. Currently, there are no officially recognized gene preserves in Alaska specifically established for salmon. The state's Finfish Genetics Policy came about as a result of concern that the development and operation of a hatchery system could have a detrimental impact on wild salmon populations. The policy has not been revised since 1985.

Management of a mixed-stock fishery is complex. Factoring hatchery fish into this management equation only makes a hard job more difficult. It is important not to overharvest small salmon populations that may contain unique adaptive traits (and genes). Given the number of streams in Alaska (and the corresponding number of salmon stocks), coupled with the size of the Alaska Department of Fish and Game's staff and budget, conducting the monitoring required to ensure that no wild salmon stocks are being negatively impacted by overfishing or invasion of hatchery strays is nearly impossible. In Prince William Sound alone, the Department currently monitors 150 to 200 of the approximate 800 streams for escapement. In order to monitor all 800, more staff and budget would be needed. The use of thermal marking is a significant advance in technology that enables a closer and more thorough monitoring of mixed-stock fisheries and consequently better protection of wild stocks. At present, there is inadequate information to provide for reliable and timely estimates of wild-stock escapements and run sizes that are needed to direct management of the mixed-stock fisheries, especially for those that harvest chum salmon in Southeast Alaska.

Competition for resources between hatchery and wild salmon stocks has become a significant concern. Based on a review of the literature and discussions with biologists, geneticists, and fishery managers, it is widely believed that extensive ocean ranching may pose a threat to the ocean's carrying capacity and the protection of salmon biodiversity. This may be the most important issue for assessing risks to wild salmon, especially for populations with comparatively small numbers of individuals, and it may be more significant than the risk of loss or change in genetic diversity due to hatchery practices. The potential for hatchery-bred salmon to displace wild fish in the ocean, coupled with the overall lack of knowledge about complex dynamics of the North Pacific ecosystem, suggests that it would be prudent to manage the hatcheries in Alaska conservatively, especially in years of lower ocean-productivity indices.

Fisheries management currently has little data on the effects of ocean variability on marine survival of salmonids even though salmon stocks clearly respond to shifts in climate. Ongoing scientific pursuits should help pinpoint which physical and biological processes lead to changes in salmon growth and survival so that, as the ocean enters a new climate regime, we are able to predict and account for changing trends of fish growth and survival due to marine variables.

With respect to fish-culture practices, Alaska's hatcheries are among the best in North America. The main reasons for this are both fortuitous and purposeful. By concentrating on pink and chum salmon, Alaska's ocean-ranching program has avoided many of the attenuated problems (e.g. domestication and ecological) with long-term rearing species like steelhead trout and coho salmon. Given the late date at which Alaska's ocean-ranching program was established, the state was able to benefit from mistakes made elsewhere. The program started on better footing by having genetic oversight of operations through fish transport permits, hatchery siting, egg takes, broodstock development, etc. Oversight of fish diseases by the state's pathology department has been exemplary and closely follows Alaska's Fish and Shellfish Health and Disease Control Policy.

Given the biologic and management questions of ocean ranching, prioritizing research objectives can help narrow existing information gaps. The State of Alaska has an extensive permitting procedure for starting a hatchery, thorough pathology guidelines, and an adequate genetics policy. However, once operating, hatcheries do not face stringent supervision, monitoring, or evaluation. As can be seen by perusing the reports or plans currently available, it is difficult if not impossible to gauge whether hatchery programs are impacting wild stocks.

Monitoring of hatchery practices is a duty and responsibility of each of the Regional Planning Teams established by the Alaska Department of Fish and Game. Judging from the type of reports they produce (e.g., annual hatchery management plans), their primary concern is development of hatchery-production plans and evaluating the resulting contribution to fisheries. Extensive documentation exists for egg takes, incubation, rearing, and broodstock, as well as for fisheries management for hatchery returns including common property fisheries, special harvest areas, cost recovery, and marking/tagging studies. While this is useful information, it is difficult to ascertain whether the Regional

Planning Teams perform any substantive review of hatchery operations as is specified in the description of planning team duties. For instance, there is virtually no information about whether the egg take reflects the run-timing characteristics of the stock, the degree to which adequate numbers of spawners are used for hatchery broodstock, how often a stock has been used as a brood source, straying rates, or the number and final destination of fish that escape the cost-recovery harvest. Some plans have information that addresses the protection of wild stocks, however, there is almost no information on how effective any of the proposed measures have been. As to whether a site for a hatchery is appropriate (one of the public benefit criteria), there is no published documentation addressing this point.

This report concludes that industrial-scale hatchery salmon production, which releases billions of smolts into the North Pacific Ocean, could be jeopardizing Alaska's wild salmon. Additionally, there are legitimate management questions as to whether hatchery operations in Alaska are in line with current Alaska Department of Fish and Game policies, including the Sustainable Salmon Fisheries Policy.

INTRODUCTION

Today there is much concern over the status and fate of wild salmon populations. Fueling this are recently published reports by several preeminent scientists questioning the degree to which human activities have impacted the overall biodiversity of wild salmon. In response, Trout Unlimited launched its Alaska Salmonid Biodiversity Program in Alaska in January 2000. Soon thereafter, the Program published a survey of its concerns about Alaska salmon and salmon fisheries (Konigsberg 2000). One concern focused on the future management and protection of wild salmon biodiversity and specifically identified Alaska's ocean-ranching program as a potential threat to wild salmon biodiversity. To further investigate this, Trout Unlimited contracted with the University of Alaska Anchorage's Environment and Natural Resources Institute (ENRI) in October 2000 to review and summarize information on both the documented and theoretical threats associated with ocean-ranching programs to Alaska's wild salmon populations.

This report is the result of that investigation. It begins with an overview of North Pacific Rim hatchery production and then reviews specific scientific and management issues associated with hatchery production. Topics addressed include straying and the potential genetic impacts of introgression and hybridization versus the demographic effects of displacement. Data germane to the ecological interactions between wild and hatchery fish are presented, such as density-dependent competition for resources, predation, and altered behaviors of hatchery-produced salmon compared to wild salmon. Marine concerns, such as understanding the ocean's carrying capacity and predicting global climatic regime shifts, are considered as well as management implications. Finally, it provides an in-depth look at Alaska hatchery management and fish-culture practices, policies, and the biologic concerns associated with managing mixed wild and hatchery stock fisheries. This report does not address the socioeconomic issues associated with the ocean-ranching industry.

Note that the terms *stock* and *population* are used interchangeably throughout this report as are the terms *ocean ranching* and *salmon ranching*. With the exception of sockeye salmon *(Oncorhynchus nerka)* aquaculture, where juvenile sockeye are released into natural freshwater environments for rearing, the preponderance of Alaska hatcheries are located adjacent to the sea and produce pink salmon *(Oncorhynchus gorbuscha)* and chum salmon *(Oncorhynchus keta)* that are released directly into marine waters. Rather than use the terms *enhancement* and *supplementation*, which have imprecise meanings, this report simply distinguishes between hatchery-produced and wild or naturally-produced salmon.

NORTH PACIFIC RIM HATCHERY PRODUCTION

Since 1991 Canada, Japan, Russia, and the United States have annually released 5 to 6 billion hatchery-reared salmon into the Pacific Ocean (Beamish, et al. 1997; North Pacific Anadromous Fish Commission [NPAFC] 1995). A brief overview of hatchery production of the North Pacific salmon fishery by major areas of production is presented below to help establish the scale of these activities. A more detailed section covering Alaska management, regulations, and policies is presented later in this report.

BRITISH COLUMBIA, CANADA

The joint federal/provincial Salmonid Enhancement Program (SEP) of Canada was initiated in 1977 with the long-term objective of doubling the catch of Pacific salmon *(Oncorhynchus spp.)*, steelhead trout *(Oncorhynchus mykiss)*, and sea-run cutthroat trout *(Oncorhynchus clarki)* by protecting, rehabilitating, and enhancing fish stocks throughout British Columbia. Projects were designed to restore depressed stocks through improved management and employment of various restoration and enhancement techniques. The methods used have included improvement of fish habitat, removal of barriers to fish migration, construction of both in-river spawning channels and groundwater side channels for spawning habitat, placement of cover to increase rearing habitat, enrichment of streams and lakes, stabilization of stream banks, and fish culture. Fish culture plays a major role in SEP. Its annual stocking programs are intended to accelerate recovery of severely depleted wild stocks and to sustain major sport and some commercial fisheries. Fish culture methods include hatcheries, spawning and rearing channels, and instream incubation boxes (Kelly et al. 1990).

Hatcheries built under SEP provide well over 10% of the total British Columbia catch of coho salmon *(Oncorhynchus kisutch)* and chinook salmon *(Oncorhynchus tshawytscha)*. SEP fish production in 1984 was over 375 million juveniles (including the six Pacific salmon species and cutthroat trout) from all enhancement techniques. Major production in 1984 was from 32 hatcheries, four spawning channels, and two side channel improvement projects. Over one-half of fish production in 1984 came from three facilities: the Big and Little Qualicum spawning channels and hatcheries and the Babine spawning channels. The Babine facility produces over 100 million sockeye salmon juveniles annually and the Big and Little Qualicum facilities produce over 80 million juveniles, most of which are chum salmon (Kelly et al. 1990).

British Columbia currently has 38 federal hatcheries, and there are also 150 public involvement projects ranging from classroom incubators to hatcheries producing about 2 million juveniles. Peak production from SEP facilities occurred in 1990 when just over 650 million fish were released including 66 million chinook, 189 million chum, 21 million coho, 283 million sockeye, and 88 million pink salmon. Since then there has been a declining trend, with significant reductions of released juvenile chum salmon into the rivers of the Georgia Basin. Approximately 429 million fish were released in 1998; chum (154 million) and sockeye (186 million) salmon were the most numerous (R. Cook, pers. comm.). Up to 80% of the juvenile coho salmon in southern British Columbia coastal waters have been attributed to enhancement projects (Noakes et al. 2000a).

JAPAN

Japan operates the most extensive ocean-ranching program in the world both in terms of the number of hatcheries and the number of juveniles released annually. There are 150 hatcheries on Hokkaido and 165 on Honshu (Heard 1996), most of which are operated by private fisherman cooperatives.

From the mid-1980s to the mid-1990s, over 2 billion juvenile salmon were released annually from these hatcheries. Most were chum salmon, and a little over 100 million pink and 10 million masu *(Oncorhynchus masu)* salmon were released as well. In 1995 Japanese hatcheries released just over 2 billion chum, 118 million pink, and 13 million masu salmon (NPAFC 1995).

All Japanese stocks of salmon except for masu are maintained by artificial propagation. For management purposes there is basically one stock of chum salmon, which is supported by an extensive hatchery program. Any adult fish returning in excess to those needed by Japanese hatcheries are generally harvested and not allowed to spawn naturally (Moberly and Lium 1977). Thus, any possible conflict between wild and hatchery chum salmon stocks in Japan is moot as the species exists there almost solely as a result of artificial fish culture.

SOUTH KOREA

South Korea has a small hatchery program that began in 1913. Hatchery-produced chum salmon are released in 12 streams on the east coast of South Korea. Between 1970 and 1995 the number of juvenile chum salmon released annually increased from 8 thousand to 16 million (Seong 1998).

RUSSIA

The first salmon hatcheries in Russia were built by the Soviets in the 1920s at Teplovka Lake (a tributary to Amur River) and at Lake Ushkovskoye (a tributary to Kamchatka River). The Japanese also built a number of salmon hatcheries in the late 1920s in the northern part of Sakhalin Island and in the Kurile Islands that came under Russian control following World War II. A total of 25 hatcheries were in operation by 1964. Subsequently, the more inefficient hatcheries were abandoned. There are currently 22 operating in the far east of Russia: 17 on Sakhalin Island, 4 on Amur River tributaries, and 1 on a Kamchatka River tributary. The number of juveniles released from these hatcheries between 1985 and 1990 was between 600 and 700 million; about 450 million were pink salmon and 200 million were chum salmon (Dushkina 1994). In 1995, approximately 478 million hatchery fish were released; almost all were pink and chum salmon along with a few million sockeye and coho salmon (NPAFC 1995). About 500 to 550 million Pacific salmon fry are released annually; about 52% are pink and 48% are chum (Radchenko 1998).

U.S. PACIFIC NORTHWEST

Development of salmon hatcheries in the U.S. Pacific Northwest began in the late nineteenth century. Hatcheries have played an increasingly prominent role in salmon supplementation and enhancement in the region ever since. Most public hatcheries were built to mitigate for extensive losses of natural habitat due to industrial development, urbanization, and especially to damming of major river systems like the Columbia. In the Columbia River Basin alone, for example, there are now nearly 100 hatcheries producing about 200 million juveniles each year (Flagg et al. 2000).

Chinook was the first salmon species to be artificially propagated in western North America; this occurred in 1872 on the McCloud River in California. More chinook salmon have been produced from hatcheries than any other species in the Pacific Northwest. Today, the Columbia River Basin is the center of chinook hatchery production, with approximately 27% of the world's chinook salmon being cultured there (Mahnken et al. 1998). Hatchery production of chinook salmon in Washington State began in 1895 at the Kalama (a Columbia River tributary) hatchery. Production grew to about 50 million released fish by the late 1930s. By the early 1980s, more than 300 million chinook salmon were being released from Pacific Northwest hatcheries.

Coho salmon are among the most successful of hatchery-cultivated species in the Pacific Northwest.

In the 1960s advances in feed, disease prevention, and better understanding of the early life-history culture requirements of coho salmon led to improved survival of hatchery fish. Increased reliance on hatchery coho salmon led to rapid expansion of production through the 1970s. In 1981 a record 198 million hatchery coho salmon were released from Pacific Northwest hatcheries. In the following years coho salmon production in the Pacific Northwest stabilized and then began to decline. By 1995 only 72 million coho were released from Pacific Northwest hatcheries (NPAFC 1995).

In 1995 approximately 470 million fish were released from hatcheries in four Pacific Northwest states: California, Idaho, Oregon, and Washington. About 64% of the hatchery fish in this region are produced in Washington, where hatchery enhancement has been an integral part of salmon management programs since the early 1900s. By 1976 there were 52 separate salmon enhancement projects operating statewide, 39 of which were hatcheries. The total 1976 enhancement effort resulted in release of over 151 million chinook, coho, chum, and pink salmon. By 1985 this program had grown to 111 projects statewide including 70 hatcheries. The total release for 1985 was over 365 million fish; over 99% of these were chinook, coho, and chum salmon (Kelly et al. 1990). In 1995 Washington hatcheries released just over 300 million fish: 159 million chinook, 57 million coho, 59 million chum, 16 million sockeye, and 11 million steelhead. In the same year Oregon released 80 million fish, California 67 million, and Idaho 17 million; most of these fish were chinook salmon (NPAFC 1995).

ALASKA

There was a flurry of private hatchery construction in Alaska during the early 1900s (primarily in Southeast, Prince William Sound, and Kodiak Island), but it was short-lived and with little apparent success. An amendment in 1900 to the Alaska Salmon Fisheries Act required any person, company, or corporation taking salmon for commercial purposes in Alaska waters to establish a hatchery (Roppel 1982). This amendment was poorly conceived and not stringently enforced. A number of canning companies did construct hatcheries, but they were poorly sited. Water was often of poor quality and quantity, and insufficient numbers of salmon returned to provide eggs for incubation. Two major company hatcheries were built in Southeast Alaska near Ketchikan: one at Boca de Quadra and the other at Heckman Lake. The latter was eventually enlarged to a capacity of 110 million eggs and at the time was the largest in the world (Roppel 1982). By 1936 all hatcheries in Alaska had closed.

Only one attempt was made to propagate salmon in Alaska between the 1930s and 1950s. It was an experimental pink salmon hatchery operated by the U.S. Fish and Wildlife Service (FWS) at Little Port Walter on south Baranof Island in Southeast Alaska. By then a complete reversal of management philosophy had taken place since the federal government first mandated artificial propagation. A policy of regulating the fisheries replaced that of artificial propagation and remained in effect in Alaska until the 1970s.

In the mid-1970s, commercial salmon harvests in Alaska reached near historic lows (20 to 25 million fish) compared with the very high salmon harvests of the 1930s (100 to 126 million fish). To counteract declining commercial salmon harvests, the state embarked on an ambitious salmon enhancement program. By 1988 the Alaska Department of Fish and Game (ADF&G) was operating 16 hatcheries throughout Alaska, which were annually producing more than 300 million juvenile salmon (Kelly et al. 1990). There are currently 2 state hatcheries, 27 private hatcheries, and 3 federal hatcheries operating in Alaska (Figure 1). The state hatcheries primarily produce salmonid species targeted for sport fisheries. Private hatchery corporations are permitted to operate salmon hatcheries and recoup their operational costs from the harvest of adult fish. Two of the federal hatcheries are generally used for

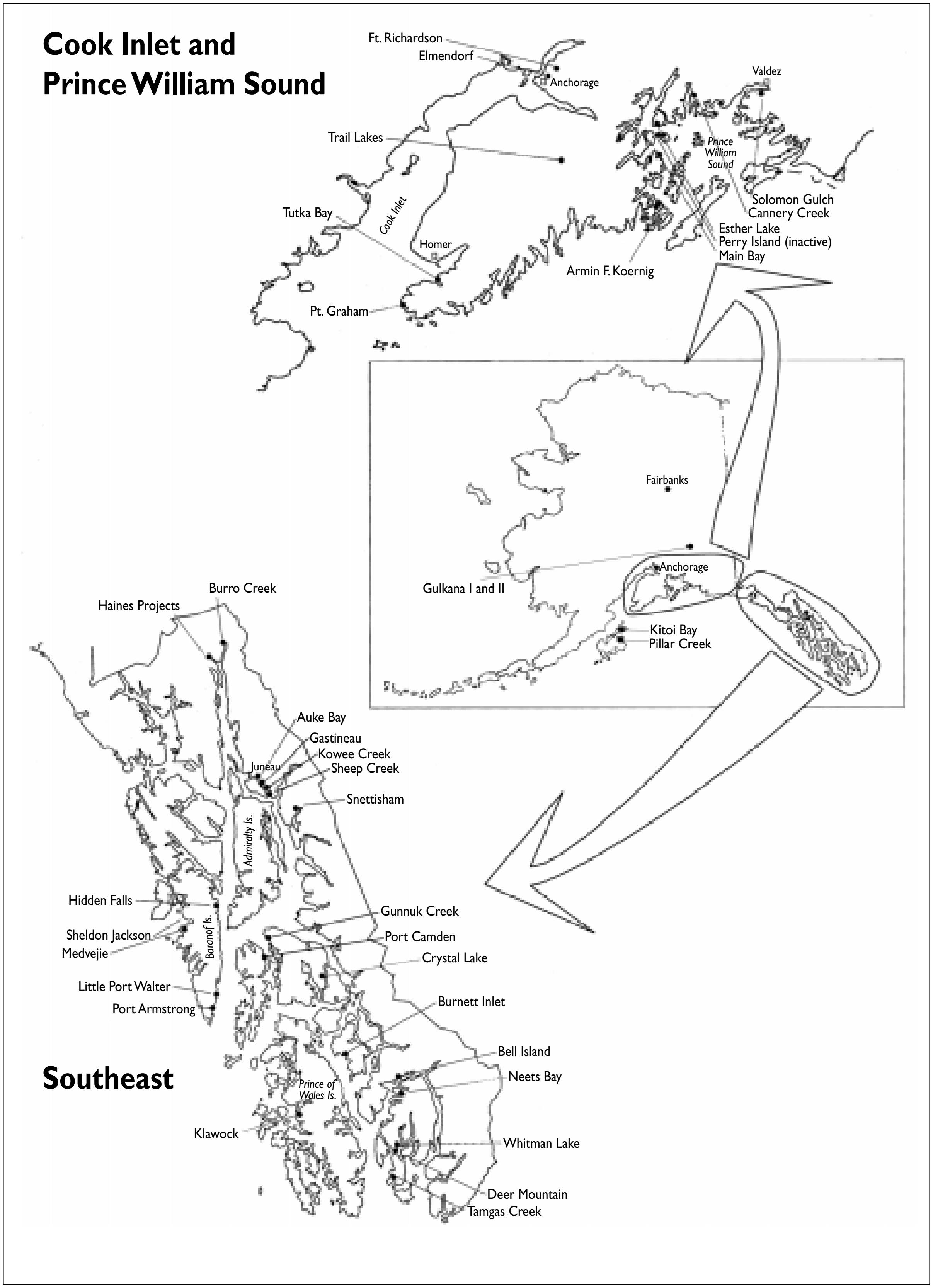

Figure 1. Hatchery locations in Alaska (McNair 2001).

research and the third is operated by the Metlakatla Indian Community with oversight by the U.S. Bureau of Indian Affairs (McNair 2001).

Pink and chum salmon make up the largest proportion of salmon produced in Alaska hatcheries and all come from private hatcheries. Prince William Sound and Southeast Alaska are the predominant regions in which hatchery production occurs. The Prince William Sound Aquaculture Corporation (PSWAC) operates the largest hatchery program in North America, releasing more than 400 million pink salmon each year. A little over 1.4 billion salmon were released from Alaska hatcheries in 2000, including nearly 600 million pinks in Prince William Sound and 385 million chums in Southeast. Production levels, in terms of egg take and releases, were at about this level throughout the 1990s (McNair 2001).

Hatchery-produced fish accounted for roughly 34% of the commercial common property harvest of salmon in 2000 (McNair 2001). Of these, 64% were chum; 42% were pink; 24% were coho; 4% were sockeye; and 19% were chinook (Table 1). Regionally, the relative hatchery contribution varied considerably from a high of nearly 80% of all salmon caught in Prince William Sound; 27% in Southeast; 10% in Cook Inlet; 32% in Kodiak; and 0% in the Chignik/Alaska Peninsula, Bristol Bay, and Arctic-Yukon-Kuskokwim areas (Table 1).

Table 1. Alaska commercial harvest of hatchery-produced fish in 2000.

	Percentage of Hatchery-Produced Fish in Commercial Harvest by Species					Percent of Total Harvest
Region	Chinook	Sockeye	Coho	Pink	Chum	
Southeast	30	16	20	1	73	27
Prince William Sound	0	34	65	82	88	80
Cook Inlet	8	15	3	2	0	10
Kodiak	0	16	40	37	26	32
Chignik/Alaska Peninsula	0	0	0	0	0	0
Bristol Bay	0	0	0	0	0	0
Arctic-Yukon-Kuskokwim	0	0	0	0	0	0
Statewide	*19*	*4*	*24*	*42*	*64*	*34*

BIOLOGIC ISSUES

Salmon hatchery operations have a long history and figure prominently in the fisheries programs of all of the states, provinces, and nations that have indigenous salmon populations. From the outset hatcheries have been surrounded by controversy, and their perceived benefits have waxed and waned periodically with changing public attitudes and with scientific advances in their operations. This section of the report focuses on the fundamental biologic issues associated with salmon hatcheries: genetics, homing/straying, ecological interactions, and limitations of the marine environment.

GENETICS

Populations of many fish species, particularly the salmonids, are characterized by complex structures of subpopulations representing historically developed population aggregates. Such aggregates share common spawning areas and times, yet maintain independent morphologic and behavioral characters and a high degree of genetic isolation. These population systems as a whole are characterized by long-term genetic stability due to reciprocal balance between dynamic factors, such as random genetic drift and migration and the stabilizing influence of natural selection (Ryman and Utter 1987). In other words, wild fish are adapted to their environment.

In general, declines in population productivity from habitat degradation and the nongenetic effects of overfishing have caused greater losses in productivity or population resilience than has genetic degradation. In the long term (e.g., over scores of generations), however, the harmful effects of accumulated genetic degradation within populations, loss of populations and the associated genetic diversity, and the accompanying hindrance of genetic adaptation to changing environmental conditions may equal or exceed the effects of habitat degradation and overfishing. The productivity of populations and their resilience to environmental change is a result of their genetic diversity (Busack and Currens 1995). Even a modest loss of adaptiveness for already degraded populations may cause extinction in the absence of rapid genetic recovery or favorable human intervention (Reisenbichler 1996). Furthermore, different salmonid populations use spawning, rearing, migratory, and oceanic resources in a variety of ways and can be expected to show a similar diversity in response to changing environmental conditions. This diversity therefore can be expected to buffer total productivity for the resource against periodic or unpredictable changes. Events of the recent past, in particular the eruption of Mount St. Helens and the strong El Niño events, remind us that, on an evolutionary time scale, sudden and drastic change is the rule rather than the exception. Loss of interpopulational diversity thus may lead to a reduction in overall productivity and a greater vulnerability to environmental change (Waples 1991).

Conservation of genetic resources and minimization of genetic risks from artificial propagation are emerging as a central fisheries management issue, and discussion about the role of genetics in fishery management has increased markedly since the 1970s. This can be seen by the numerous papers, symposia, and workshops on the topic (Allendorf and Waples 1996; Busack and Currens 1995; Campton 1995; Kelly et al. 1990; National Research Council 1996; Reisenbichler 1996; Reisenbichler and Rubin 1999; Scientific Review Team 1998; Sound Science Review Team 1999; Waples 1991, 1999).

Many lines of evidence suggest that hatchery production may adversely affect wild stocks. In the last 100 years, at least 27 species and 13 subspecies (40 taxa) of North American fish have become extinct. Among possible contributing factors that have been suggested to have led to such extinctions are effects of introduced species (27 of 40 taxa), hybridization (15 of 40 taxa), and overharvesting (6 of 40 taxa) (Williams et al. 1989). These results can be linked at various levels to hatchery operations or fish stockings, justifying widespread concern among many biologists about loss of genetic diversity. However, while it is easy to identify risks that hatcheries pose for natural populations, it is not so easy to predict whether deleterious effects will occur or, if they do, how serious the consequences will be (Waples 1999).

Stock or fish transfers among hatcheries or watersheds are well documented. This is especially true for salmon and steelhead in the Pacific Northwest where artificial gene flow and mixing of previously isolated gene pools have historically been standard practices. In the Columbia River, similar gene frequencies characterize several hatchery populations of chinook salmon (Utter et al. 1989). All hatchery summer steelhead for Washington State comes from just two stocks. Campton (1995) feels that any genetic effects caused by the importation of exogenous fish or gametes should not be considered caused by hatcheries per se, but rather an effect caused by a management process that used too few donor stocks.

The indefinite perpetuation of a population of fish is contingent upon maintenance of sufficient genetic diversity to allow adaptation to environmental changes (Thorpe et al. 1981). The extinction of a discrete population (or stock) is tantamount to a loss of genetic diversity within the species. The need for genetic material preservation is a universally accepted concept and is a fundamental purpose of the International Biosphere Reserve Program initiated by the United Nations. Virtually all biologists agree that a wide range of genetically diverse traits exists in naturally spawning wild stocks and that these are worth protecting (Kelly et al. 1990).

Genetic variability within and among fish populations constitutes the resource base that enables a species to survive and adapt to changing environmental conditions (Gharrett and Smoker 1993a, b; Gharrett et al. 1999b; Philipp et al. 1986). This variability is derived from a combination of many heritable traits developed and maintained through a complex set of long-term natural selective processes. Within a population, the number, frequency, and diversity of alleles present can measure genetic variability. Alleles are the variant forms of genes that are the basic units of heredity; the particular set of alleles present gives a stock its genetic uniqueness. In order to determine the extent to which two fish stocks differ genetically, scientists examine their genotypic and phenotypic structure. Genotypes can be studied qualitatively by molecular biologic techniques such as DNA sequencing, DNA and protein electrophoresis, and analyses with histochemical stains. Phenotypic differences between stocks can be teased apart to reveal the underlying genetic and environmental components by comparing phenotypes of individuals from different stocks raised in similar environments and measuring phenotypes of related individuals raised in contrasting environments. Both molecular/genotypic and phenotypic approaches can be used to estimate actual gene differences between stocks and the adaptive significance of those differences.

A great deal of protein electrophoretic information has been collected on salmon and on steelhead, rainbow, cutthroat, and brown trout *(Salmo trutta).* These data have been of value in a variety of ways and have enabled large genetically distinct groups of salmon to be identified. It is now known that three major, genetically distinct groups of sockeye salmon occur: one in Asia, one in Alaska to mid-British Columbia, and one ranging from mid-British Columbia south (Varnavskaya et al. 1994). These large genetically distinct groups may be comprised of many stocks. For example, a survey of electrophoretic diversity of 52 sockeye populations throughout Southeast Alaska identified three geographic groupings corresponding to the southern inside waters, the far southeastern islands (including Prince of Wales Island), and inside waters of northern and central Southeast Alaska (Wood et al.

1994). In British Columbia, five distinct groups of chum salmon, consisting of 83 separate stocks, have been identified (Kondzela et al. 1994).

A primary concern with hatcheries is their role in influencing genetic change (Utter 1998; Waples 1991). Indeed several studies have detected genetic differences between hatchery-produced and wild populations (Nielsen et al. 1994; Skaala et al. 1990, 1996). Unintended changes in allele frequencies or gene combinations in populations can potentially depress productivity (Busack and Currens 1995).

More recent studies have demonstrated that genetic changes may occur in farmed Atlantic salmon *(Salmo salar).* Altered allele frequencies and lowered heterozygosities in these fish relative to wild source populations have been recorded in Scotland and Ireland (Crozier 2000). An issue with farmed salmon involves the potential effects of interactions between them and the wild populations they come in contact with after escaping from sea pens. In Northern Ireland, the genetic status of a small wild population of Atlantic salmon was studied after an escape of farmed salmon from nearby sea cages led to interbreeding. Juvenile salmon in the first generation after interbreeding showed significant differences in the frequency and occurrence of some alleles. Observations of temporal change, the presence of a previously absent allele, and the genetic disequilibria reinforce a general conclusion that genetic change in the wild Atlantic salmon population reflects the influence of one or more episodes of escaped farmed salmon breeding in the river (Crozier 2000).

Direct genetic effects from hatchery production may occur if cultured fish hybridize with wild fish. Hybridization of different gene pools can theoretically have two important genetic consequences: loss of interpopulational genetic diversity and outbreeding depression (Waples 1991). According to Campton (1995), the natural spawning of hatchery fish in the habitat of wild populations can potentially lead to one or more of several outcomes: decreases in between-population genetic variation, decreases in within-population genetic variation, and decreases in fitness of the wild population (outbreeding depression).

Although hybridization typically increases the average gene diversity within the hybridizing populations, it also results in loss of gene diversity between populations (Waples 1991). With salmonids, the concern is that a variety of locally adapted stocks will be replaced with a smaller number of relatively homogeneous ones (Allendorf and Leary 1988). This process of consolidation tends to limit the evolutionary potential of the species as a whole (Waples 1991). The principal mechanisms leading to hybridization of hatchery and wild fish are (1) unintentional straying of hatchery fish into wild spawning grounds and (2) deliberate releases of hatchery fish to either increase population size or as conservation measures intended to save populations at risk or reintroduce native populations that have been eradicated. The reproductive effectiveness of hatchery-reared salmonids in the wild has been analyzed in several systems (Fleming and Petersson 2001; Garcia-Marin et al. 1999; Williams et al. 1996).

Decreases in fitness can occur when two genetically diverged or reproductively isolated populations interbreed (outbreeding depression). Extensive arguments have been made regarding the potential for outbreeding depression in Pacific salmon (Gharrett et al. 1999a). While many studies have demonstrated phenotypic differences between hatchery and wild fish, relatively few are clearly genetic. Examples of local adaptation appearing to have a genetic basis are rate of embryo development, homing ability, rheotactic swimming ability in emerging fry, outmigration timing of smolts, timing of returning adults, and variations of fecundity and egg size (Campton 1995; Hebert et al. 1998; McGregor et al. 1998; Smoker et al. 1998, 2000).

One often-mentioned negative effect from artificial propagation is a genetic change that reduces fitness for natural reproduction. Apparent loss of fitness in hatchery populations of resident trout has been demonstrated and widely accepted (Ryman and Utter 1987). However, this potential hazard has not been universally accepted as real or relevant to management of salmon. Skepticism stems from the anadromous life history of salmon. Culture of salmon involves rearing in captivity during freshwater stages and then release to use marine food supplies. Accordingly, measuring genetic changes and corresponding loss of fitness becomes complicated for populations experiencing natural conditions for much of their life cycle (Reisenbichler and Rubin 1999). Consequently, there is a reluctance to accept the argument that the genetic fitness of hatchery fish to produce viable fry declines substantially under natural conditions. There are also examples of hatchery fish successfully spawning in the wild like the chinook salmon in the Umatilla and Walla Walla tributaries to the Columbia River where they had been extirpated by dams, indicating that hatchery production is not necessarily correlated with a complete loss of fitness.

In Alaska, there exists a correlation in Prince William Sound of marine survival (one important component of fitness) in hatchery pink salmon and wild pink salmon. The high productivity estimated in both components suggests no measurable depression of saltwater fitness in either after more than ten generations of hatchery culture (W. Smoker, pers. comm.). However, Reisenbichler and Rubin (1999) argue that published information, along with studies in progress, collectively provide evidence that artificial propagation of steelhead trout, chinook and coho salmon, and probably other Pacific salmon results in significant genetic changes that lower fitness. At least eight studies have shown genetic differences between hatchery (ocean-ranched) and wild populations of Pacific salmon in behavioral or physiological traits that could reduce the fitness of hatchery fish (Reisenbichler and Rubin 1999). For example, development rate may change in response to novel water temperature regimes (Lannan 1980); time of spawning and growth rate may change due to either artificial or natural selection (Nickelson et al. 1986); and antagonistic behavior may increase (Swain and Riddle 1990), territorial behavior decrease (Norman 1987), and predator avoidance decrease (Berejikian 1995) in response to unnatural conditions in the hatchery.

Two published studies (Leider et al. 1990; Reisenbichler and McIntyre 1977) and three in progress (according to Reisenbichler and Rubin 1999) found the survival of naturally spawning hatchery fish was less than that for wild fish. The reproductive success of hatchery adults was lower than that of wild adults, and relative survival of hatchery fish consistently declined through successive life-history stages. These studies suggest the same conclusion: hatchery programs that rear steelhead trout or chinook salmon before release may genetically change the population and thereby reduce reproductive success when these fish spawn in natural systems (Reisenbichler and Rubin 1999). Reisenbichler and Rubin (1999) suggest that genetic change in fitness results from traditional artificial propagation of anadromous salmonids held in captivity for extended periods. In similar studies, Fleming and Gross (1989, 1992, 1993) demonstrated many changes in coho behavior, wherein hatchery coho were less able to compete for mates and had less ability to spawn successfully in the wild than did wild-origin fish. No comparable data are available for sockeye salmon, but it seems prudent to assume that the same conclusion holds. No comparable data are available for species (pink, chum) held in captivity for shorter portions of their life cycle, nevertheless similar though smaller genetic changes may be expected (Reisenbichler and Rubin 1999).

The potential for genetic interactions between hatchery and wild salmonid populations in the North Pacific has increased considerably since the 1970s. This is because efforts to mitigate losses to wild stocks from overfishing, destruction of habitat, and blockage of migratory routes have been focused on artificial production from hatcheries. This increases the pool of hatchery fish capable of breeding in the wild due to straying, and thus increased the opportunities for genetic interactions between wild and hatchery fish. Waples (1991) identifies three issues of concern: (1) direct genetic effects (caused by hybridization and introgression); (2) indirect genetic effects (principally due to altered selection regimes or reductions in population size caused by competition, predation, disease, or other factors); and (3) genetic changes to hatchery stocks (through selection, drift, or stock transfers) that magnify the consequences of hybridization with wild fish. Busack and Currens (1995) recognize four different types of genetic hazard: (1) extinction, (2) loss of within-population variability, (3) loss of among-population variability, and (4) domestication. According to Campton (1995), the potential genetic effects of hatcheries and hatchery fish can be grouped into three categories: (1) the genetic effects of hatcheries and artificial propagation on hatchery fish, (2) the direct genetic effects of hatchery fish on wild populations due to natural spawning and potential interbreeding, and (3) the direct genetic effects of hatchery fish on wild populations due to ecological interactions or management decisions that affect abundance.

One of the risks associated with hatcheries is domestication. Busack and Currens (1995) define domestication as the changes in quantity, variety, or combination of alleles within a captive population or between a captive population and its source population in the wild as a result of selection in an artificial environment. Waples (1999) defines it as any genetic change that results directly or indirectly from human efforts to control the environment experienced by a population. Considerable improvements have been made in both fish culture and fisheries management such as improved broodstock collection and mating protocols, more natural rearing conditions, focus on local broodstock, and release strategies more friendly to wild fish (Waples 1999). Although it may be possible to eliminate intentional selection from hatchery programs, it generally will not be possible to eliminate nonrandom broodstock sampling and unintentional selection that occurs in the hatchery environment. The hatchery environment is different from the natural environment, and a successful hatchery program changes the mortality profile of the population and results in more fish surviving to enter the wild. Because of these factors, Busack and Currens (1995) concluded that some level of domestication is inevitable in a captive population. The management significance is simple: changing mating protocols will not eliminate genetic change from artificial propagation, and genetic changes in cultured populations cannot be avoided entirely. Although many factors can help reduce the nature and extent of the resulting genetic changes, they cannot be avoided entirely. Alternative mating protocols have been identified and more natural rearing systems are under development, but their effect on domestication has yet to be evaluated (Waples 1999).

A serious hatchery management concern is inbreeding, as it reduces the amount of genetic variation in a hatchery population. Repeated inbreeding may lead to inbreeding depression, the reduction of the mean phenotypic value. This may be greatest for traits that are components of fitness such as fertility, sperm viability, and survival of various life stages (Schonewald-Cox et al. 1983). Inbreeding depression and subsequent reductions in genetic variability have been demonstrated in cutthroat (Allendorf and Phelps 1980), brown (Ryman and Stahl 1980), and rainbow (Kincaid 1976) trout. The cited studies demonstrated several undesirable effects of inbreeding such as reductions in development, growth rate, survival, hatching, and fertility. Because traits related to fitness are susceptible to inbreeding depression, managers try to limit inbreeding. Salmon hatchery stocks have not generally experienced inadvertent inbreeding or measurable inbreeding depression as demonstrated in some wild and hatchery trout species (Lannan and Kapuscinski 1984). This is likely due to the comparatively large founder populations used in salmon hatcheries versus the limited broodstock used in trout hatcheries. A consensus of biologists is that the goal of hatcheries involved in fishery enhancement should be to make every effort to avoid inbreeding and maintain high fitness of the hatchery stock. However, many believe it is not possible to adequately mimic the successful reproductive strategies fish use in nature to maintain their genetic viability (Gharrett and Shirley 1985). Fish culturists, thus, have been encouraged to compensate for inadvertent loss of genetic variability by avoiding mating practices that foster loss of variability and by following certain procedures to minimize inbreeding. Best hatchery practices use a large founder or effective population size, provide crosses between wild and hatchery fish every season, use random mating, mate fish from all parts and age classes of a run, and avoid intentional selection of any given trait (e.g., large size, brightness) to help conserve genetic variability.

HOMING/STRAYING

What do homing and straying mean? For a wild fish, home is the natal stream where it incubated, hatched, and emerged. Nearly all salmon return reliably to their natal stream to spawn. Homing is a well-known feature of their biology; through it local populations are genetically isolated and are able to adapt to local environments. It is known that there is extensive variation among populations in many traits and this variation often has adaptive value. Such local adaptations have presumably arisen because homing fidelity leads to reduced levels of gene flow between populations using specific habitats and because there is genetic control of the traits that adapt the salmon for those habitats (Quinn 1997). For hatchery fish released at a remote location, the hatchery where they are reared and the release site could both be considered homes. While there is some tendency to return to the ancestral area, hatchery-reared salmon generally return to the site where they were released (Quinn 1997).

The other side of homing is straying. During straying, a small portion of salmon return to spawn in a stream different from their natal stream, maintaining genetic communication among local populations and, in turn, genetic diversity (Heggberget 1994). Patterns of straying vary between species and among populations and are poorly understood. Salmon move into non-natal streams for a variety of reasons. Upstream migration is characterized by a certain amount of exploratory movement. It is technically difficult to study straying, and it requires observations of marked fish. Consequently, most data come from observations of artificially cultured salmon (Quinn 1993).

Homing and straying have adaptive value for populations; the relative advantages may depend on environmental conditions, other life-history traits, and possibly the relative frequencies of homing and straying (Quinn 1997). A long-term balance between homing and straying is important to the fitness of salmon populations (Heggberget 1994). Straying from hatchery populations poses a risk to wild salmon populations because, if it results in interbreeding, genes from hatchery populations can be introduced into wild populations and adaptive gene complexes in wild fish can be disrupted (Gharrett 1994; Reisenbichler 1996).

There is concern that gene flow from hatchery strays may dilute the gene pool in populations of locally adapted wild fish. If a hatchery produces a large number of salmon, straying by even a small percentage of them has the potential to compromise the genetic makeup of nearby small wild populations. For example, in the 1980s strays from an ocean-ranching facility in Oregon were considered low (about 6%), but these strays accounted for about 74% of the fish in nearby streams (Quinn 1997). The absolute number of strays, a small percentage of the hatchery population, was large relative to the local wild population. While most concern is that strays will influence wild gene pools, wild salmon may also stray into a hatchery. One year an estimated 65% of wild coho salmon returning to the Yaquina River watershed in Oregon entered a local hatchery (Quinn 1997). Decoying of wild salmon into hatcheries can both reduce the number of wild fish and contribute to genetic mixing. Nonetheless, inclusion of wild salmon in hatchery broodstocks has often been practiced as it theoretically slows domestication and thus the potential effects of outbreeding depression (W. Smoker, pers. comm.).

Some natural colonization by salmon occurs. The relationship between straying and natural colonization is not well understood and little research has been done. In Alaska, new habitat appears as glaciers recede and this habitat is colonized as it becomes suitable for spawning (Milner 1987), hence colonization is now and recently has been important and frequent in most of the range of Pacific salmon. It is readily observed in recently glaciated landscapes and as a consequence of catastrophic landslides, volcanic eruptions, etc. It appears that soon after colonization straying rates may be high and that after populations become established only modest straying occurs (Quinn 1997). Nonetheless, in recent times translocation has been more common than natural colonization. Most translocations of salmon have been unsuccessful. There are, however, several successful examples: the inadvertent translocation of pink salmon into the Great Lakes as well as deliberate introductions of chinook and coho salmon into the Great Lakes resulted in rapid colonizations. The translocation of chinook salmon into one river in New Zealand led to unaided colonization of several river systems (Quinn 1997). There have also been successful and purposeful introductions of sockeye salmon into the upper Frazer River in British Columbia, Fraser Lake in Alaska, and Lake Washington in Washington. Evidence of reproductive isolation was found in Lake Washington sockeye after fewer than 13 generations (Hendry et al. 2000).

Little information exists on comparative straying rates between fish species. Straying is often thought to be greater in pink salmon than in other species, but definitive evidence is lacking. The most data exist for coho and chinook salmon and indicate large amounts of homing variability among populations, even within small geographical areas (Quinn 1997). Coho salmon straying rates are thought to be low in undisturbed populations (Dittman and Quinn 1996; LaBelle 1992). Most tagging occurs in hatchery fish; wild salmon are tagged less frequently and the data are seldom analyzed to produce estimates of straying. Consequently, most estimates of straying come from hatcheries. The overall estimate of homing in hatchery fish is 80% to 100% (Quinn 1997). Hatchery-produced salmon may or may not stray with the same frequency as wild salmon. Few studies have been conducted on hatchery and wild fish in the same area. Many experiments also suffer from a number of technical shortfalls, such as being poorly controlled, not being replicated, the study of homing variability being incidental to other goals, and failing to account for straying into and out of a population (only the dispersal of strays from the marking site is documented) (Quinn 1997). Quinn (1997) specifically mentions three studies of straying rates in salmon. In one case, wild chinook salmon in Washington State homed at a higher rate than did members of a hatchery population. On the other hand, hatchery and wild coho on Vancouver Island, British Columbia, did not significantly stray at different rates nor did Atlantic salmon in England.

Coded-wired tagging has provided a large database that can be used in homing studies. It is interesting to note that these data show a wide variation in spatial and temporal patterns of straying. The proportion or distance salmon stray is not the same in all hatcheries or regions, and the proportion of salmon straying into and out of a hatchery can vary considerably. Straying rates between 0% and 30% have been documented (Quinn 1997). In addition to differences in straying among rivers, straying can also vary from year to year. Straying variability can be associated with environmental changes like the eruption of Mount St. Helens or El Niño. Age at return can also contribute to straying variability, as older chinook salmon tend to stray more than younger fish (Quinn 1997). Even though chinook salmon hatcheries in Southeast Alaska are sited more than 50 kilometers from wild chinook rivers, tagged hatchery chinook have been detected among some wild spawning salmon in the region (Heard et al. 1995). One important study of wild pink salmon straying in Prince William Sound was not published because of concerns over direct effects of wire tags on homing and because it indicated very large rates of straying among populations. It is reviewed in the context of a later study of whether or not wire tags affect homing (Thedinga et al. 2000). This is more evidence that straying among pink salmon populations in western Prince William Sound is probably naturally large.

Some hatchery practices may promote straying. The most obvious is the transporting of fish from one locality to another. This is often referred to as "seeding" new habitat. Improper or incomplete imprinting may increase the straying rate of populations released from hatcheries. Fish released too long before or after the critical parr-smolt transformation may not experience the appropriate combinations of temporal, spatial, and physiological stimuli necessary for successful homing (Unwin and Quinn 1993). The site of release for hatchery fish can affect the amount of straying. Generally, local populations home better than transplanted ones; salmon home better to their natal site than a new site; and transplanted populations may show some tendency to return to their ancestral location (Quinn 1997).

Studies of small chum salmon populations on Vancouver Island indicate that degrees of genetic exchange between strays was lower than that inferred by the number of strays in the spawning area. Simply counting stray hatchery fish on spawning grounds may not provide a reliable estimate of the genetic interaction between hatchery and wild populations (Quinn 1997). It is not known whether straying hatchery salmon spawn successfully with wild salmon or if any loss of fitness and productivity occurs, but the potential risk is a strong concern within Alaska's ocean-ranching program (Smoker et al. 1999).

ECOLOGICAL INTERACTIONS

There exist many layers of biological diversity: within population, between population, behavioral, physiological, molecular, and ecological. Some stocks that have no obvious molecular differences may still have substantial ecological differences (e.g., run timing, preferences of substrate or habitat for redd construction and for incubation, intertidal versus upstream spawning, etc.). There are a number of ecological interactions that can take place between hatchery and wild fish. They can take the form of competition for food or space, predation, and negative social interactions when large numbers of hatchery fish are released in association with small numbers of wild fish. Given the controlled environmental conditions in a hatchery, it is not surprising that fish reared under these conditions are markedly different than their wild counterparts in behavior, morphology, survival, and reproductive ability. Artificial culture environments condition fish to respond to food, habitat, conspecifics, and predators differently than do wild fish (Flagg et al. 2000). Seemingly, the only similarities in hatchery and wild environments for salmonids are water and photoperiod (Reisenbichler and Rubin 1999). Flagg et al. (2000) summarized the major differences between hatchery and wild salmonids (Table 2).

Phenotypic differences observed between cultured and wild fish are both genetically and environmentally controlled. There is a positive relationship between smolt size and survival of hatchery fish that has encouraged hatchery managers to release larger smolts to maximize hatchery returns. The problem is that wild salmon life-history strategies have evolved based on the sizes they have been able to achieve under the temperature and nutrient limitations of the natural environment. Two potential negative impacts can result from this hatchery management scenario. One is the immediate impact on the ability of wild fish to avoid competition and predation pressures compounded by the presence of abundant, larger hatchery fish. The other, and perhaps more serious, is the long-term selective pressure being exerted on wild fish to accommodate the larger conspecifics in the ecosystem (Scientific Review Team 1998).

Salmon species that spend more time rearing in hatchery environments (coho, sockeye, chinook) are more

Table 2. Relative differences between wild and hatchery salmonids (Flagg et al. 2000).

Wild Salmonid		Hatchery Salmonid
Lower survival egg to smolt *Higher* survival smolt to adult	***Survival***	*Higher* survival egg to smolt *Lower* survival smolt to adult
Efficient forager *Lower* aggression *Lower* social density *Higher* territorial fidelity *Disperse* in migration *Bottom* habitat preference *Flee* from predators	***Behavior***	*Inefficient* forager *Higher* aggression *Higher* social density *Lower* territorial fidelity *Congregate* in migration *Surface* habitat preference *Approach* predators
More variable shape *Brighter* color *Larger* kype	***Morphology***	*Less* variable shape *Duller* color *Smaller* kype
Smaller eggs *Fewer* eggs *Higher* breeding success	***Reproduction***	*Larger* eggs *More* eggs *Lower* breeding success

susceptible to subtle environmental changes than are those that do not (chum, pink). Although hatchery rearing increases egg-to-smolt survival, the post-release survival of cultured salmonids is often lower than wild-reared fish. Research conducted since the 1960s suggests that post-release survival of hatchery fish represent both adaptive differences between hatchery and wild populations and environmental differences between hatchery and natural rearing environments (Flagg et al. 2000). Poor survival of both hatchery strains in natural environments and wild strains in hatchery environments were found in steelhead trout (Reisenbichler and McIntyre 1977). In other steelhead studies, naturally spawned and reared hatchery offspring experienced greater mortality than offspring of wild fish during all three major life-history stages (Chilcote et al. 1986; Leider et al. 1990). These studies suggest that adaptive differences occurred between hatchery and wild populations in a relatively short time period.

Many studies have indicated that the hatchery-rearing environment can influence the behavior of salmon. Levels of aggression and antagonistic behavior appear to differ between domesticated and wild populations. Juvenile salmonids from domesticated and wild populations appear to demonstrate adaptive differences in antagonistic behavior, and the behavioral development of domesticated and wild fish appears dependent upon their rearing environment (Flagg et al. 2000). Cultured and naturally-reared salmonids respond differently to habitat. In most cases wild fish use both riffles and pools in streams, while hatchery fish primarily use pool environments. Hatchery strains are typically more surface oriented than are wild fish. Most of the innate surface orientation of hatchery fish is likely an adaptive response to the practice of introducing food at the surface of the water (Flagg et al. 2000). Predation is a major factor affecting the survival of hatchery-reared fish. Experimental evidence indicates that hatchery strains of salmonids have increased risk-taking behavior and lowered fright responses compared to wild fish (Flagg et al. 2000).

Another impact of hatchery management on the ecological status of wild fish involves pre-smolt releases on stream carrying capacity through added competition. Hatchery fish are seldom released in numbers that are related to the carrying capacity of the receiving stream. The pre-smolt juveniles and any residuals will compete with their wild counterparts and lower the wild fish success by changing optimum habitat use of the wild fish (Scientific Review Team 1998). Hatchery coho releases into naturally seeded streams in British Columbia led to little demonstrable increase in smolt production on the east coast of Vancouver Island. Irvine and Bailey (1992) evaluated the success of outplanted coho juveniles and concluded that supplementation prior to summer low-flow periods did little to increase production. Thus, for releases to be successful in increasing smolt yield, releases would need to be timed to take advantage of available habitat after summer low-flow periods had ended (summer low flows created survival bottlenecks).

Hatchery practices have altered reproductive behavior by relaxing selection pressure on secondary sexual characteristics (kype) used in breeding competition in the wild, while increasing selection pressure on primary sexual characteristics (such as quantity and quality of eggs). Relaxation of breeding competition led to hatchery coho salmon with less pronounced kypes and breeding colors while developing larger and more numerous eggs than comparably sized members of the wild stocks from which they were derived (Fleming and Gross 1989). The same researchers found that hatchery male coho allowed to spawn naturally were less aggressive and less active than wild males. Either inadvertently or intentionally, hatcheries often develop strains that spawn at different times than their ancestral stock. The most common practice is to select for early run timing by spawning a disproportionate higher percentage of the early returning fish. An advantage of a temporal separation from a management perspective is to separate stocks in a fishery and minimize interbreeding. A disadvantage is that if interbreeding does take place, the progeny of domestic strains and wild-domestic crosses may emerge prior to peak abundance of natural aquatic food sources and thus suffer higher mortality rates. Granath et al. (2000) found significant differences in hatch times for crossed coho salmon in Southeast Alaska.

MARINE ENVIRONMENT

Climatological Influences

Despite increased awareness of the marine effects on salmonid growth and survival, scientists still have a rather poor understanding of the ecology of salmon once they leave freshwater (Brodeur et al. 2000). There exists a lack of comparable understanding of the marine environment to that of freshwater despite evidence that this habitat may be more significant to population variability. An incomplete understanding about the basic aspects of salmon biology in marine waters has hampered the ability to predict natural variability in salmon production (Brodeur et al. 2000).

Although climatological factors such as precipitation affect freshwater systems as well as salmon survival, scientists believe that ocean conditions contribute to variability in salmon survival and growth, particularly in the first few months after leaving freshwater. Early marine survival is governed in part by both water temperature and salinity. This period of ocean entry is a critical one in the life history of salmonids. The timing of ocean entry has evolved through natural selection to minimize predation and maximize growth (Pearcy 1992). Although the most visible part of a salmon's life cycle is completed on the freshwater spawning grounds, most growth and about one-half of mortality occurs in the ocean.

Following entry into the ocean, most North American salmon begin a rapid and highly directed migration north and west. They remain exclusively upon the narrow coastal shelf, migrating up and around at least as far as the Aleutian Islands and do not enter the open ocean for many months. The confinement of the entire North American population of juvenile salmon to a narrow strip of coastal ocean makes them especially vulnerable to problems resulting from competition for food or climate change (Welch 1999). The climate of the North Pacific alternates between two general ocean states. One is dominated by a weak winter Aleutian Low (pressure) resulting in negative sea-surface temperature anomalies (cooling). The second occurs in response to an eastward displacement and intensification of the Aleutian Low and is characterized by positive sea-surface temperature anomalies (warming) (Cooney and Brodeur 1998).

Numerous recent studies indicate that fluctuations in climate are the major source of widespread, regionally, coherent changes in the marine survival rate for many salmon species (Hare et al. 1999). Mysak (1986) showed that El Niño affected both Bristol Bay and Fraser River sockeye salmon populations. Several studies have connected dramatic changes in Alaska and West Coast salmon production to decadal scale climate regime shifts in the North Pacific (Beamish and Bouillon 1993; Francis and Hare 1994; Francis and Sibley 1991; Hare 1996; Hare and Francis 1995). This climate phenomenon is known as Pacific Decadal Oscillation or PDO. It is described as a pan-Pacific, recurring pattern of ocean-atmosphere variability that alternates between climate regimes every 20 to 30 years (Hare et al. 1999). Hare et al. (1999) found that salmon catches in Alaska have varied inversely with catches from the U.S. West Coast during the past 70 years. Results of their analysis suggest that the spatial and temporal characteristics of this inverse catch/production pattern are related to climate-forcing events associated with the PDO.

Clues left by decaying salmon at the bottom of lakes in Alaska point to climate change and overfishing as causes of the large swings in the size of the state's salmon runs. Records of prehistoric salmon abundance have been reconstructed from analysis of stable nitrogen isotopes in sediment cores (Finney 1998). Cores from Karluk Lake show minimum salmon escapement occurring during the mid-1900s, early 1800s, early 1700s, and mid-1500s. Relatively high values were observed from the early 1900s, late 1700s, mid-1600s, and late and early 1500s. In general, sockeye salmon runs were larger during periods of warm climates and smaller during cold periods.

There is increasing evidence of persistent patterns and synchronous changes in the ocean environment in the Pacific Ocean. Evidence is also accumulating to show that large-scale trends in Pacific salmon abundance are linked to trends or regimes in climate and resulting ocean conditions (Beamish et al. 1999). The fluctuations in salmon abundance have been shown to correspond to shifts in zooplankton abundance that can be linked to physical changes in the ocean. The trends in salmon abundance are not necessarily the same for all areas of the ocean, as climate shifts can cause large-scale oscillations in ocean productivity with regional impacts. Fluctuations in Pacific salmon abundance in this century are synchronous with large fluctuations in Japanese sardine abundance, a relationship that can be traced back to the early 1600s. The synchrony in the fluctuations suggests that Pacific salmon abundance may have fluctuated for centuries in response to climate (Beamish et al. 1999).

Since 1976 a major change has occurred in the Northeast Pacific Ocean, with unfavorable ocean conditions for salmonids in the Coastal Upwelling Domain and highly favorable conditions farther north in the Coastal Downwelling and Central Subarctic Domains and the Bering Sea. High sea levels and warm temperatures along the coast, an intense Aleutian Low, and weak upwelling are associated with these changes (Pearcy 1996). In the late 1970s, an intensification of the Aleutian low-pressure system in the North Pacific Ocean apparently resulted in a warming of the sea surface along the northern North America coast and cooling farther offshore (Cooney and Brodeur 1998). This event was associated with exceptionally strong year-classes of many marine and anadromous fishes and signaled the beginning of a period of increasing productivity for salmon north of British Columbia. Conversely, this shift in ocean climate produced an opposite effect on fish off the Pacific Northwest, most notably on coho salmon (Mantua et al. 1997). Coded-wire tagging studies indicate that changes in ocean conditions could be partially responsible for survival declines of coho and chinook salmon in the Pacific Northwest (Coronado and Hilborn 1998a).

Favorable ocean conditions, growing enhancement operations, and improved management practices have led to dramatic increases in Pacific salmon production over the last 20 years. Production in 1994 was about double the amount in the mid-1970s. The largest increases have been for pink and sockeye salmon. Evidence exists for at least two previous ocean states or regimes affecting Alaska salmon, one ending in the 1940s after which production fell and the other concluding in the late 1970s and followed by increasing production for two decades (Beamish 1993; Beamish et al. 1999).

Salmon sensitivity to temperature is widely recognized and any climate change is likely to affect survival rates. Long-term impacts from any carbon dioxide-induced global warming may prove to have major implications for sustainability of salmon. If salmon continue to maintain the sharp thermal limits that they have been shown to follow over the past 40 years, then any global warming could adversely affect them. Warming oceans could force salmon to migrate farther north in search of suitable temperatures or force them deeper out of the sunlit surface water where food is greatest (Welch 1999).

Ocean Carrying Capacity

Large-scale climatic factors affect ocean productivity and thus carrying capacity for salmon (Cooney and Brodeur 1998). Review of research on the physical and biologic factors affecting ocean production indicated that climate-induced variation in productivity and fishing are the two major factors affecting ocean production of salmon (Myers et al. 2000).

Carrying capacity is a measure of the biomass of a given population that can be supported by a given ecosystem. It changes over time with the abundance of predators and resources. Carrying capacity is determined by several processes including primary productivity, food-web dynamics, number of trophic links, ecological efficiencies, fraction of production consumed by competitors, and predation. In addition, the carrying capacity of a species is modulated by the size of the region inhabited, which in turn is influenced by temperature and availability of food (Pearcy et al. 1999). All of these factors are dynamic, fluctuating over seasons, years, decades, and millennia.

Dramatic changes have occurred in the North Pacific Ocean in recent years. Some recently documented changes are significant warming of the ocean during the 1990s, shallower winter mixed-layer depth and reduction of nutrients entrained into the euphotic zone, changes in seasonal maxima of a dominant subarctic copepod with peak biomass occurring earlier in the upper water column, unusual coccolithophore blooms in the Bering Sea, and regions of depleted nitrate during the 1990s (Pearcy et al. 1999). All of these changes may affect the carrying capacity of the North Pacific. The ocean's carrying capacity for salmon is dynamic in time and space, constantly changing on interannual, decadal, centennial, and millennial time scales.

Humans impact estuarine and coastal regions through activities that may exacerbate global warming, by introducing exotic species, by creating chemical pollution, and by physically altering habitats (e.g. clear-cut logging practices, building subdivisions, dredging, etc.) and bottom fishing (Brodeur et al. 2000). When these anthropogenic factors are set against the backdrop of natural variability, their effects on ocean carrying capacity may be further exaggerated (Brodeur et al. 2000). The estuarine and ocean carrying capacity for salmon may be compromised by the attempt to make up for declining natural runs by increasing hatchery production, thus leading to density-dependent food limitation in winter months (Pearcy et al. 1999).

Density-Dependent Competition

A fundamental assumption of ocean ranching has been that salmon use only a small fraction of available coastal and ocean forage. Food limitations in these environments were not given serious consideration until salmon began returning at smaller sizes and older ages (Cooney and Brodeur 1998). Several investigators in the 1970s estimated that salmon consumed only a few percent of the zooplankton and that salmon production could be increased significantly. Since these early studies, several salient estimates have changed. Even though only a fraction of the primary production is used by salmon, as recognized in earlier studies, the high trophic level of salmon and the complex food web with many other consumers and competitors suggest that substantial increases in the production of salmon in ocean waters of the Pacific are unlikely (Pearcy et al. 1999). Declines in both the size and size at age of salmon harvested and increases in the age of maturity have been documented over the past 20 years around the Pacific Rim (Bigler et al. 1996). This is important evidence for density-dependent growth and may suggest that the carrying capacity of oceanic waters of the North Pacific is being approached for salmonids (Pearcy et al. 1999).

Competition for food among salmon has been shown. The diet of pink salmon may change between years of strong and weak year classes, with a shift from zooplankton to more nutritious prey like squid. Squid compete with immature salmon for zooplankton, while providing a food source for maturing salmon. Both the growth and diet of chum salmon have been correlated with the abundance of pink salmon; when pink salmon are less common, chum salmon may shift their diet from gelatinous zooplankton to more nutritious prey (Pearcy et al. 1999).

Releases of hatchery fish increased rapidly after the 1960s and are presently between 5 and 6 billion, about 25% of the total number of juvenile salmon entering the ocean (Heard 1998). According to Beamish et al. (1997), of the total number of juvenile salmon entering the ocean, about 84% of chum, 23% of pink, and 5% of sockeye salmon are produced at hatcheries. Estimates of annual food consumption by pink salmon in Prince William Sound rose from less than 100,000 metric tons prior to 1976 to more than 300,000 metric tons after 1988, when hatchery production began dominating returns (Cooney and Brodeur 1998). Recent levels of wild and hatchery production in the North Pacific Ocean have placed substantial forage demands on ocean-feeding domains (Pearcy et al. 1999). Recent studies in Prince William Sound found Dungeness crab megalopae composed 35% to 65% of the stomach contents of pink salmon. Despite the curtailment of fishing on these crabs in Prince William Sound, their productivity remains low. The large numbers of hatchery pink salmon being released in Prince William Sound could be having a significant and unintended impact on other ecosystem components like crab (Boldt et al. 2001).

Evidence for a limited ocean carrying capacity comes from negative relationships between numbers of fish and their rates of growth. Density-dependent growth of some stocks has been suggested (reviewed by Pearcy 1996). Klovach and Gritsenko (1999) suggested that limited ocean carrying capacity might explain why fish became smaller during periods of high salmon abundance. There has been a decrease in mean body length, mean weight, and fecundity and an increase in the mean age of matured fish. A decrease in size of the fish may lead to corresponding decreases in fecundity and energy reserves available for the freshwater migration. In 1994 a mass softening of chum salmon tissue was discovered in Asian salmon. Some of these fish also had unusual elongated body shapes. The causes behind this appear to be dietary. Studies have documented a shift in the diet of Asian chum salmon to include a large quantity of low-caloric forage like salps, jellyfish, and ctenophores, which were only rarely found in other salmon. In the 1960s, when salmon abundance was much lower, these organisms were not so prevalent in the diet of chum salmon. Previously, these organisms were part of chum salmon diets only in years of high pink salmon abundance (Klovach and Gritsenko 1999). Klovach and Gritsenko (1999) concluded that the high numbers of Japanese hatchery chum salmon feeding in the ocean creates densities of fish which, if not exceeding carrying capacity, then at least considerably exceed an optimal density. Some Russian scientists believe that competition with the chum juveniles of Japanese hatchery origin during the marine-rearing phase has prevented the recovery of wild Russian chum stocks (Radchenko 1998). These studies are consistent with the hypothesis that hatchery releases by one country along the Pacific Rim may affect the size, number, and value of adult salmon returning to other countries thereby creating scientific and management problems of international concern.

In contrast to growth, survival does not appear to be as density dependent. Survival of hatchery-produced pink and chum salmon in Alaska appears to mirror that of wild fish from the area surrounding the hatchery: when survival of hatchery salmon is high, wild stocks from the surrounding area also survive in greater numbers. In some years, this appears to be a localized phenomenon with different survival rates within a region. Coronado and Hilborn (1998b) presented data summarizing ocean survival over time and hatchery releases for Pacific coho populations. The graph of ocean survival for southern British Columbia coho showed a strong inverse relationship to the total number of hatchery-produced salmonids released. Salmon survival shifts appear to be caused by changes in local environmental conditions, possibly related to fluctuations in climate (ADF&G 1999; Coronado and Hilborn 1998a, b).

FISHERY MANAGEMENT IMPLICATIONS

Forecasting future trends in the abundance of fish populations has not been particularly successful. Historically, many hypotheses about the relationship between fish populations and marine environmental parameters have been suggested. Only in the last several years have these hypotheses become more refined. It is possible that improved forecasting will result from an increasing understanding of the synchronicity between persisting trends in climate/ocean conditions and patterns of marine survival of salmon (Beamish et al. 2000).

Beamish et al. (1999) and others have noted persistent trends in the dynamics of fish populations in relation to climate/ocean conditions and term these regimes, which they define as a multiyear period of linked recruitment patterns in fish populations. If natural trends in Pacific salmon abundance occur, then fisheries management should account for this phenomenon when developing strategies. Beamish et al. (2000) found that survival of coho salmon from California to British Columbia decreased after 1989 in synchrony. This large-scale synchronous change over the southern range of coho salmon distribution indicates linkage with a common event. Shifts in the pattern of April flows in the Fraser River and the intensity of the Aleutian Low appeared to be indices to this change in survival. The trend towards low marine survival may persist as long as the trends in the climate indicators do not change.

Survival rates for coho salmon were estimated for all coded-wire tagged fish in the Pacific Northwest between 1971 and 1990. During this time there was considerable geographic variation, with most regions south of northern British Columbia showing declining survival and more northern areas showing increasing survival. According to Coronado and Hilborn (1998b), ocean conditions have been the dominant factor affecting coho survival since the 1970s and a major reduction in exploitation rates is necessary to maintain the populations. Moreover, during lower productive regimes there is concern as to what impact large numbers of hatchery-produced salmon may have on wild populations, and it has been suggested that prudent management practices be adopted during less productive regimes. High harvest rates in ocean fisheries targeted toward abundant hatchery stocks make conservation of wild stocks especially difficult when ocean productivity is low (Beamish et al. 1997).

Environmental indices changed around 1990, indicating the productive North Pacific Ocean regime of the 1980s was changing. There were continued increases in much (but not all) of Alaska marine productivity and a concomitant sharp drop in southern British Columbia—but not northern British Columbia ocean productivity (Welch et al. 2000). Hatchery enhancement has contributed to increased salmon production in the late 1900s, especially in Japan and Alaska. If the ocean carrying capacity is being reached, increased hatchery releases may not increase the biomass of salmon produced. Catches of pink, chum, and sockeye salmon by the major salmon-producing countries in the 1900s shows high catches in the early and late 1900s and low catches in the mid-1900s (Beamish et al. 1997). The early and late 1900s correspond to favorable ocean/climate conditions and the mid-1900s to unfavorable. The high catches in the early 1900s were almost entirely wild fish, while those of the late 1900s included a significant number of hatchery fish.

Given the two favorable ocean environmental regimes, about the same number of fish were produced but hatchery-produced fish appeared to replace wild fish in the late 1900s. Estimates of the percentage of hatchery-produced coho salmon in the Strait of Georgia have been made over time. The percentage of hatchery fish has increased from about 25% in the early 1980s to nearly 50% in 1990 to approximately 75% in 1998 (Noakes et al. 2000b). These estimates suggest a gradual replacement of wild fish with hatchery fish over time. Evidence from Prince William Sound also suggests that hatchery pink salmon replaced rather than augmented wild production (Hilborn and Eggers 2000). A critique of this analysis, based on different assumptions and statistical analysis, questions the rate at which hatchery-produced pink salmon may be replacing wild salmon (Wertheimer et al. 2001).

MANAGEMENT ISSUES

The reassessment of management's fundamental assumptions about the role of hatchery production has led to much public debate, most recently over the federal proposal to breach or remove the four Snake River dams to aid in the recovery of salmon. This would have been an unthinkable action just a few years ago. To avoid the problems of the past, fundamental assumptions need continuous examination and management programs must be flexible to change, when warranted, in response to new information (Lichatowich et al. 1999). Throughout their history, hatchery programs have exhibited a chameleonic behavior, changing to match the social and economic environment while retaining the same conceptual foundation. In the nineteenth century fish culture offered a means to restore eastern U.S. fisheries, provide an income for farmers, and increase the food supply of an expanding nation. The agricultural goals of the U.S. fish culture movement dictated the kinds of scientific questions that were relevant and may explain why fisheries science developed its own ideas and theories distinct from those of systems ecology (Bottom 1996). These ideas emphasized the improvement of fish through hatchery selection as well as the introduction and acclimatization of species in new environments.

New understanding about fish adaptations to their environment along with the recent collapse of salmon production in the Pacific Northwest have undermined the old agricultural model of applied fisheries science (Bottom 1996). Presently, there is a continuing search for an analytical solution to a value-based problem. According to Bottom (1996), a more important role for fisheries than ecosystem management will be to foster a better understanding and appreciation of human ecosystem dependence.

Throughout their history, hatchery programs have been implemented under the assumption that relationships among reproduction and harvest could be manipulated through human intervention to be simpler and more predictable. Production has largely been brought under control in some watersheds like the Columbia River, where 80% of the salmon is of hatchery origin. Even though most of the salmon are of hatchery origin, less salmon are returning to the Columbia River Basin today than at any time in recorded history. The hatcheries have failed to achieve their original objective of replacing production (Lichatowich et al. 1999).

The use of hatcheries to supplement depleted stocks has generated nearly endless disagreement. Faced with the general collapse of salmon in the Pacific Northwest, four independent scientific advisory boards have or are currently examining restoration programs in various parts of the region (Independent Science Group 1996; National Fish Hatchery Review Panel 1994; National Research Council 1996; Scientific Review Team 1998). The conclusions and recommendations of these different groups were almost identical and the following points were identified as common denominators (Flagg and Nash 1999):

- Hatcheries have generally failed to meet their objectives.
- Hatcheries have imparted adverse effects on natural populations.
- Managers have failed to evaluate hatchery programs.
- Hatchery production was based on untested assumptions.
- Hatchery production should be linked with habitat improvements.
- Genetic considerations have to be included in hatchery programs.
- More research and experimental approaches are required.
- Stock transfers and introductions of non-native species should be discontinued.

- Artificial production should have a new role in fisheries management.
- Hatcheries should be used as temporary refuges, rather than for long-term production.

The Northwest Power Planning Council's Independent Science Advisory Board concluded that it is skeptical of the efficacy of hatcheries in fisheries enhancement but does not discount their functionality in fish and wildlife restoration (Independent Science Group 1996).

The above evaluations and conclusions are focused on hatchery operations in the Pacific Northwest, and it remains to be seen to what degree they apply to Alaska's ocean-ranching program. Proponents of Alaska's system are quick to claim that hatchery programs in Alaska have either met their objectives or have been closed down. They note that about a quarter of all hatcheries have been closed, that mixed hatchery and wild stock fisheries have been managed based on the productivity of wild stocks, and that sufficient resources have been devoted to evaluation of hatchery efficacy. Alaska has, to some degree, learned from mistakes made elsewhere and Alaska's management reflects this.

Recently, there has been a growing appreciation that long-term sustainability of salmon requires conservation of natural populations and their habitats (National Research Council 1996). As a result of this paradigm shift, many hatcheries are now being asked to minimize impacts to natural populations (Waples 1999). The recent examination of salmon management's conceptual framework has led to the recommendation that it be replaced with an alternative (Independent Science Group 1996). The new framework proposes that restoration activities must consider the entire ecosystem. It recognizes the complexity of salmon life history and that the biodiversity of wild stocks must be conserved (Independent Science Group 1996). Biodiversity has become a familiar term outside of scientific circles. Ways of measuring and mapping it are advancing and becoming more complex, yet a consensus about how to conserve biodiversity is still developing and the resources available to manage diminishing biodiversity are scarce. One problem is that policy decisions are frequently at the local scale, whereas biodiversity issues are more often regional or national in scope.

Many have argued that critics of hatcheries often confound biologic factors intrinsic to hatcheries with effects of fisheries management. One should be careful not to exaggerate the dichotomy between biology and management. No fish hatchery exists in a vacuum, and they are usually designed to meet one or more management objectives. Many management factors involve both fisheries management and fish culture. For example, selective breeding, when it occurs, is carried out by fish culturists to achieve a fisheries management objective. Two factors that are primarily a function of management are mixed-stock fisheries and stock transfers (Waples 1999).

In an analysis of salmon and steelhead hatchery production, Miller (1990) studied over 300 projects in North America. Among his observations was that evidence for the successful rebuilding of runs was scarce. Projects were more successful at just returning fish. Adverse impacts to wild stocks had been shown or postulated from about every type of hatchery introduction. He concluded that there were no guarantees that hatchery production could replace or consistently augment natural production. Miller found that most supplementation projects have been so poorly documented that it is impossible to determine what has happened. Cuenco et al. (1993) also examined historical cases of successful and unsuccessful supplementation and found quite a few successful supplementation projects. Among the best known is the case of successful supplementation of the Lake Washington sockeye, which were originally from the Skagit River. Repeated stocking of Skagit sockeye started the current run of Lake Washington sockeye.

MIXED-STOCK FISHERIES

A major management concern involves different exploitation rates between hatchery and wild stocks mixed in commercial and/or sport fisheries. Overharvest of wild stocks in mixed-stock fisheries could have a profound impact on survival of wild stocks. When abundant hatchery stocks are targeted for high harvest, less abundant wild stocks cannot withstand the high exploitation rates, resulting in underescapement of wild fish. The optimum harvest rate of wild stocks is much lower (generally 40% to 75%) than that of hatchery stocks (90% to 95%) (Wright 1981). It also should be noted that depressed stocks, such as the interior Fraser River coho, could not withstand exploitation rates in excess of 10%. The protected hatchery environment generally allows a high rate of fertilized egg to fry or juvenile survival while, in contrast, the average overall survival rate of wild salmonids from fertilized egg to adult is lower. Subsequently, fewer fish (or eggs) are needed to maintain a hatchery population. In mixed-stock fisheries, it is difficult (if not impossible) to harvest one stock at the optimum level without over- or underharvesting other stocks (Ricker 1973). Where overfishing of wild stocks has been permitted, adverse effects have been measured. Some examples are disappearance of the summer chinook stock in the Columbia River, disappearance of coho stocks in the Columbia and Snake Rivers, and decline of wild stocks caught in the highly productive channel-raised sockeye fishery of Babine Lake, British Columbia.

Ideally, establishment of separate fisheries on wild and hatchery stocks (usually involving geographically separate terminal fisheries) is the preferred management technique. This usually involves manipulations through reprogramming of hatchery production that would directly impact harvest in specific fisheries. This can involve changes in stocks reared at a hatchery or changes in the hatchery environment that would affect migration behavior and availability of returning adults to a fishery. The most common technique is establishment of a terminal fishery. The goal is to allow as much exploitation in mixed-stock fisheries as practical and then to harvest all remaining hatchery adults in a terminal single-stock fishery (Evans and Smith 1986). However, a terminal fishery is not always possible because of geographic or socioeconomic barriers. When a mixed-stock fishery is inevitable, the recommended first priority is to reduce exploitation rates to accommodate the less productive wild stocks (Argue et al. 1983; McDonald 1981; Ricker 1973). Risks to wild stocks from overharvest can be reduced by siting facilities where harvests are not mixed or by using tags to identify hatchery fish in mixed harvests. In areas of mixed-stock fisheries, large-scale marking programs (thermal otolith marks) have been initiated to contain the risk (Smoker et al. 1999).

Patterns of salmon migration complicate management. Conservation of weak stocks by time and area closures may not be a good option for stocks that pass through numerous fisheries over an extended period en route to their spawning streams. Artificial production of salmon stocks through hatcheries has the potential to adversely affect wild runs via overexploitation. This concern can be amplified by the geographic location of hatcheries and release sites. Long-term declines have occurred in coho stocks with high exploitation rates from Georgia Strait, British Columbia (Shaul 1994).

The generic management goal of maximizing harvest underscores hatchery management philosophy. The management concept of maximum sustainable yield has not only impacted escapements of wild fish in mixed-stock fisheries, but has also affected nutrient input from carcasses that enriched otherwise nutrient-impoverished streams. The dependence on artificial production in the Pacific Northwest has exaggerated the deficit in nutrient transfer of many drainages from that historically experienced. Consequently, reduction of carcass contribution to nutrient loads in salmon-spawning streams is an indirect ecological impact of hatchery management (Scientific Review Team 1998). Nutrients delivered from the ocean by salmon are important in the nutrient-poor streams of Alaska.

ALASKA'S HATCHERY PROGRAM

HISTORY

Due to the depressed state of Alaska's salmon fishery in the late 1960s and early 1970s, many (including fishermen, processors, and legislators) felt it was time to attempt to propagate fish by means of hatcheries. The public and the Alaska legislature seemed more enthusiastic about the program than professional fishery biologists. State and federal fishery management agencies often expressed concerns about adverse biologic consequences. The biologists stated a preference for rehabilitating wild stocks over the propagation of hatchery stocks. Questions such as genetic intermingling, disease, and competition were raised, but it was decided to proceed with an eye toward protecting wild stocks. Concerns were known to legislators but seemed speculative in the face of cries for relief from communities. It was hoped that potential problems could be mitigated by exercising reasonable precautions, such as regional management plans and careful siting of hatchery facilities to segregate hatchery and wild stocks (Alaska Senate 1992).

By 1968 public concern over the depressed salmon fishery was high, and a general obligation bond authorization for $3 million to build hatcheries was passed by the Alaska legislature and overwhelmingly approved by the public. In 1971 the legislature created the Fisheries Rehabilitation, Enhancement, and Development Division (FRED) of ADF&G to operate public hatcheries and coordinate fish enhancement activities. In 1973 the United Fisherman's Association (UFA) was formed, organizing commercial fishermen at the state level. Fishermen's groups like UFA were a driving force behind the state's salmon hatchery programs (Alaska Senate 1992), and they soon lobbied for private nonprofit (PNP) hatchery programs. In 1974 the Alaska legislature passed the Private Salmon Hatchery Act. It was amended in 1976 and 1977 to add the Fisheries Enhancement Loan Program, which provided for low-interest loans to regional aquaculture associations and added a provision for the formation of regional associations that would own and operate the PNP hatcheries (Olsen 1994).

It soon became evident that the costs of developing private salmon hatcheries were far greater than anticipated. New methods of financing construction and operation were sought (Alaska Senate 1992). Accordingly, the 1974 law was amended the following year to allow proceeds from the sale of salmon or salmon eggs to be applied to debt retirement as well as to operating costs. In 1975 another state low-interest financial source was made available to hatcheries when the commercial fisheries loan program was expanded to include hatcheries. In 1977 legislation was passed to create a Fisheries Enhancement Revolving Loan Fund that relaxed conditions for obtaining loans. In 1988 legislation was passed to allow private aquaculture corporations to take over operations of state hatcheries. FRED was combined with the Division of Commercial Fisheries by executive order in 1993 and subsequently most FRED hatcheries were transferred to regional associations under long-term cooperative lease arrangements (Heard 1996). ADF&G closed 3 hatcheries and transferred 13 to the PNP corporations. Except for the Deer Mountain hatchery, these were owned by the state but operated for ADF&G under contract with various PNPs. Deer Mountain was owned by the City of Ketchikan and operated by ADF&G; today it is owned by the Ketchikan Indian Corporation. The four state hatcheries that produced fish for recreational fisheries were transferred to the ADF&G Division of Sport Fish in 1993. In 2000 the state's Crystal Lake Hatchery was contracted to the Southern Southeast Regional Aquaculture Association, leaving only the two sport fishery hatcheries near Anchorage directly under ADF&G's control.

Since 1980, five state hatcheries have been closed that were not taken over by PNPs: East Creek, Russell Creek, Big Lake, Sikusuiliaq, and Clear. East Creek was an experimental sockeye hatchery in Bristol Bay that encountered infectious hematopoietic necrosis virus (IHNV) disease problems and was shut down in 1981. Russell Creek was a chum hatchery in the False Pass area that was closed in 1992. It was poorly sited from a management perspective, causing allocation conflicts between sockeye and chum salmon and between different management-area chum salmon runs. The Big Lake hatchery was a sockeye hatchery that had a history of low cost-recovery harvest and closed in 1993. Sikusuilaq was an experimental chum hatchery near Kotzebue above the Arctic Circle that was closed in 1995. The Russell Creek, Big Lake, and Sikusuilaq hatcheries were all ultimately closed as cost-reduction measures by ADF&G (S. McGee, pers. comm.). The Clear hatchery was a Division of Sport Fish hatchery that was closed in 1997; its mission was absorbed by the Division's hatcheries in Anchorage. Table 3 summarizes significant events in Alaska's fishery enhancement program.

PLANNING

The commissioner of ADF&G is authorized to designate regions of Alaska for the purpose of salmon enhancement and to develop and maintain Regional

Table 3. Time line of fishery enhancement events in Alaska (McNair 2001).

Year	Event	Number of State Hatcheries	Number of PNP Hatcheries	Number of Federal Hatcheries
1934	Federal research station Little Port Walter constructed			1
1950	Federal hatchery at Auke Creek constructed			2
1953	1 territorial hatchery constructed (Kitoi Bay)	1		
1954	1 territorial hatchery constructed (Deer Mountain)	2		
1958	1 territorial hatchery constructed (Ft. Richardson)	3		
1965	1 state hatchery constructed (Fire Lake)	4		
1969	1 state hatchery constructed (Crystal Lake)	5		
1971	Fisheries Rehabilitation, Enhancement, and Development (FRED) Division created by legislature			
1973	2 state hatcheries constructed (Crooked Creek and Gulkana)	7		
	State enhancement projects at Starrigavan and Halibut Cove started			
1974	2 state hatcheries constructed (Beaver Falls and East Creek)	9		
	Legislature authorizes permits for PNP hatchery operators to salmon ranch			
1975	4 PNP permits issued (Sheldon Jackson (#3), Port San Juan (#2), Perry Island (#1), and Sandy Bay (#4)		4	
	2 state hatcheries constructed (Big Lake and Tutka)	11		
1976	AS 16.10.375 passed, designating regions for Regional Planning Teams and enhancing salmon			
	1 state hatchery constructed (Elmendorf)	12		
	2 PNP permits issued (Burnett Inlet (#5) and Kowee Creek (#6)		6	
1977	1 PNP permit issued (Gunnuk Creek (#7)		7	
	2 state hatcheries constructed (Klawock and Russell Creek)	14		
	State enhancement project at Karluk Lake started			
1978	1 PNP permit issued (Whitman Lake (#8)		8	
	2 state hatcheries constructed (Cannery Creek and Hidden Falls)	16		
1979	3 PNP permits issued (Sheep Creek (#11), Meyers Chuck (#10), Salmon Creek (#9)		11	
	1 state hatchery constructed (Snettisham)	17		
	1 state hatchery closed (Fire Lake)	16		
1980	1 PNP permit issued (Burro Creek (#12)		12	
	2 state hatcheries constructed (Clear and Main Bay)	18		
	1 hatchery at Tamgas Creek constructed (Metlakatla Indian Community/BIA)			3

Planning Teams (RPTs). RPTs currently have three primary duties: (1) develop and update regional comprehensive salmon plans, (2) review hatchery permit applications, and (3) review hatchery operations. RPTs comprise three members of the local aquaculture association and three members of ADF&G. Criteria that are used to determine public benefit from the hatchery program include: (1) whether or not the hatchery makes a significant contribution to the common property fishery, (2) whether or not the

Year	Event	Number of State Hatcheries	Number of PNP Hatcheries	Number of Federal Hatcheries
1981	1 state hatchery closed (East Creek)	17		
	2 state hatcheries constructed (Sikusuilaq and Trail Lakes)	19		
	4 PNP permits issued (Medvejie (#16), Port Armstrong (#13), Solomon Gulch (#15), Salmon Creek (#14)		16	
	1 PNP permit revoked (Salmon Creek (#9)		15	
1982	2 PNP permits issued (Eklutna (#17) and Favorite Bay (#18)		17	
1983	3 PNP permits issued (Neets Bay (#19), Crittenden Creek (#22), and Esther (#20)		20	
	1 state hatchery completed (Broodstock Development Center)	20		
1984	1 PNP permit issued (Santa Ana (#21)		21	
1985	1 PNP permit issued (Port Camdem (#23)		22	
1986	1 PNP permit issued (Beaver Falls (#24)		23	
1987	State enhancement projects at Starrigavan and Halibut Cove started			
1988	Aquatic Farm Act signed; statute passes allowing contracting of hatchery operations			
	4 state hatcheries contracted to private sector (Kitoi Bay, Trail Lakes, Cannery Creek, Hidden Falls)	16		
	4 PNP permits issued (Hidden Falls (#28), Cannery Creek (#26), Trail Lakes (#27), Kitoi Bay (#29)		28	
	1 state hatchery constructed (Pillar Creek)	17		
	2 PNP permits revoked (Sandy Bay (#4) and Salmon Creek (#14)		26	
1990	CSHB432 becomes law prohibiting finfish farming in Alaska			
	1 PNP permit issued (Bell Island (#30)		27	
1991	5 state hatcheries contracted to private sector (Main Bay (#31), Tutka, Gulkana (#30), Pillar Creek (#38), and Beaver Falls (#24) – Beaver Falls and Tutka tallied elsewhere	12		
	Portions of 6 state hatcheries paid for by private or federal funds		30	
1992	1 state hatchery closed (Russell Creek)	11		
	2 PNP permits issued (Haines projects (#34) and Port Graham (#33)		32	
	1 PNP permit revoked (Meyers Chuck (#10)		31	
	FRED Division merged with the Commerical Fisheries Division to form the Commercial Fisheries Management and Development (CFMD) Division			
1993	3 state hatcheries transferred from CFMD Division (Broodstock Development Center, Elmendorf, & Ft. Richardson)			
	2 state hatcheries contracted to private sector (Crooked Creek and Klawok)	9		
	1 state hatchery closed (Big Lake)	8		
1994	4 PNP permits issued (Tutka (#32), Crooked Creek (#35), Klawok (#36), Deer Mountain (#37)		35	
	1 state hatchery contracted (Deer Mountain)	7		
	Ft. Richardson Hatchery merged with Broodstock Development Center	6		
1995	1 PNP hatchery under new management (Klawok (#38)			
	1 state hatchery transferred from CFMD to Division of Sport Fish (Crystal Lake)			
	1 state hatchery closed (Sikusuilaq)	5		
1996	1 state hatchery contracted (Snettisham (#39)	4	36	
	1 state hatchery transferred from CFMD Division to Division of Sport Fish (Clear)			
	3 PNP permits revoked (Crittenden Creek (#22), Santa Ana (#21), and Favorite Bay (#18)		33	
1997	1 state hatchery closed (Clear)	3		
	2 state contracted PNP hatcheries closed (Beaver Falls (#24), and Crooked Creek (#35)		31	
	1 PNP hatchery closed & reopened under new management (Burnett Inlet (#5), now #40)		31	
1998	1 PNP hatchery closed (Eklutna (#17)		30	
2000	1 state hatchery contracted to private sector (Crystal Lake Hatchery)	2	31	3

Note: Perry Island, Kowee Creek, Port Camden and Bell Island are not active PNP sites (total = 27 active operational PNPs) hatchery production protects wild stocks, (3) whether or not the hatchery operation is compatible with the regional comprehensive salmon plan, and (4) whether or not the site for the hatchery is appropriate (Alaska Board of Fisheries 1999).

Regional comprehensive salmon plans have been completed by RPTs for the following regions: Southern Southeast, Northern Southeast, Yakutat, Prince William Sound/Copper River, Cook Inlet, Kodiak, Chignik, Alaska Peninsula/Aleutian Islands, Bristol Bay, Yukon River, and Norton Sound/Bering Strait. Regional comprehensive planning progresses in stages. Phase I sets the long-term goals, objectives, and strategies for the region. Phase II identifies potential projects and establishes criteria for evaluating the enhancement and rehabilitation potentials for salmon in the region (McGee 1995). Many regions, including Northern and Southern Southeast, Prince William Sound/Copper River, Yakutat, Cook Inlet, Kodiak, and Bristol Bay completed their plans in the 1980s. Others, like Chignik, Alaska Peninsula/Aleutian Islands, and Norton Sound/Bering Strait, completed their plans in the 1990s. Most of these plans were written for a 20-year period and some, like Northern and Southern Southeast were updated in the 1990s. One region, Prince William Sound/Copper River, developed a third planning phase in 1994 that incorporated the allocation and fisheries management plans of the Board of Fisheries with hatchery production plans. Each region approached the development of its regional comprehensive plan differently and the resulting documents reflect this (Krasnowski 1997).

PNP statutes provide for regional aquaculture associations comprised of representative fishery resource user groups within regions. In order to obtain a hatchery permit, these groups must be PNP corporations. Aquaculture associations can (1) build and operate hatcheries, (2) assist ADF&G in developing regional salmon plans, (3) authorize tax assessments on commercially caught salmon to support ranching (a 1%, 2%, or 3% assessment is chosen by vote of the members), and (4) provide for the sale of a portion of returning hatchery fish to help cover operational costs and repay state loans (Heard 1996). Before an aquaculture association or other PNP corporation can build and operate a hatchery, it must obtain the necessary hatchery permits from ADF&G.

PERMITTING

The permit application procedure for a PNP hatchery is described in Title 5 of the Alaska Administrative Code (AAC 40.100–40.990). Application procedures include pre-application assistance, management feasibility analysis, application form and fees, determination of acceptance by ADF&G for formal review, RPT review, completeness determination by the commissioner, and a provision for reconsideration. The ADF&G Divisions of Commercial Fish, Sport Fish, and Habitat and Restoration; the principal pathologist; and the principal geneticist review the hatchery permit. A public hearing and full review by other state and federal agencies is required through the coastal zone consistency process. A basic management plan (BMP) is developed as part of the permit. The BMP includes a description of the facility, special harvest areas, broodstock description and development, and hatchery stock harvest management. The permit application process is shown in Figure 2. In 1975 the first PNP permits were issued for four locations: Perry Island, Port San Juan, Sheldon Jackson, and Sandy Bay. Forty PNP permits have been issued since inception of the program. The PNP permit process usually takes one to two years to complete (McGee 1995). A hatchery permit is nontransferable.

When a permitted hatchery becomes operational, an annual management plan (AMP) is developed for each year of operation. Specific plans for egg takes, cost recovery, harvests, fry and smolt releases, and marking and recovery are included and approved in this plan. AMPs are developed by ADF&G in conjunction with the operator and are reviewed by the fisheries management divisions and RPT before approval by the commissioner (McGee 1995). Any PNP permit holder is to submit an annual report to

ADF&G, which is to include but not be limited to information pertaining to species; broodstock source; and number, age, weight, and length of adult returns attributable to hatchery releases (ADF&G 1996). Even though statutes permit inspection of a hatchery by ADF&G personnel at any time the hatchery is operating, the annual reports along with the AMPs constitute the primary PNP-monitoring vehicles. The PNP regulation process is shown in Figure 3.

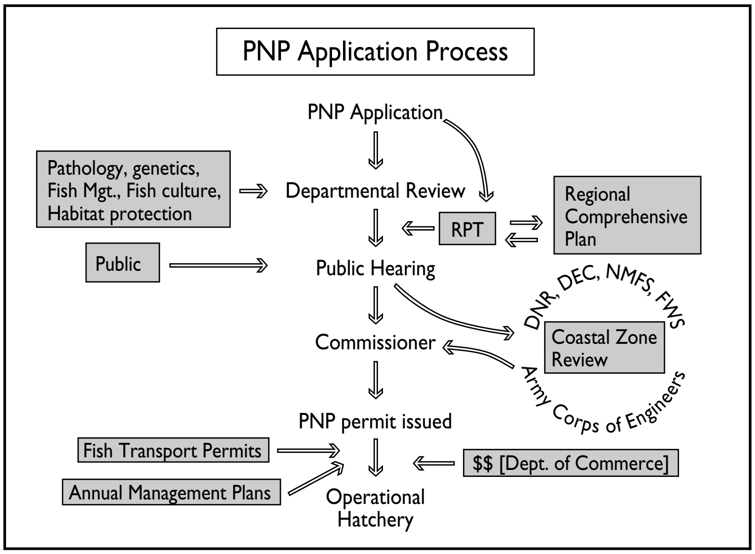

Figure 2. PNP application process chart (McGee 1995).

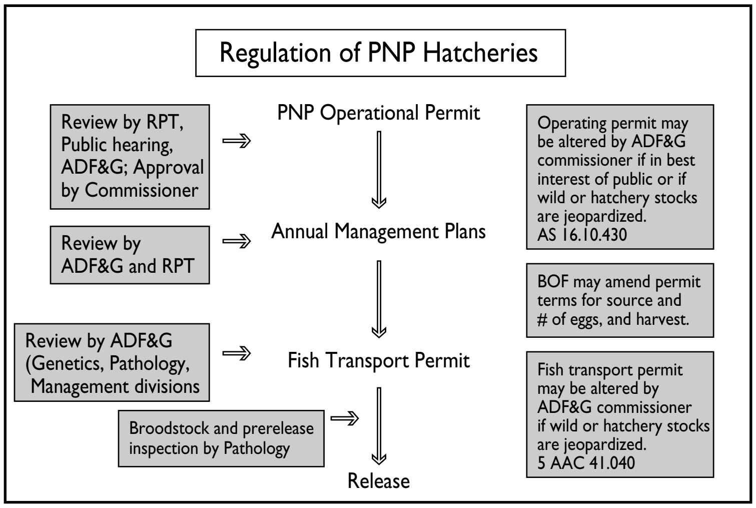

Figure 3. Regulation of PNP hatcheries (McGee 1995).

Alaska statutes (AS 16.10.400–430) place responsibility for the PNP program with the commissioner of ADF&G. It is the exclusive authority of the commissioner to issue permits for the construction and operation of salmon hatcheries. The commissioner may place conditions on a permit. All PNP permits include a fish transport permit (FTP). Title 5 ACC 41.005 states that no person may transport, possess, export from the state, or release into the waters of the state any live fish unless that person holds an FTP issued by the commissioner (McGee 1995). The principal pathologist and geneticist, as well as the region's regional supervisors for the ADF&G divisions review all FTPs. Additional PNP permit conditions may include the following: no placement of salmon eggs or resulting fry into waters of the state except as designated in the permit, restrictions on the sale of eggs or fry, no release of salmon before ADF&G approval, destruction of diseased fish, and ADF&G control of where salmon are harvested by hatchery operators.

The commissioner of ADF&G has the power to revoke a hatchery permit if he or she determines that after five years from the date of issue, the permit holder has not undertaken substantial work to operate a facility in compliance with the terms and conditions specified in the permit. Seven hatchery permits have been revoked to date: Salmon Creek #9 and #14, Crittendon Creek, Santa Anna, and Favorite Bay due to lack of progress toward operating a facility; Sandy Bay as the result of a natural disaster (landslide); and Meyers Chuck because of a violation of the terms of the permit when an unauthorized habitat alteration in an anadromous stream took place (S. McGee, pers. comm.).

The commissioner can also consider a permit alteration, suspension, or revocation based on an internal review that deems the hatchery operation performance is inadequate. RPTs use the following criteria to review, evaluate, and make recommendations to the commissioner: (1) hatchery survival standards, (2) the transport of broodstock from wild sources, (3) hatchery contribution to common property fishery, (4) hatchery impact on wild stocks, (5) fulfillment of production objectives, and (6) mitigating circumstances (ADF&G 1996). More recently, several of the amendments have resulted in a downward adjustment of allocated egg takes due mostly to lack of facility capability or use. Since 1999 the hatcheries in Prince William Sound have had their permits adjusted downward about 150 million pink salmon eggs. Also in 1999, the hatchery at Solomon Gulch lost its allocation for fall chums due to nonutilization and a concern for potential overfishing of local wild coho salmon stocks (S. McGee, pers. comm.). Permitted hatchery capacity for chum salmon in Southeast Alaska was reduced by 119 million eggs between 1997 and 1998 and by another 90 million in 2000.

POLICIES

As described below, various policies were implemented in Alaska to guide hatchery development and to protect wild stocks.

In 1975 ADF&G formulated a provisional Finfish Genetics Policy, which was revised in 1978 following legislative approval of the PNP program. It was revised again in 1985 by a review team comprising scientists from ADF&G, PNP organizations, the University of Alaska, and the National Marine Fisheries Service. The policy represents a consensus of opinion and is intended to be reviewed periodically to ensure the guidelines maintain consistency with current knowledge (McGee 1995). The revisions clarify the rationale for the guidelines and reduce ambiguity in the policy. The current policy contains recommendations designed to protect the genetic integrity of wild stocks. It restricts stock transport, calls for identifying significant or unique stocks and establishing wild stock sanctuaries, and helps maintain adequate genetic variability in hatchery-produced stocks to enable them to adapt to changing environmental conditions (Genetic Policy Review Team 1985). The policy includes considerations for selective breeding practices to ensure diversity within hatcheries and from donor stocks.

Alaska's Fish Resource Permits Policy was approved in 1994 to replace an outmoded 1983 policy. This policy covers the various types of permits required for the collection and/or transportation of live fish in any life stage used for scientific, educational, propagative, or exhibition purposes (McGee 1995).

Alaska's Fish and Shellfish Health and Disease Control Policy was completed in 1988. Its purpose is to prevent the dissemination of infectious diseases to fish and shellfish without creating impractical constraints for aquaculture (McGee 1995). Regulations require that the state pathologist approve any transfer of live salmon and that all salmon eggs brought into any hatchery be disinfected. The policy also includes a separate fish culture document (Sockeye Salmon Culture Manual) that outlines breeding and hatchery protocols for sockeye salmon (Smoker et al. 1999). These special considerations for sockeye salmon were deemed necessary because of the persistent threat of IHNV disease in culture facilities. ADF&G may inspect hatchery facilities at any time they are operating. Each facility is inspected at least every other year by state pathology staff, and each broodstock is examined for disease prior to use in a hatchery (McGee 1995).

In 1992 Alaska's Salmon Escapement Goal Policy was approved to establish the basis and mechanisms for setting escapement goals for the state's wild salmon stocks. Then, in 2001 the Board of Fisheries adopted a revised policy as regulation.

It is intended to support the statute to provide for a wild-stock priority while managing fishery resources on a sustainable yield basis. In 1992 the Board of Fisheries also adopted the Policy for the Management of Mixed Stock Salmon Fisheries (5 ACC 39.220). This regulation makes conservation of wild stocks and sustained yield the highest priority when allocating salmon resources (McGee 1995).

In 2000 the Board of Fisheries adopted the Sustainable Salmon Fisheries Policy to further effect sustainable fisheries management. The policy is based on five central principles: (1) protect wild salmon and habitat, (2) maintain escapements, (3) apply effective management system, (4) encourage public support and involvement, and (5) manage conservatively when there is uncertainty (ADF&G and Alaska Board of Fisheries 2000). This policy recognizes the need to protect wild salmon stocks, as well as to conserve and maintain normal ecosystem functions.

SITE SELECTION

According to various ADF&G salmon plans, hatchery sites and remote release sites were to be selected to minimize the chance of returning hatchery stocks mixing with wild stocks. During the early 1970s, some biologists testified in legislative resource hearings concerning PNP hatcheries that intermingling of returns of wild and hatchery stocks could be minimized if barren systems were used as hatchery sites. By this time, however, several hatcheries (Ft. Richardson, Fire Lake, Deer Mountain, Kitoi) had already been placed on producing streams. In addition, the then director of the FRED Division felt siting was not a problem and that it was better to have the problem of too many fish returning (regardless of where they came from) than not enough (Alaska Senate 1992).

In general, the siting of the PNP hatcheries was determined in the permit review process by ADF&G and PNP staff. In 1974 an ADF&G policy on permitting PNP hatcheries in Alaska addressed permitting on streams depleted of salmon or for insignificant producers. Most early decisions were based on the reviewers' knowledge of the area and relevant fisheries. Hatchery siting decisions were often determined by who owned the land and the reliability of the water source. In the case of chinook salmon, however, guidelines were written in 1983 to minimize the chance of hatchery and wild stock mixing. No hatcheries in Southeast Alaska were to be built on streams with natural runs of chinook salmon (Denton et al. 2000). Current permit regulations state that a hatchery is to be located in an area where a reasonable segregation from natural stocks occurs. However, when feasible, it is also to be placed in an area where returning hatchery fish will pass through traditional salmon fisheries (ADF&G 1996). Given the nearly statewide distribution of salmon in Alaska, it is nearly impossible to avoid siting a facility close to a salmon stream.

STOCK SELECTION

In general, the broodstock for hatcheries is to come from stocks as close to the facility as practical. The 1985 Finfish Genetics Policy prohibits transport if there would be significant interaction with "significant or unique wild stocks." Just what "significant" or "unique" stocks are is rather vague and is left up to ADF&G interpretation. The policy prohibits transport of salmon between regions of Alaska and from outside the state; it permits transport within regions only with consideration of the risks. The policy has been enforced with rigor in preventing transfers of salmon to Alaska from outside of the state. Coho and chinook are the only species of salmon that have been transplanted in Alaska from outside the state. Several coho and chinook stocks were brought into the state from Washington in the 1960s and 1970s. Most of these fish came from either the Green River or Carson hatcheries and were placed in Alaska hatcheries at Crystal Lake, Fire Lake, Starrigavan, and Fort Richardson. The last egg transfers to come into Alaska from outside the state were chinook from Carson, Washington, in

1971 to Little Port Walter; coho from Green River, Washington, in 1972 to Crystal Lake; and coho from the Columbia River in 1979 to Tamgas Creek. There were also a few uses of broodstock from inside the state but outside of the region. For example, coho eggs were taken in the 1970s from Bear Lake (Seward) and Ship Creek (Anchorage) and used at Crystal Lake (Southeast). (See Appendix A for broodstock source for hatcheries).

In Southeast Alaska, eight ancestral chinook salmon broodstocks (Andrew Creek, Big Boulder Creek, Chickamin River, Farragut River, Harding River, King Salmon River, Tahini River, and Unuk River) have been used in hatchery production. Presently five of these broodstocks are being used, with two (Andrew Creek and Chickamin River) accounting for the majority of releases since 1988. The Broodstock Development Project at Little Port Walter maintains Chickamin and Unuk stocks in isolation from each other (and all are wire tagged) (W. Smoker, pers. comm.). Andrew Creek stock has been used at five hatcheries (Crystal Lake, Gastineau, Hidden Falls, Medvejie, and Sheldon Jackson). Most hatcheries in Southeast are 50 to 240 kilometers from any endemic chinook salmon stock (Denton et al. 2000).

Numerous coho broodstocks have been used in Alaska hatcheries; over 30 have been used in Southeast. Sashin Creek, a stock from the southern end of Baranof Island, is one of the more common and farthest traveled stocks. It is found at four hatcheries: three on Baranof Island (Hidden Falls, Medvejie, Port Armstrong) and one near Juneau (Auke Creek). However, there is no hatchery production of coho at Auke Creek. Sashin Creek coho were transferred to Auke Creek as part of a "norms of reaction" experiment in the early 1980s, but all were marked and none were allowed entry to Auke Creek (W. Smoker, pers. comm.). Also, Sashin Creek coho are not released at Medvejie. They are transported from the hatchery back to several hanging lakes (inaccessible to naturally-spawning salmon) on the east side of Baranof Island between Port Armstrong and Hidden Falls. Ketchikan Creek fish (originally from Reflection Lake) are used as broodstock for three hatcheries: Deer Mountain, Tamgas Creek, and Burnett Inlet. Most of the other hatcheries use stocks in close proximity to the hatcheries.

There are over 20 stocks being used for chum salmon broodstock, most in Southeast Alaska. All chum salmon broodstock sources have come from within the same region as the hatchery. Hidden Falls hatchery is the most used broodstock by other hatcheries and originated with three stocks: Kadashan, Clear, and Seal Bay. In turn, this broodstock has been used at the Medvejie Creek, Gastineau, Gunnuk Creek, and Indian River hatcheries. The three Gastineau hatcheries have the most complex mixture of broodstock, with at least six stocks being incorporated. The Whitman Lake and Neets Bay hatcheries both used the same three stocks (Carroll, Cholmondelay, and Disappearance) to start their broodstock. Cholmondelay and Disappearance Creeks are fall-run stocks and Carroll River is a summer-run stock.

Pink salmon are raised at fewer hatcheries in Alaska than are coho or chum. In Southeast, pinks are being raised at four hatcheries with about 10 stocks being used as broodstock. Most of these have come from sources close to the hatcheries and, with the exception of the Gastineau hatcheries, little broodstock interchange has taken place among hatcheries. In Prince William Sound, pinks make up the largest number of salmon being cultured. They are raised at four hatcheries with broodstock coming from Cannery Creek and Solomon Gulch, both of which are in close proximity to the hatcheries. The Koernig hatchery used three principal sources for broodstock (Duck/Galena Bay, Larson, and Ewan). This broodstock was also used for the Norenberg hatchery. Of these only Duck/Galena Bay made any significant contribution in even years. Larson (the site of Koernig hatchery) is an intertidal waterfall with a few fish spawning below it. Only Ewan contributed significantly in odd years. The broodstocks at Koernig have been moved to the Noerenberg hatchery on the western side of Prince William Sound.

Sockeye salmon are the least cultured salmon in Alaska due to a difficulty in culturing them because of their high potential for disease. There are currently five hatcheries plus two incubation box facilities raising sockeye salmon. Most of the hatchery sockeye broodstock come from remote sites (distant from the hatchery location), and the progeny are released back at these sites.

STRAYING

Straying rates for pink salmon from hatcheries in Prince William Sound specifically, and among wild pink salmon populations generally, may be significantly higher than for other salmon species (Sharp et al. 1993). Joyce and Evans (1999) used recoveries of thermally marked otoliths to determine if pink salmon strays from hatcheries could be detected adjacent to three Prince William Sound hatcheries (Noerenburg, Koernig, and Cannery Creek) in 14 selected streams in Prince William Sound. They purposefully studied streams where straying from the hatcheries would be most likely detected and did not systematically sample streams across Prince William Sound. The proportion of hatchery salmon in stream escapements ranged from 26% to 97%.

An obvious explanation for the large contribution of hatchery salmon to wild escapements in Prince William Sound lies in the numerical dominance of hatchery over wild salmon runs. In 1997 the commercial fishery in Prince William Sound harvested about 25 million hatchery pinks and 1.2 million wild pink salmon (Joyce and Evans 1999). The proportion of hatchery salmon in stream escapements may become large even when straying rates are small. The study also showed that straying was highly correlated with distance between the hatchery and donor stream origin. The Noerenburg and Koernig hatcheries had straying rates five times those for the Cannery Creek hatchery. The broodstock from the Noerenburg hatchery was obtained from pink salmon spawning streams located distant from the facility, while the Cannery Creek hatchery stock was obtained from Cannery Creek. Broodstocks from the Koernig and Noerenburg hatcheries originated from streams considered unstable, and they may have more tendencies to stray (Joyce and Evans 1999). This is probably due to the fact that these broodstocks were from intertidal spawning stocks that probably have intrinsically much lower homing fidelity than do upstream stocks (W. Smoker, pers. comm.). High rates of straying in Prince William Sound relative to other locations may reflect recent geologic instability in the Sound. The 1964 earthquake caused widespread habitat destruction in the intertidal zone of streams. A large proportion of Prince William Sound pink salmon are intertidal spawners, and a high level of straying was likely among returning salmon that found natal streams no longer accessible (Halpuka et al. 2000).

In another study using thermal mark recoveries in Southeast Alaska, returning pink salmon of Prince William Sound hatchery origin were found over 450 direct distance miles away from the hatchery (Agler et al. 2000). Thermally marked otoliths from chum salmon originating in Gastineau hatchery near Juneau have been recovered in watersheds near the hatchery (Smoker et al. 1999).

FISH CULTURE

In order to help maintain genetic variance in hatchery stocks, several guidelines for fish culture were outlined in the Finfish Genetics Policy. These include the following: a single donor stock cannot be used to establish or contribute to more than three hatchery stocks; a minimum effective population *(Ne)* of 400 should be used for broodstock development and maintained in hatchery stocks (however, small population sizes may be unavoidable with chinook and steelhead); and to ensure all segments of the run have the opportunity to spawn, sliding-scale egg takes for donor stock transplants will not allocate more than 90% of any segment of a run for broodstock. There is also a caution in the policy to keep the male-to-female sex ratio as close to 1:1 as possible (Genetic Policy Review Team 1985).

The AMP for each hatchery outlines their respective fish culture procedures and is reviewed by ADF&G genetics staff for adherence. The FTP is used to authorize the broodstock and stocking location requested by each PNP in their respective AMPs. Prior to 1998 there was a potential for genetics review of the FTP without knowing what was in the AMP. ADF&G altered its review procedures and now staff geneticists routinely review both the FTPs and AMPs prior to their being approved by the commissioner (D. Moore, pers. comm.).

GENETIC DIVERSITY

Identification of the origins of salmon harvested from a mixed-stock fishery is a management concern as well as a conservation concern for biological diversity. The ADF&G Gene Conservation Laboratory has successfully used genetic data to identify regional stock components for selected populations of chinook, chum, pink, and sockeye salmon.

Data have been collected throughout the North American range for chinook salmon. Allele frequency differences are sufficient to identify differences among chinook stocks from eight large regions: Western Alaska, Southeast Alaska, British Columbia (non-Frazier), Fraser River, Washington Coastal, Puget Sound, Columbia River, and California-Oregon. At least two distinct lineages of chinook are present in Alaska: one composed of populations from Southeast and one of populations from west and north of the Copper River. Populations within Southeast Alaska are more divergent than those in the Western region. Three distinct groups are apparent within Southeast Alaska: Chilkat River, King Salmon River, and remaining Southeast populations (Crane et al. 1996).

A comparison of allele frequency data collected in western Alaska with data available for Pacific Rim chum populations suggests that populations of the Alaska Peninsula-Gulf of Alaska lineage were derived from Cascadia (the Pacific Refugium) and belong to a larger southern lineage, which includes populations from Southeast Alaska, British Columbia, and the Pacific Northwest. In contrast, populations from Northwest Alaska appear to be derived from a northern lineage with affinities to Asian populations. Populations of the northwest lineage occur in the largely unglaciated areas of Alaska north of the Alaska Peninsula, and the more southern lineage occurs in the glaciated and unglaciated areas of the Alaska Peninsula, Kodiak Island, and Southcentral Alaska (Seeb and Crane 1999).

ADF&G has conducted a pilot study of pink salmon from Northwest Alaska to Northwest Washington using DNA markers. Populations were found to be organized by latitude; populations that are geographically farthest apart are also genetically most divergent. In Prince William Sound, ADF&G found genetic differences between even- and odd-year fish and within-year differences between early and late spawning aggregates. Genetic differentiation has been found among streams and within streams, as well as between tidal and upstream spawning fish. These differences indicate that pink salmon in Prince William Sound are not one randomly interbreeding population, but rather a collection of populations with restricted gene flow (ADF&G 2001).

ADF&G has developed a sockeye salmon database of genetic information for the Upper Cook Inlet and Chignik River drainages and is currently working to expand the database to include Kodiak Island and the Bristol Bay drainages.

DISEASE PROTOCOLS

Risks of infectious disease dissemination have been reduced by rigorous enforcement of Alaska's Fish and Shellfish Health and Disease Control Policy (Holmes and Burkett 1996), which restricts transfer of salmon and requires inspection of facilities and examination of salmon. There have been several instances where IHNV disease has been detected in hatchery sockeye, and the fish have been destroyed. Because of this threat, Alaska has a sockeye-breeding protocol for hatcheries.

FISHERIES MANAGEMENT

Management of Alaska's salmon fishery began when Congress passed the Alaska Salmon Fisheries Act in 1889 to protect and regulate Alaska's fisheries; it was amended several times between 1900 and 1906. The Act prohibited obstruction of spawning streams and any fishery above tidewater in streams less than 500 feet wide (Pennoyer 1979). Prohibiting fishing out of stream mouths adversely affected fishery efficiency in order to reduce the prospect of overharvesting, but it necessarily established mixed-stock fisheries that are prone to overharvesting the weak stocks. With Alaska statehood in 1959, the legislature invested authority for management of Alaska's fisheries to ADF&G and the Alaska Board of Fish and Game (later separated into the Board of Fisheries and Board of Game). ADF&G was given authority to promulgate emergency orders to summarily open or close seasons or areas or to change weekly closed periods (Pennoyer 1979). The governor appoints members to the Board of Fisheries (also known as the Board of Fish). The Board of Fisheries has no administrative, budgeting, or fiscal powers but is charged with allocating salmon within and among different user groups and promulgating management regulations that are enforced by ADF&G. The Board of Fisheries holds hearings regarding regulations and policies affecting Alaska's fisheries throughout the state and maintains a system of advisory committees to obtain local input in making regulations.

Management of resources in waters within three nautical miles from shore is the responsibility of the State of Alaska (Pennoyer 1979). ADF&G manages the salmon fishery in discrete management areas. These include six fish and game resource management regions (Southwest, Southcentral, Southeast, Arctic, Interior West, and Interior Central) and four commercial fisheries management regions (Southeast, Central, Arctic-Yukon-Kuskokwim, and Westward). Because of the discrete nature of these areas, there is no comprehensive salmon management plan for the entire state and each management area has its own goals and objectives. In addition, ADF&G may promulgate certain statewide management policies that are signed by the commissioner of ADF&G, such as its Finfish Genetics Policy.

The mixed-stock and mixed-species nature of the Alaska fishery, as well as its system of allocation to specific user groups, creates complicated management issues. Even though the commercial fishery is by far the largest, the recreational, subsistence, and personal use fisheries all target on salmon. Meeting the needs of these diverse user groups while maintaining salmon population levels can be problematic. Although goals and objectives may differ from management area to management area, the ultimate salmon management goal statewide is to harvest surplus salmon from each stock while providing adequate escapement levels.

Article VIII of the Alaska Constitution mandates that renewable state resources be managed in a sustainable manner. This is the guiding principle behind the state's current fisheries management, whose goal is to produce maximum sustained yield. According to Alaska Statute (Title 16), it is the policy of ADF&G to manage for wild salmon stocks by ensuring adequate escapement. The commissioner approved the Salmon Escapement Goal Policy in 1992 to establish the basis and mechanisms for setting escapement goals for wild salmon stocks. The Alaska Board of Fisheries adopted a revised Salmon Escapement Goal Policy in 2001. This policy affirms the mandate to manage fishery resources on a sustainable yield basis.

A further relevant historical point is to note the growing dependency of commercial fisheries in Southcentral and Southeast on hatchery production. For example, salmon fisheries in the Gulf of Alaska are notable because hatcheries produce the majority of some salmon species in some areas and, in specific fisheries, the majority of salmon harvested.

Within this region, 56% of the salmon in the traditional commercial harvest were of hatchery origin in 1999, and the percentage is higher if cost-recovery fisheries are included. In Prince William Sound in particular, hatchery production provides a majority of the pink and chum salmon harvested and a substantial fraction of the sockeye and coho salmon harvested. In 1999 hatchery pink salmon contributed 84% of the number of pink salmon harvested by commercial fisheries in Prince William Sound (P. Mundy, pers. comm.).

Special Harvest Area

The harvest of salmon in Alaska, regardless of whether the fish were naturally or artificially propagated, may be conducted only pursuant to regulations adopted by the Board of Fisheries. The harvest of salmon returning to a PNP hatchery is governed by regulations adopted by the Board of Fisheries and is a common property fishery. The operation of PNP hatcheries brings with it the obligation to provide the hatchery operator with a certain portion of the hatchery run for recovery of operational costs and broodstock to sustain production. Cost-recovery harvests and broodstock collection take place within a designated area termed the special harvest area (SHA). Where hatchery returns enter a segregated location near the release site and can be harvested without significantly affecting wild stocks, a SHA is designated for each hatchery by regulation adopted by the board or by emergency orders issued by the commissioner. A PNP permit holder may harvest salmon for the hatchery only in the applicable SHA. However, this does not prevent a SHA from being open to commercial, sport, or subsistence fishing. Harvesting of salmon within the SHA, whether by the hatchery or the common property fishery, is opened or closed by regulation or emergency order. SHA boundaries are set in 5 AAC 40 or in a PNP permit issued by the commissioner (ADF&G 1996). A SHA is very similar to a terminal harvest area, except that a terminal harvest area is solely a common property fishery and does not have to be related to a hatchery.

Cost-recovery requirements and broodstock needs are determined in advance of the season and published in the AMPs. Based upon returns to the SHA, interception of hatchery returns by the common property fishery is adjusted to meet the hatchery's goals. Management strategies are developed each year based upon the specific cost-recovery and broodstock requirements, the forecast returns, and other factors as appropriate. These management strategies are formalized annually for each hatchery in the AMP (Prince William Sound - Copper River RPT 1994).

Mixed-Stock Fisheries

In Alaska, the ocean-ranching program has complicated management since its inception by the intermingling of hatchery and wild fish in the common property fishery. The regions where this has become a major concern are Kodiak, Cook Inlet, Prince William Sound, and Southeast (Krasnowski 1997). The mixed-stock fishery has apparently recently reduced some wild stocks below desirable numbers as evidenced by low wild pink salmon returns to the Coghill District in northwest Prince William Sound (Smoker et al. 1999). A few wild stocks of chum salmon in Southeast Alaska have probably experienced some detrimental effects of large-scale enhancement efforts, and at least one (Sheep Creek) may have been extirpated (Halupka et al. 2000).

The concern of overexploitation of wild fish can be amplified by the geographic location of hatcheries and release sites. For example, the Neets Bay and Whitman Lake hatcheries in Southeast Alaska are located along the migration pathway of numerous wild Behm Canal stocks (Halupka et al. 2000). The sustainability of high exploitation rates for southern Southeast Alaska and Lynn Canal coho and chum salmon is a concern. Declines in the early-run coho salmon in the Skeena and Taku Rivers may be caused by overharvest in the fishery directed at sockeye salmon. A similar concern exists for late-run coho salmon from Lynn Canal that are harvested in a fishery directed at chum salmon runs to the Chilkat River (Halupka et al. 2000). Wild coho salmon returning to Salmon Lake are of special concern due to increased fishing pressure targeting hatchery-produced (Medvejie) chum and coho salmon in the Deep Inlet SHA (Schmidt 1996).

Attempts to reduce risks to wild stocks from overharvest have been implemented by siting facilities where harvests are not mixed (e.g., Hidden Falls) and by using tags to identify hatchery fish in mixed harvests (e.g., Nakat Inlet). In areas of mixed-stock fisheries, large-scale marking programs (thermal otolith marks) have been initiated to contain the risk (Smoker et al. 1999).

Escapement

Wild Stocks. In order to achieve biological escapement goals (BEG) to ensure maximum sustained yield, managers depend upon in-season assessment of relative annual abundance. BEGs have been formulated by ADF&G for salmon by major river system. The in-season assessment is accomplished by using numerous methods including catch data from ongoing fisheries, test fisheries, aerial surveys, and weirs. The effectiveness of in-season management is evaluated by spawning escapements and exploitation rate estimates for indicator stocks. To monitor escapements ADF&G uses weirs, aerial surveys, towers, sonar, mark-recapture studies, and ground counts of spawners or carcasses on index streams. The methods may vary from region to region. Escapement goals for Alaska streams were established in the 1960s and 1970s and revised in 1991 for Prince William Sound, Cook Inlet, and Bristol Bay (Fried 1994). In Prince William Sound, for example, there are over 800 pink salmon streams. ADF&G seasonally monitors between 150 and 200 of these (which serve as the index streams) with weekly aerial surveys. ADF&G also enumerates escapements of two major sockeye systems in Prince William Sound by daily weir counts. Escapement was met for all index streams between 1990 and 2000 except in 1992, a year with very low returns in Prince William Sound for all stocks (Sharp et al. 2000).

In Southeast Alaska, there are over 5,000 streams producing anadromous fish. About 3,000 of these are principal salmon-producing streams and coho, pink, and chum salmon are found in most all of them. Most escapement estimates in Southeast are done by aerial survey along with some weir data and mark-recapture estimates. Escapement trends for coho salmon are primarily monitored for 34 streams in six stock groups (Yakutat, Lynn Canal, North-Central, Taku, Stephens Passage, Southern Inside), and none of these streams showed declining trends in escapement between 1981 and 1996 (Van Alen 2000). Helicopter surveys and weirs are used to count chinook escapements at 27 locations in 11 river systems. ADF&G is in the process of developing new spawner-recruit (S-R) escapement goals for chinook in Southeast to replace those established prior to 1985. New S-R escapement goals have been established for six systems (Situk, Alsek, Unuk, Chickamin, Blossom, Keta), and chinook escapements to these six systems have generally been within or above goal ranges since 1981 (Van Alen 2000). Reliable indices, or estimates, of annual escapements are available for just a handful of the over 200 systems in Southeast that produce sockeye salmon. Total run size is estimated for nine systems primarily using weir counts with mark-recapture studies as backup. Two systems (Chilkoot and Italio) have shown a downward trend in sockeye escapement counts over the 1980 to 1996 period (Van Alen 2000).

Since 1960, ADF&G has intensively monitored pink salmon escapements in 1,588 Southeast streams, but usually fewer than half are surveyed in any given year. Most counts are by aircraft and foot with occasionally counts by helicopter, weirs, or mark-recapture studies. Escapement trends were estimated using peak aerial survey counts from 652 streams between 1960 and 1996. Overall, escapement indices showed an upward trend for both northern and southern Southeast Alaska pink stocks. Florence Creek (Admiralty Island) was the only one of the 652 index streams to show a significant downward escapement trend (Van Alen 2000). ADF&G does not have a standardized program for indexing the escapement of chum salmon in Southeast, but aerial and foot escapement survey counts dating back to 1960 are available in its database. Baker et al. (1996) evaluated escapement trends for 45 chum salmon stocks and found declining escapements in 10. A decline in escapements of Chilkat River chum salmon has been an ADF&G concern since the mid-1980s (Van Alen 2000).

There are approximately 800 streams on Kodiak Island where salmon have been documented. Of these, 4 support chinook, 39 support sockeye, 150 support chum, 174 support coho, and all support pink salmon. The majority of sockeye and all chinook salmon escapement counts are obtained from weirs that are located on 12 spawning systems. Some pink, chum, and coho salmon escapement counts are also obtained from weirs, but most come from aerial surveys. Since the 1980s, the BEG has been met or exceeded for chinook, sockeye, pink, and coho salmon on Kodiak Island. Chum salmon production has been variable and low since 1992, nevertheless, the BEG has been achieved in 9 of 10 years between 1988 and 1998 (Prokopowich 2000).

There are approximately 582 documented spawning streams within the Alaskan Peninsula and Aleutian Islands. Most salmon escapement estimates are derived from aerial surveys plus five weirs that are used for monitoring sockeye salmon. Escapement estimates for the area are indexed totals and are limited to chinook, sockeye, pink, and chum salmon. Since 1989, average indexed total escapements have been above the escapement goal range for all species (Shaul and Dinnocenzo 2000). The Chignik River on the Alaskan Peninsula is in a separate management area and is monitored by a weir. Chinook and sockeye salmon escapements were above the BEG in 1997.

In general, Upper Cook Inlet salmon stocks are in good condition insofar as assessments of spawning escapements have been conducted. The best assessments are sonar counts of sockeye entering the larger watersheds (Kasilof, Kenai, Crescent, Susitna), followed by weirs. The majority of salmon spawning localities in Upper Cook Inlet have no direct assessment of escapements. The overall return of sockeye salmon in 1998 was low. Since the late 1980s, the Crescent River sockeye salmon run has declined and ADF&G is reducing the BEG for this system to reflect a decreased capability of the system to rear fish. Recent returns of sockeye to Fish Creek in Knik Arm have been poor and in 1998 produced less than 50% of the desired escapement. Chum salmon production has been relatively poor in recent years for the Susitna Basin. Coho stocks have generally produced strong runs throughout the 1980s and 1990s except for 1997, which was a substandard year in most drainages. After experiencing a significant downturn in the early 1990s, chinook salmon escapements continue to trend upward (Ruesch and Fox 1999).

In Bristol Bay, several indicators of run size are used including the False Pass fishery, Port Moller test fishery, tower counts, sonar, and aerial surveys. Sockeye salmon dominate the fishery in Bristol Bay and spawning escapement requirements have been defined by ADF&G for eight river systems there (Naknek, Kvichak, Egegik, Ugashik, Nushagak, Togiak, Wood, Igushik). Sockeye escapement goals were met or exceeded in all of these systems in 1999. Two of these systems (Kvichak and Nushagak) had difficulty meeting escapement goals for the 10-year period from 1989 to 1998. The 10-year escapement average for the Kvichak system was 12% below the goal (ADF&G 2000).

The vast size and remoteness of the Kuskokwim, Yukon, and Norton Sound areas present challenges to monitoring salmon escapements. Aerial spawning surveys have been the principal means of monitoring salmon escapements but over the past few years the use of weirs, counting towers, and sonar operations has increased. Most of the BEGs for these areas are based on average annual escapements from aerial surveys. Many of these are being reviewed and modified. Seven projects using weirs, counting towers, or sonar were operated in the

Kuskokwim area in 1999 to better monitor escapement. Escapement at the Kogrukluk River weir in 1999 was just over half of the BEG for chinook, under 50% for coho, and 54% for chum salmon (Burkey et al. 2000).

Most monitoring in the Yukon Drainage is for chum or chinook salmon and includes sonar (hydroacoustic), ground surveys, counting towers, and mark-recapture projects. Chinook salmon minimum escapement goals were generally achieved in the Alaskan, but not the Canadian portion, of the Yukon Drainage in 1999. The 1999 run was larger than the very weak 1998 run but below that of 1997. Escapements of summer chum in the Anvik River, the largest producer of summer chum in the Yukon Drainage, were above the escapement goal from 1991 to 1997. In 1998 no escapements in monitored tributaries met escapement goals and ranged from 27% to 81% below average. In 1999 the summer chum run in the Anvik was 12% below the minimum escapement goal. The 1998 and 1999 fall chum runs into the Yukon River were 46% and 44% of normal run size expectations. With the exception of the upper Tanana River, spawning escapements were below average but still within minimum escapement goals. In the Toklat River (Tanana Drainage), the 1999 escapement estimate was 86% below the minimum escapement goal and the lowest on record since 1982 (Bergstom et al. 2001).

Escapement projects in Norton Sound include counting towers on seven rivers, a test net on the Unalakleet River, and a weir on the Nome River. Overall, in 1998 returns of chinook salmon were average to above average, coho salmon were average to below average, and chum salmon were below average. Several streams in the northwest area (Pilgrim, Sinuk, and Nome) had chum escapements below goal. Escapement indices for Shaktoolik and Unalakleet were also below escapement goals in 1998 (Brennan et al. 1999). Also of concern in the Nome area was the fact that no chum salmon returned to the Penny and Cripple Rivers in recent years, causing concern for the extirpation of these populations (Clark 2000).

A recent review of salmon escapement data and estimation methods in western Alaska was conducted by a group of scientists who were asked by the commissioner of ADF&G to assist the Alaska Board of Fisheries (Independent Scientific Review Committee 2001). The group concluded "…the basic data on stock and recruitment are not as precise as would be desirable." Of particular concern was the general inability in many instances to allocate catches to river of origin, which precluded keeping track of trends in productivity by river system.

Hatchery Stocks. Ideally, one does not want escapement of hatchery fish but sufficient returns to the facility for the purpose of cost recovery and broodstock use. In most years, this is what takes place at PNP hatcheries. Occasionally, especially during broodstock development, there have been insufficient returns or a hatchery has harvested into its broodstock and not ended up with enough eggs. There have also been a few instances when too many fish returned and hatchery fish spilled over into adjacent streams and beaches. In 1998 a huge return of pink salmon in Prince William Sound flooded the processors and an unknown number went unharvested. In 1996 a large chum salmon return went underharvested in Southeast and many dead chums were noted on beaches. When this happens, there is a greater potential for hatchery fish to migrate to nearby streams and spawn with wild stocks. This is an undesirable scenario and ADF&G will take appropriate action including adjusting fishery openings or modifying hatchery permits to rectify the situation.

Discriminating Hatchery Fish in the Harvest

Understanding the relative impact of fisheries on wild stocks requires knowing what proportion of the harvest is of hatchery origin. This is akin to the need for managers to know the origin of wild salmon by watershed in order to track trends in productivity and to set escapement goals. Recognizing hatchery fish in the harvest has recently become much easier due to advances in mass tagging technologies.

The first major breakthrough in distinguishing between large numbers of hatchery and wild fish came with the use of coded-wire tags (Riffe and Evans 1998; Sharr et al. 1996). Coded-wire tags allowed reasonably precise estimates of the proportion of hatchery salmon in each harvest by the end of the season. However, its use for in-season management was limited by technical difficulties that have since been solved by thermal mass-marking. Thermal marking of otoliths was initiated in Prince William Sound in 1995, and since 1997 all hatcheries there are so marking released fish. This tool has greatly increased ADF&G's ability to manage the fishery, for within 24 hours managers can determine what percent of the catch is hatchery and to a degree of precision not possible with the previous marking technology. This information gives managers the basis for opening, closing, or otherwise modifying the fishery to control the proportion of wild salmon in catches to ensure wild salmon escapement. Since 1997, all escapement goals in Prince William Sound have been met or exceeded and the thermal-marking tool is likely responsible for this success.

In Southeast Alaska, it is felt that better segregation of the chum salmon runs has made the fishery easier to manage than in Prince William Sound; nevertheless, ADF&G is encouraging all hatcheries to thermally mark all chum salmon (S. McGee, pers. comm.). Currently, most Southeast hatcheries are thermally marking chum and sockeye salmon and all pink salmon are marked at the Gastineau hatcheries. Northern Southeast and Douglas Island PNPs have been doing so since 1997, and the Southern Southeast Regional Aquaculture Association is in the process of implementing structural changes to its facilities that will enable marking 100% of released chum salmon. Some smaller operations, like the Gunnuk Creek hatchery, have not yet been able to comply with this request due to complex water quality and allocation problems. Due to ongoing research projects and complex U.S.-Canada treaty considerations, coded-wire tagging operations are still used for chinook and coho salmon marking.

CONCLUSIONS

There has been little systematic evaluation of the effects of hatcheries on natural systems. Most evaluations of hatcheries are economic rather than biologic, as might be expected given the commercial purpose of large-scale hatchery production. Another commonly recognized benefit from hatcheries is stocking with trout and salmon throughout the United States for sport fisheries. The most common and accepted biological benefits attributed to hatcheries are their use for research and as possible refuges for threatened or endangered species. Critics of hatcheries often do not agree among themselves on the nature and severity of the risks hatcheries pose or on ways to minimize them (Waples 1999). Various scientific reports have asserted that hatchery-produced salmon stocks have reduced or replaced wild stocks (Eggers et al. 1991; Hilborn and Eggers 2000), while others offer differing views (Smoker and Linley 1997; Wertheimer et al. 2001). Some argue that genetic diversity can be reduced by artificial propagation (Reisenbichler and Rubin 1999), others diminish the risk (Campton 1995), and others minimize it (Cuenco 1994). Given these divergent views and the lack of data that prove any one view, research is needed to shed light on the issues and hopefully provide practical solutions.

Alaska's ocean-ranching salmon hatcheries operate amidst considerable uncertainty. Perhaps the most striking feature in conducting this review was encountering so many gaps in the available scientific data from which one can fairly draw conclusions on the effects hatcheries may or may not have on wild salmon. Alaska has been successful in augmenting salmon harvest, but in accomplishing this, the question of whether salmon biodiversity has been adequately protected is unanswered. The robust and reliable data necessary to evaluate interactions between hatchery and wild salmon populations have not, in most cases, been collected. Decisions regarding the efficacy of hatcheries or ocean ranching should be based on sound science. Unfortunately, due to uncertainties and gaps in the available data, management decisions are more often based on short time frames and focused on local concerns rather than on long-term time frames and whole ecosystems. Better data are needed to bring consensus among scientists and managers on how to figure uncertainties, such as ocean carrying capacity and genetic risk to wild fish from hatchery straying, into the complex management equations. Until such data are available and algorithms for using them developed, the prudent course for management is a conservative one.

In the comprehensive salmon plan for Prince William Sound, one of the recommendations is that the proportion of hatchery salmon straying into wild stock streams must remain below 2% of the wild-stock escapement over the long term (Prince William Sound - Copper River RPT 1994). This recommendation is obviously not being followed. Straying of hatchery fish in Prince William Sound and Southeast is a major concern that is not being adequately addressed and needs to be brought fully into the light. Without proper monitoring, it cannot be said with certainty what impact high hatchery straying rates are having on wild fish. Potentially it is of significant magnitude and may not be in line with Alaska's Sustainable Salmon Fisheries, Finfish Genetics, and Salmon Escapement Goal Policies, or with the wild stock priority statute as it relates to the protection of wild stocks.

After more than 30 years of debate about the impact of hatchery fish on the genetic diversity of wild salmon populations, there still is no definitive answer to this concern (even given the increase in the body of knowledge). It may be easy to identify risks that hatcheries pose for natural populations; it is not so easy to predict whether deleterious effects have occurred or, if they have, how serious the consequences will be. One problem with genetics research is that it can be costly and lengthy. Regardless, it is prudent to continue investigations in this area. Given the documented incidence of straying of hatchery fish, especially pink and chum salmon in Prince William Sound and Southeast Alaska, an increased commitment to genetic studies and monitoring of wild stocks proximal to hatcheries for any detectable genetic changes is warranted. Elucidation of salmon population structure is always important information for developing management programs designed to conserve biologic and genetic diversity.

Is Alaska's Finfish Genetics Policy sufficient to protect the state's wild salmon? Protection of wild stocks is a principal objective of the policy, which is considered to be one of the more conservative policies in the country (Davis and Burkett 1989). That said, the policy has not been revised since 1985 and could be updated to ensure that the most recent molecular genetic knowledge and technologies are used. There are examples of hatchery practices that are out of compliance with this policy and accepted practices elsewhere. The policy calls for a single donor stock to be used in no more than three hatcheries. Five Andrew Creek chinook and four Sashin Creek coho stocks have been used at Southeast hatcheries. It is difficult to follow the trail of chum salmon hatchery stocks in Southeast, but it appears that the Hidden Falls hatchery is made up of at least three separate stocks that in turn have been used (albeit to a limited extent) in four other hatcheries. The restriction on stock transport to within regions sounds good, but Southeast Alaska is a big region and stocks are transported over large distances. It is a recommended practice in other parts of the country and in Canada to occasionally infuse wild gametes into a hatchery population for conservation purposes. This is currently not being done in Alaska, although most hatcheries have outbred their broodstocks in one way or another, either from the inclusion of strays (e.g. Prince William Sound pinks) or from wild stock egg take programs (e.g. Gastineau coho, Neets Bay coho).

The Finfish Genetics Policy came about as a result of a concern that the development and operation of a hatchery system could, if not done properly, have a detrimental impact on wild salmon populations. A provisional policy was developed in 1975 and the most current revision was published in 1985. The policy contains guidelines that provide for the application of genetic principles to the development and management of hatchery broodstock. ADF&G applied the existing body of population genetics knowledge to the development of the Finfish Genetics Policy, but at that time there was little, if any, information on genetic impacts of hatchery-produced fish on wild populations.

The need to conserve genetic information is fundamental to salmon biodiversity conservation. Both commercial fishing and hatchery production can adversely affect conservation of genetic diversity. The Finfish Genetics Policy recommends designation of hydrological basins or geographic areas as gene preserves—perpetual repositories of genetic information for all plant and animal species inhabiting such areas. Currently, there are no officially recognized gene preserves in Alaska specifically established for salmon species. This issue has been examined by several of the RPTs. For example, the Cook Inlet RPT considered several streams on the Kenai Peninsula in the early 1990s as stock reserves or gene preserves for one or more salmon species. Unfortunately, this process was not completed due to funding constraints (G. Fandrei, pers. comm.). This is an oversight of long standing and should be addressed.

Another example of where a well-informed genetics policy is essential can be seen in evaluating hatchery-siting criteria. The majority of PNP hatcheries were permitted prior to 1992; the two large hatcheries in western Prince William Sound were permitted in 1975 and 1983. Most Alaska hatcheries were sited with land ownership and water quality as preeminent criteria, with less attention given to biologic concerns. Considerable biologic and managerial knowledge has accumulated since these hatchery sites were permitted. Many state hatcheries are located in areas that make straying into wild stock waters and complicated mixed-stock fisheries management inevitable. Both RPTs and the Finfish Genetics Policy address hatchery siting. In view of the mandate to protect wild stocks, the hatcheries in western Prince William Sound (as well as others, especially some in Southeast) may be less than ideally sited with regard to wild-hatchery interaction.

The question is often asked: To what extent are wild salmon stocks overexploited in mixed-stock fisheries? Management of a mixed-stock fishery is a complex problem even without hatcheries. Factoring hatchery fish into the management equation only makes a hard job more difficult. It is important not to overharvest small salmon populations that may contain unique adaptive traits (and genes). Given the number of streams in Alaska (and corresponding number of salmon stocks) coupled with the size of the ADF&G staff and state budget, conducting the monitoring required to ensure that no wild salmon stocks are being negatively impacted by overfishing or invasion of hatchery strays is nearly impossible. In Prince William Sound alone, ADF&G currently monitors 150 to 200 of the approximate 800 streams found there for escapement. In order to monitor all 800, a much larger staff and logistics budget would be needed. The advent of thermal marking is a significant advance in technology that will enable a much closer and more thorough monitoring of mixed-stock fisheries and subsequently better protection of wild stocks. Hatcheries are moving in the direction of marking all released fish, which will improve mixed-stock management.

Management of fisheries and of hatcheries must be integrated and adaptive. There is a need to change the expectations of managers and harvesters to coincide with the natural variation and uncertainty in the abundance of salmon populations (Knudson 2000). More reliable and timely estimates of wild-stock escapements and run sizes are needed to direct management of the mixed-stock fisheries, especially for those that harvest chum salmon in Southeast Alaska.

There is significant concern over competition for resources between hatchery and wild salmon stocks. Based on a review of the scientific literature and discussions with biologists, geneticists, and fishery managers about protecting salmon biodiversity, the potential impacts of extensive ocean ranching appear to pose a great concern for the ocean's carrying capacity. This may become the most important issue for assessing risks to wild salmon populations, especially for those with comparatively small numbers of individuals. It will likely become a higher risk than loss or change in genetic diversity due to hatchery practices. It has been hypothesized that hatchery-produced chum salmon from Southeast Alaska may be having a negative impact on wild stocks of chum salmon in Western Alaska through density-dependent interactions like competition for food in the marine environment. ADF&G believes that there is no conclusive evidence to link hatchery production in one part of Alaska with declines of wild salmon in another and, in fact, has seen indications of the opposite for chum salmon, where survival of both wild and hatchery chum salmon are high in Southeast Alaska (although this may not be true for fall run chums in Lynn Canal). Nevertheless, there is evidence (smaller size, soft flesh) that Asian salmon have suffered deleterious effects leading some researchers to conclude that the carrying capacity of the western North Pacific for pink and chum salmon has been exceeded. It is also thought that high numbers of pink salmon (many of them hatchery derived) may lead to lower numbers of chum salmon.

Environmental conditions favorable for producing salmon are (and have been for several years) on a decline in the northern portion of the North Pacific. Consistent with this are results of several studies indicating declines in the size of harvested salmon. Although increased competition may not lead directly to increased mortality, wild fish that survive to spawn may have fewer eggs, less energy to reach spawning grounds, and smaller bodies to contribute to the ecosystem. According to Myers et al. (2000), underlying mechanisms of the processes linking climate, ocean productivity, and salmon production are not well understood and better information is needed on salmon distribution, abundance, and migration patterns with respect to environmental conditions.

The potential for hatchery-bred salmon to displace wild fish in the ocean, coupled with the lack of knowledge about complex dynamics of the North Pacific ecosystem as a whole, suggests that it would be prudent to manage Alaska's hatcheries conservatively. In other words, it would be better to reduce the state's hatchery release numbers in years of lower ocean-productivity indices. This would comply with Alaska's Sustainable Salmon Fisheries Policy requirement to manage in accordance with the precautionary principle (manage conservatively). The state's PNP hatcheries have reached a plateau of about 1.4 billion fish released into the marine environment and since 1997 have had about 150 million pink and 200 million chum salmon egg take removed from their permits. Given the various concerns and indicators that ocean carrying capacity for salmon in the northern North Pacific is likely on a decline, the number of hatchery releases may still be high (especially for pink and chum salmon in Prince William Sound and Southeast, respectively) and may be contrary to the Sustainable Salmon Fisheries Policy.

There is a need for greater scientific and public understanding of the climatic influences on fisheries and aquatic resources. Aquatic ecosystems are vulnerable to a range of climate change impacts including temperature changes, altered stream flows and ocean patterns, reduced water quality, and coastal changes. Addressing these impacts has not yet become a priority for scientists, as well as policymakers. It is incumbent upon scientists to determine which physical and biological processes lead to changes in salmon growth and survival so that when the ocean enters a different climate regime, the role ocean conditions play in changing trends of fish growth or survival can be ascertained (Brodeur et al. 2000).

With respect to fish-culture practices themselves, Alaska's hatchery practices as a whole are among the best in North America. The main reasons for this are both fortuitous and purposeful. By choosing to concentrate on pink and chum salmon, Alaska's ocean-ranching program has avoided many of the attenuated problems (e.g. domestication and ecological) with long-term rearing species like steelhead trout and coho salmon. Given the late date at which Alaska's ocean-ranching program was established, the state benefited from mistakes that had been made elsewhere and got the program started on better footing by having genetic oversight of operations through fish transport permits, hatchery siting, egg takes, broodstock development, etc. Oversight of fish diseases by the state's pathology department has been exemplary and closely follows the Fish and Shellfish Health and Disease Control Policy.

Given the concerns surrounding the biologic and management issues of ocean ranching, prioritizing research objectives can help narrow existing information gaps. Evaluation of hatchery operations have been inadequate. The State of Alaska has a rigorous permit procedure for starting a hatchery, outstanding pathology guidelines, and a good genetics policy. These tools are all very good in getting a hatchery properly started. However, hatcheries do not face sufficient supervision, monitoring, or evaluation once they are operating. As can be seen by perusing the reports or plans currently available, it is difficult if not impossible to gauge whether hatchery programs are impacting wild stocks or not. Hatchery programs should be evaluated rigorously on an ongoing basis by independent teams of scientists to determine whether they are achieving their goals and are not compromising other worthy goals.

Monitoring of hatchery practices is a duty and responsibility of the RPTs. Judging from the type of reports they produce (e.g. AMPs), their primary concern is development of hatchery-production plans and evaluating the resulting contribution to the fisheries. There is extensive documentation regarding egg takes, incubation, rearing, and broodstock, as well as regarding management of fisheries on hatchery returns including common property fisheries, SHAs, cost recovery, and marking/tagging studies. However, there is virtually no information about whether egg takes reflect the run-timing characteristics of the stock; the degree to which adequate numbers of spawners are used for hatchery broodstock; how often a stock has been used as a brood source; straying rates; or the number and final destination of fish that escaped the cost-recovery harvest. There is some information in certain plans that addresses the protection of wild stocks, but there is almost no information on how effective any of the proposed measures have been. As to whether a hatchery site is appropriate (one of the public benefit criteria), no published documentation addressing this point was found.

In recent years, several research initiatives have been suggested that are germane to the ocean-ranching issue. The Sound Science Review Team (1999) prioritized information needs regarding fishery ecosystems, focusing on Prince William Sound, and highlighted the need to evaluate interactions between hatchery and wild salmon. The reviewers identified three areas of concern: conservation, ecology, and management and suggested 18 specific research objectives (see Appendix B). As the present evaluation of biologic and management issues relating to ocean-ranching has made clear, there is insufficient data to ascertain the consequences of interactions between wild and hatchery-produced salmon. Unresolved questions involve a range of topics: fish culture, genetics, ecological interactions, competition between hatchery and wild salmon, and climatic change. Further, how all these factors affect salmon productivity is puzzling and deserves the attention of scientists and managers alike. Alaska's Sustainable Salmon Fisheries Policy mandates that, in light of uncertainty, a precautionary approach to management will best ensure the long-term protection of salmon biodiversity. Protection of biodiversity is the best insurance policy for survival of Pacific salmon, especially in the event of significant future environmental change.

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GLOSSARY

Adaptation. Evolutionary process resulting in an organism becoming optimally suited to its environment.

Aleutian Low. A winter weather pattern over the North Pacific that influences ocean productivity.

Allele. One of two or more alternate forms of a gene or other segment of DNA.

Anadromous. Fish that migrate from freshwater spawning areas to ocean waters and return to freshwater to spawn.

Aquaculture. The cultivation of fish or shellfish for food.

Artificial propagation. Any fish-culturing activity involving modification of natural spawning, incubation, or rearing habitat.

Biodiversity. Variety and variability among living organisms and the ecological complexes in which they occur at many biological levels, ranging from genes to species to ecosystems.

Broodstock. Adult fish retained for artificial propagation.

Carrying capacity. The maximum number or biomass of organisms that can be supported by a given habitat over the long term.

Conspecific. Belonging to the same species.

Deoxyribonucleic acid (DNA). Molecule that contains the genetic code consisting of a sequence of nucleotides.

Ecosystem. A community of organisms and their environment forming an interrelated unit.

Effective population size *(Ne).* Size of an ideal population that would have the same rate of increase in inbreeding or decrease in genetic diversity by genetic drift as the population being studied.

Electrophoresis. Technique for separating molecules based on their different mobility in an electric field.

Endemic. Refers to an organism that is either indigenous in or restricted to a specific geographic locality.

Fitness. Relative survival value and reproductive capability of a given genotype in comparison with others of a population.

Fry. Juvenile salmon at the time of yolk absorption and initiation of active feeding.

Gene. Basic unit of inheritance transmitted as part of the chromosome.

Gene flow. Exchange of genes (in one or both directions) between populations.

Gene pool. Sum total of genes in a breeding population.

Genetic diversity. Totality of genetic information that exists in a stock.

Genetic drift. Variation of allele frequency from one generation to the next due to chance fluctuations.

Genetic integrity. Population genetic structure in an unimpaired or sound condition.

Genotype. Genetic identity of an individual.

Hatchery fish. Any fish resulting from artificial spawning and rearing regardless of the history of the parent stock.

Hybridization. A cross between two genetically dissimilar individuals resulting in hybrid offspring.

Inbreeding. Mating of related individuals.

Inbreeding depression. Permanent or temporary reduction in fitness due to inbreeding.

Introgression. The incorporation of genes from one species or distinct population into the gene pool of another.

Linkage. Genes are linked when they are transmitted as pairs or sets because they are located close together on a chromosome.

Migration. Movement of any number of individuals or populations from one geographic location to another.

Mixed-stock fishery. A fishery where more than one stock of fish is harvested simultaneously.

Native. Fish stocks or populations indigenous to an area resulting from natural spawning.

Natural selection. Natural process by which organisms leave differentially more/less descendents than other individuals because they possess certain inherited advantages/disadvantages.

Ocean ranching. The process of artificially hatching and releasing juvenile fish into the ocean with the intent of later harvest as adults.

Otolith. Ear bone in fish that can be sectioned for the purpose of aging and can be imprinted with characteristic markings by modulating water temperature during culture for later use in identifying fish from a particular hatchery.

Outbreeding. Mating pattern in which mating between close relatives does not usually occur.

Outbreeding depression. Decrease in fitness resulting from hybridization between distant, isolated populations.

Parr. The freshwater stage of juvenile salmon between fry and smolt.

Pacific Decadal Oscillation (PDO). A pan-Pacific, recurring pattern of ocean-atmosphere variability that alternates between climate regimes every 20 to 30 years.

Phenotype. Visible properties of an individual produced by the interaction of the genotype and the environment.

Population. Group of organisms of the same species that occupy a well-defined locality and exhibit reproductive continuity from generation to generation.

Regime. A multiyear period of linked recruitment patterns in fish populations.

Run. Seasonal migration upriver to spawn.

Selection. Process (either natural or artificial) whereby select individuals, based either on fitness or other predetermined criteria, serve as broodstock for the next generation.

Smolt. Juvenile salmon at time of physiological adaptation to life in saltwater.

Special harvest area. An area, designated by the commissioner or the Board of Fisheries, where hatchery returns are to be harvested by the hatchery operators, and in some situations, by the common property fishery.

Species. Group of individuals that can interbreed successfully with one another but not with members of other groups.

Stock. Population sharing a common environment and participating in a common gene pool that is sufficiently discrete to warrant consideration as a self-perpetuating system, which can be managed.

Strain. Group of individuals coming from a particular location or produced by a particular breeding program.

Straying. The behavior of returning to a location other than the location of origin.

Terminal harvest area. An area where hatchery returns have achieved a reasonable degree of segregation from naturally-occurring stocks and may be harvested in the common property fishery without overharvesting wild stocks.

Translocation. Moving an individual or progeny from individuals outside its indigenous geographic range.

Wild (naturally-produced) fish. Fish or stock naturally spawned and reared.

APPENDIX A

BROODSTOCK HISTORY

(Adapted from various ADF&G files)

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Table A1. Broodstock history (hatcheries operating in 1999): Southeast Region.

OPERATOR: NSRAA					
Species	**Source**	**Years**	**Distance**	**Remote Release**	**Comments**
LOCATION: HIDDEN FALLS					
Chum	Kadashan River	77–80	Same region	Kasnyku Bay	
	Clear River	78–79	Same region	Kasnyku Bay	
	Seal Bay	80–81	Same region	Kasnyku Bay	
	Hidden Falls	81–99	proximate	Kasnyku Bay, Baranof Bay, Takatz Bay	
Coho	Deep Cove	88–90	SE/nearby district	Kasnyku Bay	
	Sashin Creek	89–93	SE/nearby district	Kasnyku Bay	
	Hidden Falls	91–98	proximate	Kasnyku Bay	
Chinook	Andrew Creek	81–88	SE/nearby district	Kasnyku Bay	
	Tahini River	83–91	SE/nearby district	Kasnyku Bay, Lutak Inlet	
	Crystal Creek	85–91	SE/nearby district	Indian River, Eliza Lake, Kasnyku Bay	Hatchery stock/Andrew Creek
	Farragut River	89–90		Farragut Lake	
	Medvejie	90–93	SE/nearby district	Kasnyku Bay	Hatchery stock/Andrew Creek
	Hidden Falls	90–99	proximate	Taiya Inlet, Kasnyku Bay, Indian River	
LOCATION: MEDVEJIE CREEK					
Chum	Medvejie Creek	81–99	proximate	Deep Inlet, Bear Cove	
	Nakwasina River	82–84	SE/same district	Deep Inlet	
	Salmon Lake	82–85	SE/same district	Deep Inlet	
	Deep Inlet	85–91	proximate		
	Hidden Falls	89–99	SE/same district	Deep Inlet	

Table A1 *cont.* Broodstock history (hatcheries operating in 1999): Southeast Region.

OPERATOR: NSRAA cont.

LOCATION: MEDVEJIE CREEK cont.

Species	Source	Years	Distance	Remote Release	Comments
Coho	Sealion Cove	81–84	SE/same district		Broodstock for lake stocking
	Sashin Creek	81–99	SE/nearby district	Deer Lake	Broodstock for lake stocking
	Deep Cove	81–97	SE/nearby district	Banner Lake	Broodstock for lake stocking
	Falls Creek	82–84	SE/same district	Elfendahl Lake	Broodstock for lake stocking
	Indian River	88–98	SE/same district	Deep Inlet, Bear Cove, Shamrock Bay	
	Medvejie	91–97	proximate	Bear Cove, Shamrock Bay, Wrinkleneck Creek	
	Hidden Falls	93–97	SE/nearby district	Deer Lake	Hatchery stock/Sashin Creek
Chinook	Andrew Creek	82–83	SE/nearby district	Bear Cove	
	Crystal Lake	84–94	SE/nearby district	Bear Cove	Hatchery stock/Andrew Creek
	Medvejie	86–99	proximate	Bear Cove	Current primary source
	Little Port Walter	88–89	SE/nearby district	Bear Cove	Hatchery stock/Chickamin River
	Ohmer Creek	89	SE/nearby district	Bear Cove	
	Whitman Lake	89–90	SE/nearby district	Bear Cove	Hatchery stock/Chickamin River
	Hidden Falls	94–96	SE/nearby district	Bear Cove	Hatchery stock/Andrew Creek

LOCATION: HAINES

Species	Source	Years	Distance	Remote Release	Comments
Chum	Slough	84–93	proximate	31 Mile Creek	Incubation boxes
	Spawning Channel	90–97	proximate	17 Mile	Spawning channel
	Herman Creek	94–99	proximate	Herman Creek, 17 Mile, 31 Mile	
	31 Mile Incubator	98–99	proximate		
Sockeye	Spring Pond	90–98		Chilkat Lake	
	Garrison Creek	95		Garrison Creek	
	Chilkat Lake	97		Chilkat Lake	

OPERATOR: SSRAA

LOCATION: WHITMAN LAKE

Species	Source	Years	Distance	Remote Release	Comments
Chum	Carroll River	79–97	Same region	Nakat Inlet, Earl West Cove, Kendrick Bay	Summer chum
	Cholmondelay	86–92	Same region	Nakat Inlet, Earl West Cove, Kendrick Bay	Fall chum
	Disappearance Creek	80–94	Same region	Neets Bay, Nakat Inlet	
	Nakat Inlet	82–86	Same region	Nakat Inlet	
	Burnett Inlet	90	Same region	Earl West Cove	Hatchery stock
	Neets Bay	98–99		Nakat Inlet, Earl West Cove, Kendrick Bay	Summer chum

Table A1 *cont.* Broodstock history (hatcheries operating in 1999): Southeast Region.

OPERATOR: SSRAA cont.					
Species	**Source**	**Years**	**Distance**	**Remote Release**	**Comments**
LOCATION: WHITMAN LAKE cont.					
Coho	Indian Creek	78–82	SE/same district	Herring Cove, Neets Bay	
	Whitman Lake	81–98	proximate	Herring Cove, Nakat Inlet, Earl West Cove	
	Karta River	95–96	SE/nearby district	Old Frank Lakes	
	Ward Lake	95–97	SE/same district	Herring Cove, Neck Lake	
Chinook	Unuk River	80–90	SE/nearby district	Herring Cove, Neets Bay, Carroll Inlet	
	Chickamin River	81–99	SE/same district	Carroll Inlet, Herring Cove	
LOCATION: NEETS BAY					
Chum	Carroll River	83–97	Same region	Neets Bay, Kendrick Bay	Summer chum
	Cholmondelay	84–97	Same region	Neets Bay, Nakat Inlet	Fall chum
	Disappearance Creek	89–94	Same region	Neets Bay	
	Neets Bay	98–99	proximate		
Coho	Neets Bay	81–90	proximate		
	Whitman Lake	89–98	SE/same district	Neets Bay	Hatchery stock/Indian Creek
Chinook	Ketchikan Creek	83–99	SE/same district	Neets Bay	Hatchery stock/Unuk River
	Whitman Lake	91–99	SE/same district	Neets Bay	Hatchery stock/Chickamin River
LOCATION: BURNETT INLET					
Coho	Big Creek	84–88	SE/same district	Burnett Inlet	
	Burnett Inlet	87–92	proximate		
	Ketchikan Creek	96–98	SE/nearby district	Burnett Inlet	Hatchery stock/Reflection Lake
Sockeye	Hugh Smith Lake	98–99	Hugh Smith Lake		

OPERATOR: AKI					
Species	**Source**	**Years**	**Distance**	**Remote Release**	**Comments**
LOCATION: PORT ARMSTRONG					
Pink	Sashin Creek	83–96	Same region	Port Armstrong	
	Port Armstrong	85–99	proximate		
Coho	Blanchard Lake	88–90	SE/same district	Jetty Creek	
	Deer Lake	89–92	SE/same district	Jetty Creek	Hatchery stock/Sashin Creek
	Port Armstrong	91–98	proximate		
	Hidden Falls	93–96	SE/nearby district	Port Armstrong	

Table A1 *cont.* Broodstock history (hatcheries operating in 1999): Southeast Region.

OPERATOR: BCF

Species	Source	Years	Distance	Remote Release	Comments
LOCATION: BURRO CREEK					
Pink	Sawmill Creek	80–82	Same region	Burro Creek	
	Howard Bay Creek	83–89	Same region	Burro Creek	
	Burro Creek	83–98	proximate		
	Pullen Creek	90	Same region	Burro Creek	
	Gastineau	93			Hatchery stock
Chum	Howard Bay Creek	80–88	Same region	Burro Creek	
	Burro Creek	85–98	proximate		
	Taiya River	86–88	Same region	Burro Creek	
Coho	Taiya River	86–96	SE/same district	Burro Creek	
	Pullen Creek	87–92	SE/same district	Burro Creek	
	Sheep Creek	88–90	SE/same district	Burro Creek	Hatchery stock/Montana Creek
	Burro Creek	91–97	proximate		
Chinook	Hidden Falls	90-95	SE/nearby district	Burro Creek	Hatchery stock/Tahini River
	Burro Creek	94-97	proximate		

OPERATOR: DIPAC

Species	Source	Years	Distance	Remote Release	Comments
LOCATION: GASTINEAU					
Pink	Kowee Creek	77–86	proximate		3 hatcheries along Gastineau Channel: Gastineau, Kowee and Sheep Creeks
	Sheep Creek	80–92	proximate		
	Salmon Creek	90	Same region	Gastineau	
	Kadashan River	88	Same region	Gastineau	
	Gastineau	87–98	proximate		
Chum	Kowee Creek	76–83	proximate		
	Hidden Falls	88–93	Same region	Gastineau, Boat Harbor	
	Sheep Creek	81–96	proximate		
	Gastineau	87–98	proximate	Amalga Harbor, Boat Harbor, Limestone Inlet	
Coho	Montana Creek	85–87	SE/same district	Gastineau, Sheep Creek	
	Snettisham	86–87	SE/same district		Hatchery stock/Speel Lake
	Gastineau	89–97	proximate	Gastineau, Sheep Creek	
	Sheep Creek	88–90	proximate	Gastineau, Sheep Creek	
	Steep Creek	89–97	SE/same district	Gastineau, Sheep Creek	
Chinook	Snettisham	84–92	SE/nearby district		Hatchery stock/Andrew Creek
	Crystal Lake	84–92	SE/nearby district		
	Little Port Walter	93–96	SE/nearby district		Hatchery stock/King Salmon River

Table A1 *cont.* Broodstock history (hatcheries operating in 1999): Southeast Region.

Species	Source	Years	Distance	Remote Release	Comments
OPERATOR: DIPAC cont.					
LOCATION: GASTINEAU cont.					
	Gastineau	95–97	proximate	Gastineau, Auke Creek, Twin Lakes, Fish Creek, Taiya Inlet	No wild stock used for broodstock since 1988. All chinook may have originated from Andrew Creek or King Salmon River
LOCATION: SNETTISHAM					
Sockeye	Speel Lake	88–98	Same region	Speel Lake, Sweetheart Lake, Speel Arm, Snettisham Inlet	
	Crescent Lake	90–95	Same region	Crescent Lake, Sweetheart Lake, Gilbert Bay	
	Chilkat Lake	93–96	Same region	Chilkat Lake	
	Snettisham	96–99	proximate	Sweetheart Lake	

Species	Source	Years	Distance	Remote Release	Comments
OPERATOR: KNFC					
LOCATION: GUNNUK CREEK					
Chum	Security Bay	82–83	Same region	Gunnuk Creek, Portage Bay	
	Hidden Falls	84–88	Same region	Gunnuk Creek, Kake Sha, Southeast Cove	
	Gunnuk Creek	88–99	proximate		
Coho	Portage Creek	94–96	SE/same district	Portage Creek	

Species	Source	Years	Distance	Remote Release	Comments
OPERATOR: SJC					
LOCATION: INDIAN RIVER					
Pink	Indian River	75–99	proximate		
	Starrigavan Creek	76	Same region	Indian River	
Chum	Katlian River	75	Same region	Indian River	
	Nakwasina River	76–84	Same region	Indian River	
	Sandy Creek	79–85	Same region	Indian River	
	Deep Inlet	85	Same region	Indian River	
	Indian River	80–99	proximate		
Coho	Indian River	75–98	proximate	Crescent Bay	
Chinook	Crystal Creek	84–90	SE/nearby district	Sitka Sound	Hatchery stock/Andrew Creek
	Andrew Creek	85–87	SE/nearby district	Sitka Sound	
	Indian River	89–99	proximate	Sitka Sound, Crescent Bay	

Table A1 *cont.* Broodstock history (hatcheries operating in 1999): Southeast Region.

OPERATOR: POWHA

Species	Source	Years	Distance	Remote Release	Comments
LOCATION: KLAWOCK					
Coho	Klawock River	78–98	proximate		
	Cable River	86–92	SE/same district	Cable River	
	Thorne River	88–92	SE/nearby district	Rio Roberts	
	Karta River	93-95	SE/nearby district	Old Frank Lakes	
Sockeye	Klawock Lake	86–99	proximate	Klawock Lake	

OPERATOR: MIC

Species	Source	Years	Distance	Remote Release	Comments
LOCATION: TAMGAS CREEK					
Chum	Tamgas Creek	93–98	proximate		BIA Hatchery
Coho	Nadzaheen Creek	78–81	SE/same district	Tamgas Harbor	
	Columbia River, WA	79–81	Washington (state)	Tamgas Harbor	
	Ketchikan Creek	80–82	SE/same district	Tamgas Harbor	
	Tamgas Creek	81–97	proximate	Tamgas Harbor, Tent Lake	
Chinook	Ketchikan Creek	82–85	SE/same district	Tamgas Creek	Hatchery stock/Unuk River
	Hybrid	85–88		Tamgas Creek	Hatchery hybrid stock/ Unuk & Chickamin Rivers
	Neets Bay	86–87	SE/same district	Tamgas Creek	Hatchery stock/Unuk River
	Unuk River	87–88	SE/same district	Tamgas Creek	
	Little Port Walter	87–89	SE/same district	Tamgas Creek	Hatchery stock/Unuk River
	Tamgas Creek	87–99	proximate	Tamgas Creek	

OPERATOR: FEDERAL

Species	Source	Years	Distance	Remote Release	Comments
LOCATION: AUKE CREEK					
Coho	Auke Creek	78–86	proximate		
	Sashin Creek	82–85	SE/nearby district	Auke Creek	
LOCATION: LITTLE PORT WALTER					
Chinook	Carson, WA	71–73	Washington (state)	Little Port Walter	Washington state hatchery stock
	Chickamin River	76–95	SE/nearby district	Little Port Walter	
	Unuk River	76–95	SE/nearby district	Little Port Walter	
	King Salmon River	88–92	SE/nearby district	Little Port Walter	
	Little Port Walter	93–99	proximate		

Table A1 *cont.* Broodstock history (hatcheries operating in 1999): Southeast Region.

OPERATOR: ADF&G

Species	Source	Years	Distance	Remote Release	Comments
LOCATION: CRYSTAL LAKE					
Coho	Green River, WA	72–73	Washington (state)	Ward Lake	Washington state hatchery stock
	Blind Slough	73–78	SE/same district	Crystal Creek, Mendenhall, Salmon Creek, Sheep Creeks	
	Bear Lake	74–76	SC/Seward	Crystal Creek	
	Ship Creek	74–77	SC/Anchorage	Mendenhall River	
	Duncan Salt Chuck	78–81	SE /same district	Crystal Creek	
	Crystal Creek	79–98	proximate	Crystal Creek, Ohmer Creek, Irish Creek, Sumner Creek, Slippery Creek, St Johns Creek	
	Slippery Creek	86–87	SE/nearby district	Slippery Creek	
	St Johns Creek	86–87	SE /same district	St Johns Creek	
	Mitchell Creek	92–96	SE /same district	Mitchell Creek	
	Portage Creek	92–93	SE/nearby district	Portage Creek	
Chinook	Chignik River	71–73	AP/Chignik	Crystal Creek	
	Ship Creek	71–75	SC/Anchorage	Crystal Creek	
	Chickamin River	75–76	SE/nearby district	Crystal Creek	
	Nakina River	75–76		Crystal Creek	
	Andrew Creek	75–79	SE/nearby district	Crystal Creek	
	King Salmon River	76–77	SE/nearby district	Crystal Creek	
	Farragut River	83–93		Farragut Lake	
	Tahini River	84–86		Tahini River	
	Harding River	86–92		Harding River	
	Crystal Creek	81–99	proximate		

OPERATOR: KHC

Species	Source	Years	Distance	Remote Release	Comments
LOCATION: DEER MOUNTAIN					
Coho	Ketchikan Creek	74–98	proximate	Ketchikan Creek, Ward Lake	
	Reflection Lake	86–94	SE/same district	Ketchikan Creek, Ward Lake Reflection Lake, Margaret Lake	
	Ward Lake	90–95	SE/same district	Bold Island Lake, Ketchikan Creek, Ward Lake	
Chinook	Unuk River	77–82	SE/same district	Ketchikan Creek	
	Ketchikan Creek	81–99	proximate		

Table A2. Broodstock history (hatcheries operating in 1999): Cook Inlet Region.

OPERATOR: PGHC					
Species	**Source**	**Years**	**Distance**	**Remote Release**	**Comments**
LOCATION: PORT GRAHAM					
Pink	Port Graham River English Bay River	90–00	proximate	Port Graham	
Sockeye	English Bay River	89–00	proximate	English Bay	
Coho	Port Graham River	96-98	proximate	Port Graham	

OPERATOR: CIAA					
Species	**Source**	**Years**	**Distance**	**Remote Release**	**Comments**
LOCATION: TRAIL LAKES					
Coho	Bear Lake	89–99		Bear Lake	
Sockeye	Tustemena Lake	90–99		Tustemena Lake, Kirschner Lake, Leisure Lake, Hazel Lake	
	Packers Lake	90–97		Packers Lake, Grouse Lake	All Trail Lakes hatchery fish for remote release
	Hidden Lake	89–99		Hidden Lake	
	Chelatna Lake	89–95		Chelatna Lake	
	Big Lake	98–99		Big Lake	
	Upper Russian Lake	89–91		Bear Lake	
	South Fork Big River	89–92		Bear Lake	
	Bear Lake	92–99		Bear Lake	
LOCATION: TUTKA BAY					
Pink	Tutka Creek		proximate		

OPERATOR: ADF&G					
Species	**Source**	**Years**	**Distance**	**Remote Release**	**Comments**
LOCATION: FT. RICHARDSON					
Coho	Ship Creek		proximate	Ship Creek, Bird Creek, Campbell Creek	
	Little Susitna River			Ship Creek, Bird Creek, Campbell Creek	
	Jim Creek			Eklutna	
	Bear Lake			Homer, Seward	
Chinook	Deception Creek			Willow Creek	
	Ninilchik			Ninilchik	
LOCATION: TUTKA BAY					
Chinook	Ship Creek		proximate	Ship Creek	
	Moose Creek			Eklutna	
	Crooked Creek			Crooked Creek	
	Ninilchik			Halibut Cove, Seldovia, Homer, Seward	
	Deception Creek			Whittier, Valdez, Cordova	

Table A3. Broodstock history (hatcheries operating in 1999): Prince William Sound.

OPERATOR: PWSAC

Species	Source	Years	Distance	Remote Release	Comments
LOCATION: KOERNIG					
Pink	Duck River	76	PWS/same district		Even year source
	Larson Creek	75–76	PWS/same district		Both odd and even year source
	Ewan Bay	75	PWS/same district		Odd year source
	Koering	78–99	proximate		Wild fish mixed with hatchery broodstock
LOCATION: NOERENBERG					
Pink	Koering	85–89			Hatchery source
	Noerenberg	89–99	proximate		
Chum	Wells River		Same region		
Coho	Mile 18 Creek		Same region		
	Power Creek		Same region		
	Corbin Creek		Same region		VFDA hatchery stock
LOCATION: CANNERY CREEK					
Pink	Cannery Creek	78–99	proximate		
LOCATION: MAIN BAY					
Sockeye	Eyak Lake		Same region		Early Run
	Coghill Lake		Same region		
	Eshamy Lake		Same region		
LOCATION: GULKANA					
Sockeye	Gulkana River	73–99	proximate		Onsite incubation boxes

OPERATOR: VFDA

Species	Source	Years	Distance	Remote Release	Comments
LOCATION: SOLOMON GULCH					
Pink	Valdez Arm	81–82	PWS/same district		
	Solomon	83–99	proximate		
Coho	Corbin Creek		proximate		

Table A4. Broodstock history (hatcheries operating in 1999): Kodiak Island.

OPERATOR: KRAA					
Species	**Source**	**Years**	**Distance**	**Remote Release**	**Comments**
LOCATION: KITOL BAY					
Pink	Big Kitoi Creek	72–99	proximate		
Chum	Sturgeon River	81–85			
	Big Kitoi Creek	86–99	proximate		
Coho	Buskin River	82–85			
	Little Kitoi Lake	83–92	proximate		
	Big Kitoi Creek	93–99	proximate		
LOCATION: PILLAR CREEK					
Coho	Buskin River	93–00			Stocked in Kodiak road system lakes
Sockeye	Afognak Lake	91–00		Hidden Lake, Big Waterfall Lake, Little Waterfall Lake, Crescent Lake	All for remote release sites
	Laura Lake	93–00		Laura Lake	
	Malina Lake	91–00		Malina Lake	
	Saltry Lake	94–00		Spiridon Lake Ruth Lake	

APPENDIX B

SOUND SCIENCE REVIEW AND PLANNING TEAM RESEARCH OBJECTIVES

CONSERVATION

1. Estimate the extent and causes of migration (straying) between Prince William Sound salmon local populations.

2. Describe microclimate environmental differences and connection to genetic differences.

3. Evaluate hatchery management and fish cultural effects on straying.

4. Determine extent of outbreeding depression by appropriate controlled experimentation.

ECOLOGY

1. Determine distribution and abundance of prey, species composition, and ocean temperature along the migratory pathway.

2. Estimate growth rate of the early life stages of pink salmon.

3. Monitor bioenergetic model of growth and describe changes in optimal growth conditions over time.

4-7. Four proposals having to do with various aspects of monitoring primary production in Prince William Sound.

8. Monitor predation models focused on how predator distribution responds to localized, short-term aggregations of vulnerable prey (hatchery releases).

9. Monitor the effect of pink salmon production on regional predator population size.

MANAGEMENT

1. Identify and characterize the effects of harvest management on hatchery and wild populations.

2. Identify locations outside of hatchery terminal areas that will exploit hatchery populations with low exploitations of wild stocks.

3. Determine geographic areas that are affected by straying.

4. Determine the relationship of run entry timing and straying potential of hatchery stocks.

5. Improve precision and accuracy of forecast methods to identify run strengths of individual hatcheries.