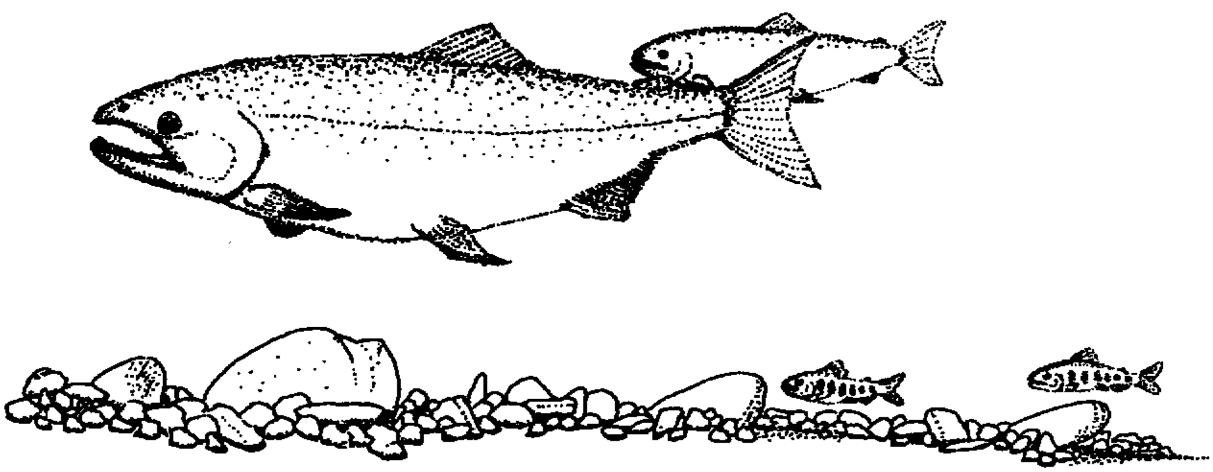
U.S. FISH AND WILDLIFE SERVICE

A REVIEW OF FACTORS RELEVANT TO THE MARINE SURVIVAL OF ANADROMOUS SALMONIDS OF WESTERN WASHINGTON



WESTERN WASHINGTON FISHERY RESOURCE OFFICE

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A Review of Factors Relevant to the Marine Survival of Anadromous Salmonids of Western Washington

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PREFACE

This document began as a literature search to complement federal hatchery evaluation activities in Western Washington. Relevant articles were read and summarized for their information on marine survival. The number of citations grew exponentially as papers and bibliographies were sought and summarized. In traditional literature reviews, the conclusions of several authors are paraphrased and grouped together in summary paragraphs. This can lead the reader to be unsure of the source of certain elements in the summary paragraph. Here I have chosen to present the interpretation of each author separately to allow you to focus on the individual citation for further reading.

Only about 20 percent of the citations in the bibliography have been referenced in this text. The overwhelming volume of published and unpublished literature on anadromous fish survival limits the utility of documents such as this one for presenting complete information and for being easily accessed. Personal interpretations of articles may also affect usage. We are now assembling the components of an automated literature access and retrieval system. Abstracts and documents relating to marine survival will be scanned and converted to computer text files. Text retrieval software will allow rapid access to the scanned text in response to user-defined queries. Any text files, including personal interpretations, like this document, can be accessed. The capital costs of installing such a text retrieval system are quickly recovered when compared to the costs of traditional labor intensive literature searches.

TABLE OF CONTENTS

MARINE DISTRIBUTION

GENERAL

Over 95% of the juvenile salmonids caught in the nearshore Columbia River area were subyearling chinook salmon. In the offshore area, steelhead were found only in late May and early June and to the north of the river mouth. Chinook and coho had a fairly uniform north-south distribution and were predominately 6km to 25 km offshore (Dawley et al. 1981).

Purse seine sampling was conducted from May to September, 1980 off Oregon and Washington from Tillamook Bay to Copalis Head. Spring chinook and steelhead were present during early sampling, only in the Columbia River plume and to the north. Coho and fall chinook were more evenly distributed and found throughout the sampling period. Concentrations of fish were found only within 28km of the shore (Miller et al. 1983).

The nearshore distribution of first summer juvenile salmon in the Gulf of Alaska results in minimal overlap with older immature salmon, which are found further offshore. This also minimizes contact with large predators such as albacore, pomfret, and jack mackerel. Overlap occurs with returning adults, but predation on juvenile salmon is rare. This may be due to swimming depths or feeding habits. Juvenile salmon migrate northwesterly in a narrow coastal band, about 20 nautical miles wide (Hartt 1980).

All five species of salmon and steelhead begin to enter the open sea by late June. Coho, chinook, and steelhead enter earlier than sockeye, chum, and pink. Southern populations migrate earlier than northern ones. In the Gulf of Alaska, sockeye, chum, and pink occur along the coastal belt from Cape Flattery to the eastern Aleutian Islands at least through September. Coho and chinook also occur mainly in the coastal belt, but some coho and chinook are well offshore by July. Steelhead are rare in the coastal belt, they apparently proceed directly offshore at the point where they enter the ocean proper. Juvenile sockeye, chum, and pinks do not scatter, but follow a definite migratory route. Washington, British Columbia, and southeast Alaska stocks migrate northward relatively near the shore. Most remain within a coastal belt less than 20 miles (32km) wide. In the northern Gulf of Alaska, where the continental shelf is wider, they extend farther offshore. First salt and second salt sockeye and chum show minimal overlap in locations. Little is known about migration habits between late September and the following spring. Apparently the fish move far out to sea and spread out over a wide area. In the coastal belt off southeast Alaska and Yakutat, first salt sockeye, chum, and pink originate from southern populations to Puget Sound. First salt coho and chinook extend to Kodiak Island and originate from as far south as California (Hartt and Dell 1986).

CHINOOK

Ninety-three percent of the coded wire tag marine recoveries of 1970 and 1971 brood spring chinook from the Columbia River basin were north of the Columbia River mouth. Snake River and Deschutes River fish showed a high percentage (40% to 50% recovery) in Oregon and California fisheries. For the respective broodyears, 63.8% and 68.1% of all recoveries were from marine fisheries (Wahle et al. 1981).

Spring chinook are found offshore in their marine life while fall chinook remain relatively inshore during their marine life (Healey 1983).

Fall chinook (ocean-type) tend to remain relatively inshore during marine life. Open-coast stocks range further north and further offshore than stocks originating from inside or sheltered coastal areas. Canadian sockeye range throughout the Gulf of Alaska. Sockeye do not move south of the 15°C isotherm (Healey and Groot 1987).

Fall chinook (ocean-type) predominate in populations south of 56°N, while spring chinook (stream-type) predominate in inland and coastal populations north of 56°N and in populations far upriver. Spring chinook are associated with areas of "low growth opportunity" (low temperature or photoperiod) or areas remote from the sea compared to fall chinook (Taylor 1990).

Priest Rapids (Columbia River) upriver bright fall chinook tend to have a more northerly marine distribution and a higher contribution to Alaska fisheries than other Columbia River stocks (Vreeland 1989).

Sportsmen at Kachemak Bay and Lower Cook Inlet, Alaska caught immature chinook from British Columbia (14 fish from Robertson Creek and Quinsam River hatcheries), Oregon (12 fish from South Santiam SFH), and Washington (2 fish). (Dudiak 1988).

Records of some Washington state hatchery mark recoveries :

Deschutes River: fish caught at northern Vancouver Island, mostly outside, but some in Johnstone Strait, south to just south of Columbia River mouth. Most recoveries were from the north.

Lewis River and Toutle River: mid-Vancouver Island to Fort Bragg, California. Seemingly equal numbers north and south.

Minter Creek: northern Vancouver Island, some Johnstone Strait, south to Fort Bragg, California. About 60% north and 40% south

Kalama River: northern Vancouver Island, all outside, south to Newport, Oregon. Most to the north.
(Ellis and Noble 1959).

Kalama hatchery fall chinook were recovered in southeast Alaska fishery. Elokomin, Oxbow, and Spring Creek fall chinook were not. Proportionately more Kalama fish were recovered in the northern part of the sampling range than were other Columbia River stocks (Wordlund et al. 1969).

COHO

Coho distribution was not correlated with sea-surface temperature, chlorophyll-a, salinity, or Secchi depth. Strong northerly winds and strong upwelling tended to disperse juvenile coho offshore and to the south. Fish were found closer inshore during periods of weak winds and weak upwelling. The center of distribution shifted northward as summer progressed. Larger fish were found farther north and farther offshore (Chung 1985).

Coho smolts from public hatchery, wild, and private hatchery stocks don't mix with one another when entering the ocean (Emlen et al. 1990).

Coho entering the ocean generally move south due to advection then actively move northward. Subyearlings and yearlings both move northward. Many coho do not migrate great distances up the coast but remain relatively near their region of release (Pearcy and Fisher 1988).

Coded wire tagged coho from Oregon public hatcheries were all found north of their ocean entry points. Washington coded wire tagged coastal coho were found north and south of their ocean entry points. None were found south of Seaside, Oregon, at the Columbia River mouth (Fisher and Pearcy 1985a).

Coded wire tagged coho were recovered south of their ocean entry points in May 1982. Strong upwelling may have caused currents that brought the smolts southward. Some fish tend to stay together during their downstream and early oceanic migrations. No net movement relative to the ocean entry point was seen in June 1982. Northward movement was seen by September. Washington origin fish migrated out of the sampled area. Chinook showed a southern movement in May and a northward movement in June (Fisher et al. 1983).

The average catch location of coho from the Big Creek SFH (Oregon, Columbia River) 1981 release and the Coos Bay SFH 1984 release was geographically compressed with later release dates (Mathews and Ishida 1989).

Coho from the Big Creek SFH (Oregon) 1966 release of two different release sizes were recovered from fisheries both north and south of the Columbia River. There was a slight predominance to the south (Johnson 1970).

Some juvenile coho were resident in near coastal waters throughout the summer. By September, all coded wire tagged coho and chinook collected were north of where they entered the ocean (Fisher and Pearcy 1985b).

CHUM, PINK, AND SOCKEYE

From tagging of fish in the ocean and recovery at site of homing - Washington chum range to the northern Gulf of Alaska, north of 57°N. Coastal coho were far-ranging, to southeastern Alaska and out to 143°W, 47°N. Most returns were from Vancouver Island. Chinook were tagged relatively close to their site of homing (French et al. 1975).

Canadian sockeye range throughout the Gulf of Alaska. Sockeye do not move south of the 15°C isotherm (Healey and Groot 1987).

In the Pacific, south of the Aleutian chain, sockeye were found most northerly, pink were found most southerly, and chum were widely distributed. Immature chum and sockeye were generally restricted to the more southerly waters and maturing fish to the north (French et al. 1971).

MARINE MIGRATION

Random searching by returning adults, coupled with reactions to environmental cues provides return rates similar to observed ones. "Map navigation" is not necessarily non-existent, but may not be occurring to the degree some postulate (Jamon 1990).

Returning adults use many different routes to return to common destinations. Pink salmon travel according to temperature change information. Movements of juveniles and adults are largely independent of currents. Homing is not considered to be random, near-random, or by extensive searching of coastlines. Celestial compass orientation doesn't account for observations. Some form of bi-coordinate navigation may be required (Neave 1964).

The presence or absence of the Sitka Eddy can influence the distribution of returning adults and possibly migrating juveniles (Mysak 1986).

Coho re-entered spawning grounds during periods of nighttime rainfall. Chinook moved in response to sharp drops in barometric pressure. Observations were made in receiving ponds under conditions of little temperature change and no flow change (Allen 1956).

Steelhead movement during daylight hours was twice that during the night. Night movement was associated with tidal currents. Mean travel depth was 1.6m. A mean of 72% of the time was spent in the top one meter of water. Median time between dives to 5m (near the halocline) was 9 minutes. No pattern of bimodal compass orientation was displayed (Ruggerone et al. 1990).

MARINE MORTALITY

GENERAL

Growth and survival during the first six months of ocean life was examined. Ocean limitation of production is unlikely unless only a small fraction of the total zooplankton production is available to salmon (Walters et al. 1978).

The ocean mortality rate is concluded to be somewhat constant at about 32% annually. A juvenile coastal mortality factor exists and is species and race dependent. Any adult coastal factor is of negligible influence on the total mortality rate (Parker 1962).

In the first 40 days of ocean life, 77% of the pink salmon population died. In the remainder of their ocean life, 18% of the original population died. This was 78% of those surviving beyond 40 days. Five percent returned to freshwater as adults (Parker 1965).

In the first 40 days of ocean life, 59% to 77% of the pink salmon population died. In the remainder of their ocean life, 78% to 95% of those surviving beyond 40 days died. The intensity of mortality is greater during the early life in the sea (Parker 1968).

During the first 18 months of marine residence, the natural mortality rate of coho decreases as weight increases. Seventy gram hatchery fish may be the optimal release size (Mathews and Buckley 1976).

The marine survival of coho is strongly correlated with early ocean growth, as estimated by spacing of the first five ocean circuli on the scales of returning adults. Marine survival and early ocean growth were positively correlated with ocean conditions indicated by strong upwelling along the northwest coast of Vancouver Island (Holtby et al. 1990).

High concentrations of the diatom *Chaetoceros convolutus* caused mortality of chinook by damage to gill epithelium. Concentrations over 5,000 chains per liter should be avoided (Farrington et al. 1988).

The mortality other than landed catch due to pelagic gill-netting equals the catch for salmon in the next-to-last year of ocean life. This mortality is about 25% of the catch in the final year of life. Mortality from trolling is about 33% for coho and chinook. Shifting from ocean trolling for Columbia River chinook to river fishing would increase total weight of the catch between 63% and 98% (Ricker 1976).

Hooking mortality; the proportion of fish hooked, retrieved, and released that die as a result of being caught and released for barbed hooks was estimated to be 0.30 for troll and sport caught chinook and coho. A factor to convert rates from barbed to barbless is probably 0.85 (Stohr and Fraidenburg 1986).

DENSITY DEPENDENCE

Survival rate and the proportion maturing are independent of stock abundance after age three. Therefore, the mortality processes responsible for the independence act early in smolt life. Smolt weight affects mean age at return (Peterman 1982a).

The mortality responsible for non-correlation of smolt-to-adult survival occurs in the first 15 months of marine life for Babine Lake sockeye. Depensatory mortality may occur during pink salmon years due to a swamping of predators (Peterman 1982b).

Oregon researchers concluded that both density dependent and density independent mortality occurs in the ocean. They rejected hypotheses of smolt quality (disease, nutrition, density, time of release, genetic diversity, quality control), loss of natural production, riverine density dependent mortality, and predominance of the declining Columbia River program (McIntyre 1985).

The demonstration of coho smolt density-independent marine survival by Nickelson (1986) was flawed by not considering the power of the test (β value) when accepting the null hypothesis. There was an 81% chance of making a Type II error, accepting a false null hypothesis (Peterman 1989).

Density dependence probably occurs in public hatchery smolts at sea. Results were determined using upwelling and sea temperature. The results are admittedly statistically weak. Other papers on density-dependence are also not the "last word" (Emlen et al. 1990).

Density dependent survival was exhibited by a few stocks of the several examined (Peterman 1978).

Coho in Oregon did not show density dependence nor was a statistically supportable technical maximum for smolt releases found (Clark and McCarl 1983).

Wild coho stock recruitment was positively affected by parent stock level and river flow and was negatively affected by parent stock density and hatchery smolt release. Hatchery stock recruitment was positively affected by smolt release level and upwelling, and negatively affected by smolt release density (Anderson and Wilen 1985).

Chum size-dependent mortality was demonstrated to occur at 45mm to 55mm fork length, when the fish move from very shallow water to an open water pelagic habitat (Healey 1982c).

Sockeye stocks in the Gulf of Alaska show decreases in adult body size and marine growth rate when large numbers of sockeye are present. Density dependent effects are manifested in early ocean life and are probably due to competition for food (Peterman 1984).

For cod and haddock, density dependent survival is more likely to occur during the early egg, larval, and juvenile stages than during later stages (Jones 1973).

PREDATION

GENERAL

Pink and chum losses in freshwater have been as high as 50% in streams as short as 2 miles. Predation on smolts by other species may be high in the estuary due to predators keying on smolt entry. Once fish are dispersed in the marine environment predation appears modest. The question remains, is there a large number of predators to compensate for their relatively low (5-20%) predation rates? Aquacultural techniques include rearing on nocturnal feeding regimes; releasing large numbers of fish at once; releasing smolts at night, during freshets, and at high tide; and avoiding incompatible combinations of salmonid predators and salmonid prey, such as coho and spring chinook preying on fall chinook or chum (Cardwell and Fresh 1979).

The mortality responsible for non-correlation of smolt-to-adult survival occurs in the first 15 months of marine life for Babine Lake sockeye. Depensatory mortality may occur during pink salmon years due to a swamping of predators (Peterman 1982b).

Kestrels were shown to have a preference for 'odd' prey, ones that were different than those encountered in previous experiences (Mueller 1975).

Predation rates increase as the trophic level approaches primary production (Dickie 1976).

A method is presented to compute a food preference index that is independent of prey abundance (Paloheimo 1979).

Predators are normally operating on the low end of their functional response curves and are capable of causing high mortality on larger prey populations. Competition among predators is significant. A review of past data shows that maximum attack rates were not being achieved. To account for certain observations, there is an influx of predators or a learning component associated with predation (Peterman and Gatto 1978).

For British Columbia coho - 17 years of data showed that interannual variability in smolt survival was driven by ocean conditions that determined smolt growth rates which subsequently affected the susceptibility of smolts to a size-selective predator (Holtby et al. 1990).

Coho, chinook, and pink salmon were attacked by the isopod, *Rocinela belliceps pugettensis*. Death was caused directly and may cause increased predation by other species of fish (Novotny and Mahnken 1971).

HATCHERY INFLUENCES

Prey that swim quickly, such as naive hatchery fish that wander, are more vulnerable to predation. They expose themselves to more predators, which themselves move slowly through their environment. The number of prey that enters a circle of radius R about a predator is related to the prey density, prey speed, and predator speed (Cushing 1975).

Juvenile wild cod and captive reared cod showed different behaviors when confronted with a predator (large cod). Reared cod remained further from the predator and were slower to approach the predator. The wild cod exhibited what may have been "predator inspection visits". Reared cod are preyed upon most heavily during the first days after release (Nordeide and Svåsand 1990).

Hatchery coho and chinook showed a 50% increase in survival in the presence of a predator (rainbow trout) after conditioning to avoid an immobile electrified plastic fish model. Avoidance conditioning took 11 days with two 1-hour training periods per day (Thompson 1966).

BIRDS

Approximately 94% of a total of 29,600 pairs of 12 bird species nest on 35 islands in the San Juan Islands, Smith Island, Minor Island, Protection Island, and Tatoosh Island. The most abundant breeding species are Rhinoceros auklet (60% of total) and Glaucous-winged gull (24% of total). Nearly 240,000 Common murres are present in the Strait of Juan de Fuca in the summer and fall (Manuwal et al. 1979).

Northern Puget Sound and Strait of Juan de Fuca populations in 1978 and 1979 were:

Common murre	240,000
Rhinoceros auklet	36,000

Protection Island is the most important bird breeding colony in the area (Kopenski and Long 1981).

Rhinoceros auklets at Protection Island number 34,000. Approximately five percent of their prey biomass is juvenile salmon (Manuwal 1977).

Gulls foraging below Wanapum Dam, Columbia River, consumed from 50 to 562 fish per hour. The consumption rate was related to the number of fish passing through the turbines and lighting conditions. It was estimated that gulls consumed two percent of the migration past the dam (Ruggerone 1986).

FISH

Predator scars that were noted on first summer juveniles in the ocean were: lamprey, seal, sea lion, shark, and other predatory fish such as daggertooth. The scarring rate was similar to that observed on older age groups, thus the restricted distribution of juveniles did not result in a high predation rate (Hartt 1980).

Sockeye in Cultus Lake, British Columbia were preyed upon in proportion to their abundance. Less than proportional predation may occur when sockeye numbers are low (Ricker 1941).

Covariation in the survival rates of age1 and age2 herring and juvenile coho salmon infers that, since they are ecologically similar, similar predation factors apply to both species (Holtby et al. 1990).

The increase in Oregon coho mortality in 1983 and 1984 may have been caused by increased predation on coho due to decreased numbers of alternate prey for predators (Fisher and Pearcy 1988).

HAKE, WHITING

Samples were taken from 1196 adult hake off British Columbia. Hake feed primarily at night. Fish, primarily herring were of greatest importance in the diet of larger hake. Euphausiids were found in 94% of the fish sampled, Pacific sandlance in 26%, Pacific herring in 5%, and euchalon in 5%. Lanternfish, juvenile rockfish, northern anchovy, and pandalid shrimp were found in three percent or less of the samples (Outram and Haegele 1972).

Hake stomachs sampled off Washington and northern Oregon from spring to fall contained mostly euphausiids by frequency and weight. Other food items found were fish and pandalid shrimp. A high incidence of empty stomachs in late day captures suggests that hake feed at night (Alton and Nelson 1970).

Hake prey off California includes red crab, euphausiids, shrimp, squid, anchovy, juvenile hake, queenfish, sea perch, sanddabs, sole, and clams (Fiscus 1979).

Hake and dogfish are responsible for high mortalities of juvenile salmon entering the ocean in certain systems. Hake winter in Northern California waters and move north as spring and summer water temperatures increase. Stomach samples showed that up to 50% mortality of young salmon may be due to hake predation (Hyatt's work as reported by Doherty in Pacific Fishing, November 1990).

Northern California Pacific hake and arrowtooth flounder stomach samples showed ocean shrimp to be the dominant prey item. Vertical migration of hake may be due to nightly vertical migration of ocean shrimp. Fish, primarily sanddabs, slender sole, and rex sole, are a large part of the diet in November and December. No salmonids were identified in stomachs (Gotshall 1969).

Chinook entering Hood Canal from Hoodsport Hatchery were preyed on by hake, rockfish, lingcod, sculpins, larger chinook in the cohort, and cutthroat trout (WDF 1959).

Whiting stocks have been fished up to the PFMC quota from 1980 to 1990, about 220 metric tons. The 1990 initiative of Alaska factory ships to fish whiting off California, Oregon, and Washington could concentrate the current eight month fishery into three weeks. Their harvesting capacity is great relative to the harvestable stock. This initiative would be a reallocation to the Alaskan fishery of an existing fishery. Whiting spawn off Baja California and migrate northward in the spring. They reach Cape Mendocino by April then move progressively north to British Columbia. During the summer they presumably head offshore into deeper water and may head south. The older, larger fish lead the migration. Ages concentrated in the fishery are two, three, and four year olds. Fish may live up to ten years (Peter Leipzig, pers. comm.).

The 1990 hake harvest off Washington, Oregon, and California was about 196,000 metric tons. The 1991 quota is 228,000 metric tons, with 36,000 tons set aside for shore-based fisheries and 192,000 tons for US factory trawlers). Factory trawlers intend to fish April and May, when Alaska fisheries are closed to them (Pacific Fishing, January 1991).

Herring off the west coast of Vancouver Island reached an historic low in the late 1960s. Levels in 1987 were near those lows. Juvenile herring survival is related to variations in hake biomass. Sablefish and cod are also important predators, but hake are the most influential. Sablefish had a strong 1977 year-class. Herring year-class strength is negatively related to sea surface temperature. It is possible that as waters warm, hake extend their range northward, increasing their predation on herring. The combined calculated predation of hake, sablefish, and cod can consume 29% to 54% of the adult herring biomass. The average annual mortality of herring is 36% (Ware and McFarlane 1988).

The recent depression of herring stocks could be the result of increased predation pressure, maybe due to a range extension of hake in response to increasing water temperatures or an increased abundance or predation rate of hake and other piscivores. The current biomass of piscivores is sufficient to account for mortality of all age one and older fish. This indicates the magnitude of predation that could focus on other species in years when herring are scarce (Holtby 1989).

DOGFISH

Dogfish consume insignificant quantities of salmon, but over five times the 1977 commercial catch of herring. Herring was 22% of the diet, euphausiids 14%, and molluscs 5%. Prey was largely pelagic, with fish predominating in the winter and invertebrates in the summer. Fish was more important as dogfish size increased. Annual consumption was five times biomass for small dogfish and 2½ times biomass for larger dogfish (Jones and Geen 1977).

COD AND POLLOCK

Cod use sight to detect food in the water column. Prey movement stimulated feeding but was not essential when feeding on familiar prey. Cod have sophisticated odor detection capabilities and can forage efficiently for buried food (Brawn 1969).

Tomcod in a population contiguous to an Alaska hatchery had an average of 3.5 pink salmon fry per stomach. It is estimated that seven percent of the 1977 emigration could have been eaten in April (Cooney et al. 1978).

Herring recruitment rates are strongly influenced by cod predation. The herring mortality rate due to cod predation averages 75% per year. Northern British Columbia cod abundance peaked in the late 1950s, and may have been responsible for the collapse of the herring reduction fishery of the 1960s (Walters et al. 1986).

Lingcod abundance in the Strait of Georgia declined from 1940 to 1980 to about 20% (Ketchen et al. 1983).

Walleye pollock that were captured at an inmigrant fish trap on Admiralty Island, Alaska were gorged on young coho, pink, and chum. From the observed state of digestion, the young had been eaten while pollock were both in the trap and before entering trap. An average of six salmon per fish was seen (Armstrong and Winslow 1968).

SALMONIDS

Early sea mortality of pink and chum is due to predation by juvenile coho. The coho prey more heavily on the smaller pinks and chum, biasing the apparent growth rate of the survivors. Chum have an advantage over pinks due to their earlier entry into the estuary and larger initial size (Parker 1971).

Juvenile salmon were found in 2.8% of the stomachs of Dolly Varden examined in the Little

Port Walter estuary, Alaska. Salmon accounted for 1.0% of total volume in those stomachs. Other food items included capelin (49.7%/78.8%, frequency/volume), fish remains (25.9%/2.3%), sand lance (18.9%/7.1%), herring (16.1%/4.0%), polychaetes (5.6%/4.7%), and crustaceans (11.8%/2.0%). Other fish with negative findings of salmon in stomachs were: Pacific cod, walleye pollock, Pacific halibut, kelp greenling, rock greenling, and black rockfish (Lagler and Wright 1962).

SCULPIN

Sculpin predation on coho fry was examined in Newaukum Creek, Washington. 9.2% of torrent sculpin stomachs contained fry, 3.1% of reticulate sculpin stomachs contained fry. Sculpin over 64mm were considered predatory-sized. Insects were the main prey item (Patten 1962).

Naive coho fry were preyed on more heavily by torrent sculpin than fry conditioned to sculpins or mixed groups of naive and conditioned coho. The naive fry may have 'learned' from the conditioned fry via a 'transferrable reaction' (Patten 1977).

Torrent sculpin removed 70% of coho salmon fry in stream aquaria on moonlit nights versus 24% on dark nights (Patten 1971).

LAMPREY

Up to 1.9% of juvenile salmon (five species) showed evidence of river lamprey marks. Attachment is dorsal, compared with ventral attachment of other lamprey species. Some juveniles survive and have scars as adults (Roos et al. 1973).

A 92mm coho juvenile was found with a 162mm lamprey attached, above the lateral line and over the anal fin. The lamprey was identified as a river lamprey, *Lampetra ayersi*, sometimes incorrectly identified as *L. fluviatilis* (Withler 1955).

MARINE MAMMALS

Marine mammal population estimates in 1976 for Pacific populations, North America and Alaska were:

California sea lion	4,000	north of California
Northern sea lion	< 250,000	
Northern fur seal	1,300,000	
Largha seal	135,000	
Harbor seal	315,000	

Most marine mammal predation occurs after fish are captured on sport or commercial gear in estuarine and river areas. The Northern fur seal preys on salmon throughout its range, but only off Washington does salmon form an appreciable part of the diet. Salmon was a higher percentage of the diet in winter than in spring. Pacific whiteside dolphin eat immature salmon off the Columbia River. Predation on smolts is not documented except in the case of beluga in Bristol Bay (Fiscus 1980).

note: the Northern sea lion is synonymous with Steller's sea lion, which was listed as threatened 11/26/1990.

Marine mammal population estimates for 1985 - Pacific populations, North America and Alaska:

Dall's porpoise	920,000	
California sea lion	157,000	
Northern sea lion	210,000	
Northern fur seal	823,000	
Largha seal	225,000	
Harbor seal	302,000	(USDOC 1985).

Marine mammal minimum abundance estimates for 1991 :

California sea lion, CA,OR,WA	67,000	
Steller sea lion	44,800	
Northern fur seal, E.Bering	871,000	
Harbor seal, WA,OR	12,390	(NMFS 1991).

Bering Sea fur seals did not recover as expected after the female harvests from 1956 to 1968. The failure to recover was not due to increased fisheries for walleye pollock and herring. Pollock became a larger part of the seals' diet while the fish size dropped. The fishery removed the larger pollock which are cannibalistic, reducing predation on the younger pollock, making them more abundant for the fishery and the fur seals (Swartzman and Haar 1983).

California sea lion prey include herring, anchovy, midshipman, hake, tomcod, jacksmelt, croaker, rockfish, soles, and squid. The center of the Northern sea lion population is off British Columbia. Their prey include lamprey, herring, salmon, hake, rockfish, sanddabs, turbot, squid, and octopus. The Northern fur seal, North American population is estimated at 1.2 million. Off California, the principal prey of fur seal are hake, squid, and anchovy. Off Washington, the principal prey of fur seal are rockfish, herring, anchovy, squid, and salmon. North Pacific Fur Seal Commission sampling showed no salmon as prey in the springs of 1958, 1959, 1960, and 1961. Salmon as prey were seen at 12.3% of total volume in the spring of 1964, 11.3% in 1965, 45.4% in 1967, and 22.7% in the winter of 1968. Off British Columbia, principal prey were herring, salmon, sandlance, and rockfish. Salmon represented 2.2%, 20.0%, 5.9%, and 12.1% of the total stomach volume for spring sampling in 1958, 1959, 1960, and 1961 respectively (Fiscus 1979).

British Columbia harbor seal populations have been increasing at 12.5% per year from 1973 through 1988. The population growth rate is due to the end of historical kills, and the rate is not yet limited by population density. The 1988 population is estimated at 75,000 to 88,000 for all of British Columbia. Other regions of the northeast Pacific are reporting similar increases (Olesiuk et al. 1990).

Northern Puget Sound and Strait of Juan de Fuca populations in 1978 and 1979 were:

Harbor seal	200+	
Sea lion	300	
Killer whale	80	(Kopenski and Long 1981).

The Washington state harbor seal population is roughly estimated at 5,000 before 1940 and 2,000 in 1972 (Newby 1973).

Sea lions and harbor seals consume salmon equivalent to about 2.5% of the annual commercial catch. Herring consumption is about 4% of the annual commercial catch. This level of predation is considered to have negligible effects on reducing existing fish stocks (Spalding 1964).

SCHOOLING

Interactions between jack and anchovy were studied in a field enclosure in Hawaii. Single predators were most successful at capturing isolated individual prey, and unsuccessful at capturing individuals in schools. Schooled predators were most successful at capturing schooled prey. The leading predator in a school was most successful at capturing isolated or schooled prey. Larger predator groups were able to break up schools more quickly, resulting in more prey becoming isolated. These prey were captured before schools reformed or joining other schools. Schooling in prey reduces the time a visually orienting predator has to align itself with an individual. Large prey schools may have evolved to satiate the feeding capacity of schooled predators and decrease the probability that an individual will be captured (Major 1978).

Schooling affords protection from predators. Frequency of detection by a predator is inversely related to the number of individuals in the school. Once school size exceeds the average consumption capacity of a predator, further increases in school size reduce the frequency of prey-predator encounters (Brock and Riffenburgh 1960).

The survival value of schooling is demonstrated using search theory. Sight range is an important determinant in whether prey is detected (Olson 1964).

MARINE FORAGE

For coho from Big Creek SFH (Columbia River) and Coos Bay SFH, Oregon, survival was not related to intraseasonal variability of the marine food supply (Mathews and Ishida 1989).

The standing stock at a particular size can be related to the standing stock at another size (Sheldon et al. 1977).

The natural mortality of herring increases with age of the fish (Skud 1962).

The marine climate was not favorable to herring in the 1960s. There was limited effect of upwelling. The downward trend was reversed in 1970 (Wickett 1978).

Herring are an important prey for cod and hake (Holtby 1989).

Under unfavorable conditions, the ocean food supply may be inadequate for all hatchery and wild salmon entering the ocean. In such cases hatchery fish may undergo greater stress than wild fish. Overstocking with hatchery fish could impair survival of both hatchery and wild stocks (Anonymous 1990).

Sockeye stocks in the Gulf of Alaska show decreases in adult body size and marine growth rate when large numbers of sockeye are present. Density dependent effects are manifested in early ocean life and are probably due to competition for food (Peterman 1984).

In the Pacific, south of the Aleutian chain, hexagrammid larvae were found in all waters sampled. *Hemilepidotus* and *Bathymaster* larvae were found only in the northern areas (with juvenile sockeye and pink). Myctophid larvae were found only in the southern areas occupied by juvenile sockeye and chum salmon (French et al. 1971).

In pink salmon at sea, when the food supply was restricted, the first physiological response was loss of lipid and moisture. Under prolonged starvation, protein was catabolized. Diurnal fluctuation in body moisture was noted and was correlated with the diurnal feeding cycle (Parker and VanStone 1966).

SALMONID FOOD HABITS

Coho and chinook can be a significant predator on Dungeness crab megalopae (USFWS-COE 1986).

Troll caught chinook food habits near San Francisco were 29% Northern anchovy, 23% rockfish, 15% euphausiids, 13% Pacific herring, 9% squid, and 4% crab megalopea. Seasonal changes were seen. From February through March, herring predominated. Euphausiids were dominant in April and May. In June and July, rockfish were the principal prey. Anchovy were common from August through November. In some cases, seasonal changes were associated with changes in location of capture. Size of prey was generally fish over one-third their own length. Ocean caught salmon that were approaching maturity had not stopped feeding, while fish caught in San Francisco Bay had almost ceased feeding (Merkel 1957).

Juvenile salmon and baitfish in shallow sublittoral and near-shore pelagic waters, less than 20m, of Puget Sound ate calanoid copepods, euphausiids, brachyuran crab larvae, insects, larvacea, and gammarid and hyperiid amphipods. Diets of chum salmon, herring, sand lance, and surf smelt less than 150mm were similar, mostly harpacticoid and cyclopoid copepods, suggesting that these species may compete for food. Juvenile chinook and coho less than 120mm ate mostly large crustaceans such as brachyuran crab larvae. Coho over 200mm and herring over 150mm caught in more offshore pelagic habitats, over 20m, ate larger crustaceans - euphausiids, amphipods, and brachyurans. Larger chinook in deep water ate mostly herring. Chinook here would compete with other piscivores, such as pollock and hake. Four species of salmonids consumed juvenile salmonids at low rates of predation. Herring showed little preference for feed items, while chinook showed the highest level of prey preference (Fresh et al. 1981).

Coho and spring chinook ate predominately herring and crustaceans around Vancouver Island. Coho diet was more pelagic and varied than chinook captured in the same areas. Crustacea were most important in early summer and fish predominated in later summer. Overall for coho, herring was 72% of total volume and seen in 21% of the stomachs. These were primarily herring age 3 and younger, which have not yet recruited to the herring fishery. Also seen were sand lance at 5% volume and 6% incidence. Crustaceans included the euphausiids *Thysanoessa spinifera, and Euphausia pacifica*, gammarid and hyperiid amphipods, young crabs and crab megalops, and occasional shrimps and copepods. Overall, for chinook, herring was 72.5% of total volume and seen as a much greater percentage of stomachs than in coho (over 21%). No trace of pilchards was found, which had been reported by earlier studies done when pilchards were common off the British Columbia coast. Larger spring chinook ate larger sized herring. Sand lance was 13.6% of volume. Crustaceans included euphausiids at 10% of volume, young crabs and crab megalops, and minor miscellaneous forms. A decline in herring stocks would not lead to decline in salmon stocks, since salmon would switch to other prey items (Prakash 1962).

Juveniles sampled in the first ocean summer showed a variety of food types and quantities. No fish caught were emaciated or starved, suggesting that the food supply is not a limiting factor (Hartt 1980).

At sea, pink salmon fed on amphipods and fish. Immature sockeye fed on crustaceans. Maturing sockeye fed on euphausiids and squid. Coho fed on euphausiids, fish, and squid. Steelhead fed on fish and squid. Chum stomach contents were too well digested to identify. Quantities present in stomachs suggested that feeding is more associated with availability than feed preferences (LeBrasseur 1966).

During July, 1950 in the San Juan Island area stomachs of pink, chum, and spring chinook contained 50% copepods, 26% dipterans, and 24% miscellaneous crustacea and unidentifiable items. Fewer Diptera were present toward the end of July. The chironomid species, *Camptocladius pacificus (Spanistoma pacifica)*, was the most common dipteran (Annan 1958).

Small chinook from 7cm to 13 cm found in California nearshore waters had stomachs containing small fish up to 4.5cm and insects representing Hymenoptera, Diptera, Hemiptera, and Coleoptera and spiders. It is hypothesized that offshore winds carried these terrestrial arthropods out to sea (Snyder 1924).

HERRING ABUNDANCE

Strait of Georgia herring stocks were reduced about one half between 1973 and 1986 (Day et al. 1986).

Herring recruitment and salinity levels are linked and follow a 6 year cycle. It is possible that following a stormy winter, which may cause high salinity, there is a longer spring phytoplankton bloom. This enhances zooplankton and ultimately herring survival. Recruitment is high following years of anomalous warming, but temperature is not related (Mysak 1986).

Strait of Georgia herring abundance was high from 1935 to 1964. The reduction fishery for oil and meal occurred in late fall and winter. Fish production was relatively unaffected by fishing. The stock collapsed from 1964 to 1967, due to several yearclasses of weak recruitment, increased efficiency of the seine fleet, and underestimation of declining spawning escapements during the 1960s. Washington stocks were unaffected by the British Columbia collapse in the 1960s, indicating that they are probably discrete stocks (Ketchen et al. 1983).

Herring recruitment rates are strongly influenced by cod predation. The herring mortality rate due to cod predation averages 75% per year. Northern British Columbia cod abundance peaked in the late 1950s, and may have been responsible for the collapse of the herring reduction fishery of the 1960s (Walters et al. 1986).

Herring off the west coast of Vancouver Island reached an historic low in the late 1960s. Levels in 1987 were near those lows. Juvenile herring survival is related to variations in hake biomass. Sablefish and cod are also important predators, but hake are most influential. Sablefish had a strong 1977 year-class. Herring year-class strength is negatively related to the sea surface temperature. It is possible that as waters warm, hake extend their range northward, increasing their predation on herring. The combined calculated predation of hake, sablefish, and cod can consume 29-54% of the adult herring biomass. The average annual mortality of herring is 36% (Ware and McFarlane 1988).

Canadian herring fishery annual catches were:

	metric tons	
before 1902	< 600	
by 1907	9,000	
1908-1919	25,000	
1919-1927	78,000	
1935	26,000	decline of dry salted herring market
1937-1946	100,000	meal and oil reduction fishery began
1947	156,000	
1948-1965	190,000	except 1953 and 1958 due to industrial disputes (Hourston 1980).

A major part of the catch fluctuation for Pacific herring is due to economic factors (Gordon 1955).

The California Current sardine and anchovy biomass declined between 1941 and 1951. From 1951 to 1969, sardines continued to decline but anchovy increased, to 2-3 times its 1941 biomass (Smith 1972).

A major spawning center for the northern subpopulation of northern anchovy was found off the Oregon-Washington coast, beyond the continental shelf. A wide range of spawning biomass is probable; 100,000 to 1,000,000 metric tons. Spawning occurs from mid-June to mid-August when coastal upwelling is peaking, water temperature is high, southern current flow is at maximum, and daylength is long. These conditions are opposite to the conditions when the California population spawns, during minimal upwelling, cold temperatures, and shorter daylength, in January-April (Richardson 1981).

ESTUARINE DISTRIBUTION AND CONDITIONS

DISTRIBUTION

In an Oregon estuary coho and chum were present for two to three months, from March to June. Chinook were present for 9 months, January and April to November (Myers and Horton 1982).

Juvenile fall chinook stayed in Coos Bay about one month before entering the ocean. Juvenile spring chinook stayed only about ten days (Fisher and Pearcy 1990).

Juvenile chinook may use the Nanaimo estuary for as little as two weeks. Fish are present in the estuary for 2½ to 4 months (Sibert 1975).

In Washington estuaries and Puget Sound juveniles of all species use neritic habitats, but chum and chinook also use shallow sublittoral habitats. Chinook may reside up to six months (Simenstad et al. 1982).

In the Duwamish River estuary salmonids were found from mid-April through early June. Abundance was related to releases from hatcheries. Chinook and chum are present for the longest period. Chum oriented to the shallow shoreline. Chinook were present in both shallow and deep water habitats. Chinook appeared to move inshore at night (Meyer et al. 1981).

In the Nisqually River estuary chum and chinook in April and May occupied nearshore areas and tidal sloughs in the marsh. Later they moved to deeper water in the Nisqually Reach. Chum entered the estuary about one month earlier than chinook (Pearce et al. 1982).

In British Columbia estuaries chum stayed in the estuary for two months in the early spring, coho for two months in late spring, and chinook were present through spring, summer, and fall. Pink and sockeye spend little time in estuary (Healey 1982b).

Chinook fry were found rearing in the Nanaimo River estuary in the intertidal zone. They were present from March to July, but peak abundance was in April and May. Growth rate was about 1.32mm per day or 5.8% of body weight per day. The average estuarine residence was about 25 days. While in the estuary they fed on harpacticoid copepods, amphipods, insect larvae, decapod larvae, and mysids. After leaving the estuary, they fed mainly on juvenile herring (Healey 1979).

CONDITIONS

Otoliths were examined with water temperature, population density, and benthic standing crop data. The growth rate of juvenile chinook dropped during their midsummer estuarine residence. This may have been due to decreased food conversion efficiency during the warm midsummer period. Freshwater otolith rings showed that fish which hatched relatively late spent less time in fresh water before entering the estuary (Neilson et al. 1985).

High spring runoff in the Columbia River enhances salmon survival. Runoff has been low since the middle 1970s (Anonymous 1990).

At the lowest levels of salinity increase in estuaries, a great number of chemical and biological reactions occur in the entering fresh water. pH drops to minimum at 0.5ppt salinity then increases as salinity increases. Many of the chemical reactions are related to the pH dynamics (Morris et al. 1978).

Algal blooms in Puget Sound occur in late April or May and recur throughout the summer. Rarely, and only briefly, does nitrate become exhausted. Phytoplankton growth is limited by vertical advection and turbulence, rapid horizontal advection by sustained winds, sinking of algal cells, and underwater light intensity which is affected by self-shading and inorganic particles. The high primary productivity of Puget Sound is due to intensive upward transport of nitrate by the estuarine mechanism (Winter et al. 1975).

The major processes controlling phytoplankton production in Puget Sound are high solar insolation and stability of the water column due to high runoff during neap tides. These conditions usually appear in late April or early May and cause blooms throughout the spring and summer. The intensity of blooms varies with the degree of mixing caused by runoff, winds, tides, and solar insolation. Only rarely does nitrate fall to limiting levels, and then only for periods of one to three days. In the summer, thermal stratification tends to result in a more stable water column. Nutrient levels in 1975 were similar to those measured in the Sound since 1932 (Campbell et al. 1976).

ESTUARINE FORAGE BASE

The estuarine diets of pink and chum are similar. Epibenthic harpactcoid copepods were the chief prey of both species in Puget Sound. Pinks preferred invertebrate eggs. Chum preferred gammarid amphipods and harpacticoids (Kaczynski et al. 1973).

Pinks and chums ate mostly planktonic copepods and larvacea (*Oikopleura spp.*). Coho ate mainly herring larvae and sand lance. Sockeye ate both plankton and fish. Pink and chum, in the presence of abundant forage, showed spatial preference for copepods in southern Chatham Sound to larvacea in northern Chatham Sound (Manzer 1969).

Food requirements are a small percentage of the total standing crop and annual production of prey, but a high proportion of preferred prey is sometimes taken. Major prey tend to be detritus feeders, thus the food web is detritus based (Healey 1982b).

Duwamish River estuary salmonids preyed on chironomid adults and larvae, gammarid amphipods, and harpacticoid copepods. Steelhead preyed heavily on the epibenthic mysid *Neomysis mercedis*. Epibenthic invertebrates and chironomids were more important to smaller salmonids, while larger fish consumed more planktonic prey like calanoid copepods (Meyer et al. 1981).

Chinook fry were found rearing in the Nanaimo River estuary in the intertidal zone. They were present from March to July, but peak abundance was in April and May. Growth rate was about 1.32mm per day or 5.8% of body weight per day. The average estuarine residence was about 25 days. Estuarine feed was harpacticoid copepods, amphipods, insect larvae, decapod larvae, and mysids. After leaving the estuary, they fed mainly on juvenile herring (Healey 1979).

Nisqually River estuary chum under 70mm ate mostly epibenthic crustaceans while those larger than 70mm ate pelagic crustaceans. Smaller chinook ate dipteran flies and spiders. Larger chinook preyed on crustaceans. Coho ate primarily juvenile fishes (Pearce et al. 1982).

Chum eat epibenthic and interstitial harpacticoid copepods during the first weeks of estuarine life. Harpacticoids preferentially eat heterotrophic food sources such as bacteria (Sibert et al. 1977).

Chum salmon juveniles were collected off Nanaimo in July and August, 1950. As fish size increased diet shifted from mostly terrestrial insects to small crustaceans to young herring. Only juvenile coho stomachs contained any aquatic insects, midge pupae which could not be identified as marine or freshwater (Foskett 1951).

Intertidal Chironomidae on the British Columbia coast are *Paraclunio alaskensis, Saunderia pacificus, S. marinus*, and *S. clavicornis*. Distribution is in clumped groups in exposed and protected rocky shores. *S. clavicornis* is the most ubiquitous, *S. pacificus* is the rarest. Adult emergence is most intense in the fall and least intense in the late spring and summer (Morley and Ring 1972).

Columbia River juveniles migrating past Jones Beach were actively feeding during migration (Dawley et al. 1981).

Columbia River coho prey on amphipods in the estuary and insects in the river (Durkin 1982).

Calanus plumchrus did not feed during the last seven months of their life cycle. Juvenile growth occurred from March to July. Growth rate was 10.6% per day (Fulton 1972).

MARINE ENVIRONMENTAL TRENDS

The mean annual air temperature rose from 1920 to 1940 then declined to 1950 at San Francisco; New Westminster, British Columbia; and Masset, British Columbia. Winter ocean temperatures show similar but not identical trends. Short term correlations were established between winter temperature and:

1) Petrale sole abundance 6 years later (positive),
2) rock sole abundance 5 years later (negative),
3) strength of lemon sole year-classes (negative),
4) halibut catch per unit effort 10 years later (positive, southern grounds),
5) halibut catch per unit effort 12 years later (positive, western grounds),
6) blackcod abundance (inversely).

No relation was seen between temperature data and the abundance and distribution of true cod (Ketchen 1956).

Environmental patterns are responsible for as much as half of the fluctuation in catch for many Gulf of Maine species. Considering total fish biomass, the Gulf of Maine was in equilibrium from 1940 to 1959. Changes in species abundance was due to fishing pressure and oceanic climate changes (Sutcliffe et al. 1977).

In the Fraser River system, sockeye and pinks that enter the ocean in the same year show a correlation in adult size, suggesting that they encounter comparable conditions in their early marine life (Ricker 1982).

EL NIÑO - SOUTHERN OSCILLATION (ENSO)

Sea surface temperature off the Pacific Northwest coast was more than 2°F above normal in last two weeks of March, 1983 and more than 4°F above normal off Northern Vancouver Island. The warm period of 1957-58 was more intense and lasted longer off southern California than the warm periods of the 1970s. The January 1983 profile resembles that of January 1958. The 1957-58 warm period lasted 18 months, and the 1972-73 and 1976-77 periods lasted 12 months (Squire 1983).

During El Niño of 1982-3, maximum temperature anomalies came in April 1983 and declined slowly. Off Washington, the anomaly peak was about 1.6°C, lower than the 1958 peak of about 2.5°C, which declined faster than the 1983 peak. Anomalously warm water extended 200km to 250km offshore and to depths of 500m. Subsurface anomalies to 100m were as great as those at the surface, indicating a very large water mass. Puget Sound did not experience surface temperature anomalies, as it did in 1958. Sea level height anomalies peaked in February 1983, were stronger than the 1958 event, and were comparable to the 1941 event. The summer of 1983 was moist and cool, the summer of 1958 was warm and dry. Upwelling was weak during 1982-3, thus production was probably low, though this was not documented. Herring abundance was low, low breeding success was seen for some fish-eating birds, and coho landed off California, Oregon, and Washington were smaller. Groundfish catches seem to have been unaffected, due to their life below the thermocline. Salmon catch in 1983 off California, Oregon, and Washington was very poor. The catch off of Alaska was a record high. The British Columbia catch was mixed. Historical data for Washington coho landings show sharp declines in 1942 and 1958-60. Chinook landings also dropped, but not as severely as coho. Oregon chinook were about 25% smaller than average, coho about 50% smaller than average (Fluharty 1984).

Fifty years of British Columbia temperature measurements show evidence of a large scale warming trend. Temperatures show coherence with global air temperature variations but no relationship with the El Niño/Southern Oscillation signal (Freeland 1990).

Strong El Niño events occurred in 1940-41, 1957-58, and 1972-73. Very strong El Niño events occurred in 1891, 1925-26, and 1982-83. An average period of 3.8 years is seen between moderate, strong, and very strong events. This period relates well to the Southern Oscillation period. Some relation is established with El Niño events and long-term (10 years or more) climatic change. Climatic changes were seen during 1864-91 and 1925-32 (Quinn et al. 1987).

Increases in sea level associated with El Niño are of higher magnitudes at middle latitudes. This rise in sea level is associated with a lowered barometric pressure. In this century, the trend has been for higher sea levels, stable temperature, and lowered surface salinity. Fraser River sockeye were positively influenced by ENSO events, southeast Alaska sockeye were only marginally correlated with ENSO. During the mature phase of an ENSO, the southward California Current is reduced and the northward flow from Oregon to Alaska is increased. One theory holds that if the thermocline in the eastern Pacific lies below the depth of the continental shelf, ENSO is less likely to propagate to latitudes above 15°N. Conversely, if the thermocline is shallow and falls on the surface of the continental shelf, the ENSO can move to higher latitudes. The propagating mechanism can be deflected to the west from its northward path if the thermocline intersects the surface at the 15°C isotherm, usually seen at about 30°N. This theory was broached during the 1982-3 ENSO event. Another theory links sea surface temperature anomalies in the north Pacific with atmospheric cell circulations, related to winter atmospheric pressure associated with the Aleutian low pressure system (Mysak 1986).

Effects of El Niño are caused by lowering of the thermocline. With a lowered thermocline, plankton are distributed lower in the water column and do not receive as much light as when restricted to upper layers, reducing photosynthesis. Inorganic nutrients below the thermocline become trapped out of the reach of the well-lit upper water layers. The 1982-1983 event saw a 4°C temperature rise in 24 hours at Paita, Peru. Upwelling still occurs, but in a much narrower coastal band. Central ocean gyres are typically oligotrophic. Biological effects are caused by food web disruption, beginning with the primary producers. Consumers are then affected by reduced production of prey organisms (Barber and Chavez 1983).

Columbia River coho returns in 1983 showed effects of El Niño. There were low survival rates, smaller adults, and sex ratios were predominately male (Mathews et al. 1985).

Fall chinook from the Spring Creek NFH broodyears 1980 and 1981 contributed more heavily to British Columbia fisheries (44 and 43% respectively) rather than to Washington fisheries as in other years. The 1978 and 1979 broods contributed at 37% and 39% to British Columbia fisheries. This northerly shift appears related to El NiÑo. Southern British Columbia hatchery stocks and Oregon coastal rivers suffered a negative impact (Vreeland 1989).

SEA SURFACE TEMPERATURE and SALINITY

A fish size decrease in populations of Pacific salmon was not correlated with ocean temperature or salinity records. However, at lower temperature sockeye were larger (Ricker 1981).

During the summer of 1990, warm ocean temperatures off northern California effectively limited commercial fishing success (commercial fisherman's testimony to PFMC, 11/14/90).

British Columbia sea level, surface temperature, and salinity fluctuate in a five to six year cycle that is coherent with regional herring recruitment and annual sockeye catch (Mysak 1986).

United States temperature and precipitation time series records from 1895-1987 were analyzed using Spearman rank and two-phase regression. Results indicate that overall trends are near zero. The only evidence for a trend is higher fall precipitation in the contiguous United States from 1970 to 1987 (Hanson et al. 1989).

High catches of butterfish in the Gulf of Mexico were associated with satellite detected sea-surface temperature fronts (Herron et al. 1989).

Murres aggregated near an oceanic front off the Pribilof Islands during 1977 and 1978, presumably due to increased food availability. Northern fulmars and auklets were unaffected by the front (Kinder et al. 1983).

Albacore and skipjack feeding was correlated with temperature fronts with associated high productivity and prey abundance, as detected by satellite imagery (Fiedler and Bernard 1987).

Albacore concentrations were detected at fronts of blue oceanic water pockets intruding into cooler, greenish coastal waters (Laurs et al. 1984).

At the lowest levels of salinity increase in estuaries, a great number of chemical and biological reactions occur in the incoming fresh water. pH drops to a minimum at 0.5ppt then increases as salinity increases. Many of the chemical reactions are related to the pH dynamics (Morris et al. 1978).

In the northeast Pacific, between 100 and 200 meters, there is a strong halocline (salinity), with constant temperature within that halocline (Fleming 1958).

Juvenile Pacific salmon are able to use estuarine salinity gradients as one of the directive cues in seaward migration (McInerney 1964).

Chum fry within an estuary actively selected fresh water on ebbing tides, day and night (Mason 1974).

Chum and pink fry responded positively to isotonic and hypertonic solutions of seawater. Coho fry responded positively to isotonic solutions. During smoltification, coho responded positively to hypertonic solutions (Houston 1957).

From 1912 to 1980, there has been a slight decrease in the size of adult sockeye. Size was not correlatable with mean salinity. A negative correlation was seen between fish size and ocean temperature. The recent trend is for cooler ocean temperatures, contradicting the observation of smaller fish size (Ricker 1982).

Coho distribution is not associated with surface salinity (Chung 1985).

OCEANIC CURRENTS and UPWELLING

Along the Oregon coast in winter the alongshore flow is northward and independent of depth. In the spring the flow is southward at all depths, but stronger near the surface. In the summer the surface flow is southward and the deep flow is northward. The southward surface flow forms a coastal jet and the deep northward velocity increases with the distance offshore (Huyer et al. 1975).

The California Current runs in a band 300km to 800km (186 to 497 miles) off the Oregon Coast. The Davidson Current flows inshore of the California Current. In spring and summer, the Davidson Current flows southward, driven by northerly winds. In fall and winter, the Davidson Current flows northward. Upwelling occurs during the southerly Davidson Current flow, out to about 10 km (6 miles) from shore. Upwelling is sporadic, depending on winds, and may occur for a day or two, or for consecutive weeks, as is the usual case in July and August. Offshore surface waters are warm, up to 17°C. Off the Oregon coast, plankton abundance was low in 1971 (relative to 1969 and 1970), a year of reduced coastal upwelling. The reduced upwelling is linked to low growth for shrimp, coho, and razor clams (Peterson and Miller 1974).

In the California Current System, active upwelling is restricted to a narrow coastal band from 10km to 25km wide. The region influenced by the upwelling is much wider. Studies off Oregon show a southward coastal jet at the surface, a mean vertical shear, a poleward undercurrent along the bottom, and persistently sloping isopycnals (equal density zones) over the continental shelf. Most upwelling off Oregon occurs during short periods, several days long, when the winds are favorable (Huyer 1983).

A jet-like undercurrent over the continental slope exists off Washington (Hickey 1979).

In a coastal upwelling event observed off Oregon in July 1973, the active upwelling zone was about 15km wide (Halpern 1976).

The survival of hatchery and wild coho smolts in the Oregon Production Area is related to the degree of upwelling and sea-surface temperature (Nickelson 1986).

Upwelling of cool deep water favors abundance of plankton prey and enhances salmon survival off the Columbia River. Warmer water and reduced upwelling, the predominant conditions from 1977 to 1986, are unfavorable for survival (Anonymous 1990).

There is a high correlation between the catch of wild adult Oregon coho and the degree of upwelling seen from April to June and the freshwater streamflow during the freshwater growth period (Scarnecchia 1981).

Coho growth, condition and stomach fullness in early summer of the first ocean year was similar in 1983 and 1984, which were years of low survival and low early upwelling, to 1981,1982, and 1985, which were years of higher survival and higher early upwelling. Year class success was probably determined early in the summer, soon after most juvenile coho entered the ocean. Growth rate selective mortality was not demonstrated. The increase in mortality in 1983 and 1984 may have been due to increased predation on coho due to decreased numbers of alternate prey for predators (Fisher and Pearcy 1988).

Some degree of ocean upwelling occurs off the west coast of Vancouver Island (Olson 1978).

The numbers of organisms found in Subarctic waters are much greater than those found in Intermediate, Central, or Tropical water masses. A greater intrusion of Intermediate waters off southern British Columbia and Washington reduced inshore samples by 90% (Aron 1962).

COMPETITION

For Puget Sound hatchery coho, summer streamflow during freshwater rearing shows a strong positive correlation with marine survival after release. It is suggested that the streamflow influenced natural production, thus an abundance of stream produced smolts enhanced the survival of hatchery smolts released the same year (Olson 1978).

Pink and chum interact to limit the numbers of one another. Chum influence pink on the spawning grounds. Pink influence chum in the early marine environment (Gallagher 1979).

Sockeye stocks in the Gulf of Alaska show decreases in adult body size and marine growth rate when large numbers of sockeye are present. Density dependent effects are manifested in early ocean life and are probably due to competition for food (Peterman 1984).

POPULATION TRENDS

For many Pacific salmon populations, fish size declined between 1951 and 1975 and then increased somewhat between 1975 and 1981 (Healey 1986).

Alaskan salmon populations were low in the 1950s and 1960s, but have risen since the mid-1970s. Columbia River chinook and coho populations declined since 1976-77 and through the 1980s (Anonymous 1990).

British Columbia chinook stocks are believed to be overexploited. Relative to conditions in 1951 coastwide catch has doubled; age composition has not changed; landings have increased for trollers, seiners, and sportsmen but not gillnetters; and the average fish size has halved (Healey 1982).

The average size of chinook has been declining since at least 1920. Part of the decrease is due to the use of trolling gear, harvesting fish before they have completed their ocean growth, often before reaching their final ocean year. Concurrently, the average age of spawning fish has been reduced, since fewer fish are alive to complete maturity. Since age at maturity is a partly heritable trait, the genetic basis for late maturation may be deteriorating. This further affects the reduction in size. Selective fishing by both gillnetters and trollers may have disproportionately reduced the abundance of stocks of large-sized fish. No evidence exists that the ocean environment has contributed to the downward trend in chinook size. Fish size has decreased during the period of ocean warming up to 1940, and during the cooling period that has occurred since then (Ricker 1980).

Marine survival rates of Puget Sound hatchery coho increased from the late 1960s to the middle 1970s (Olson 1978).

The average survival rate of Columbia River hatchery coho declined from about 7% to 2% during the 1970s (Mathews et al. 1985).

The spring chinook adult return rate to Carson NFH, Leavenworth NFH, and Rapid River SFH (Idaho) decreased from about 0.45% to 0.15% from 1965 to 1978. In the Oregon Production Area from 1961 to 1980 more hatchery smolts were released and fewer adults were produced (McIntyre 1985).

Fall chinook survival in the Columbia River peaked in 1967 and began a steady decline in the late 1960s or early 1970s. Both wild and hatchery fish were affected by the decline. British Columbia hatchery stocks have undergone a decline during the same period (Vreeland 1989).

Pink population sizes are determined by compensatory (density dependent positive), depensatory (density dependent inverse), and extrapensatory (density independent) mortality. Compensatory mortality occurs during spawning and incubation. Depensatory mortality occurs during fry migration and is due to predation. Extrapensatory mortality occurs at any stage (Neave 1953).

From 1912 to 1980, there has been a slight decrease in the size of adult sockeye. Size was not correlatable with mean salinity. A negative correlation was seen between size and ocean temperature (Ricker 1982).

California sardine populations are rebuilding. Some sardines have been reported off the Oregon coast. The historical range was from Baja California to British Columbia. Harvests in Japan have risen from 57,000 to 5,000,000 tons since 1971 (National Fisherman - West Coast Focus, March 1991).

In the 1982 fishing season off British Columbia, hake yearclasses from 1970, 1973, and 1977 were dominant. Total landings off Canada were:

1978	6,467 mt	
1979	12,435 mt	
1980	17,661 mt	
1981	25,091 mt	
1982	32,209 mt	(Beamish and McFarlane 1985).

US landings of hake were:

1978	3,000 mt
1979	13,000 mt
1980	41,000 mt
1981	45,000 mt

The increased shrimp catch off the Washington ,Oregon, and California coast since the beginning of the hake fishery in 1966 could be due to increased shrimp production as a result of decreased hake predation on shrimp (Francis 1983).

MANAGEMENT STRATEGIES

Hatchery coho were stocked into streams with wild populations. Unstocked streams were also monitored. Wild juveniles apparently were displaced in the stocked streams. Returns to both types of system were similar, but the stocked fish returned earlier. Despite similar numbers of adults, fewer juveniles were recruited in the stocked systems. The conclusion is that the earlier spawn timing of the hatchery stock resulted in the failure to establish enhanced populations (Nickelson et al. 1986).

Chinook juveniles should be protected from fishing if a maximum yield in pounds is desired. The yield cannot be increased by minimum size regulation due to direct injury and 'hyperactivity'. The most feasible alternative to minimum size regulation is temporal and spatial restriction of the fishery to known concentrations of maturing fish, with the encouragement of non-size-selective gear (Parker 1960).

Ocean fishing apparently reduced the number of 1962 brood fall chinook returning to Kalama Hatchery by 70% and the weight yield by 25%. For the 1961 brood the reduction was 50% of the numbers and 19% of the weight yield (Henry 1971).

Fin-clipped chinook were smaller, matured later, and had much poorer survival than unclipped fish. Less than one percent of all marked fish were alive at the beginning of the third year, when they became available to ocean fisheries (Cleaver 1969).

FISHING CATCH AND EFFORT

In British Columbia in 1984, despite quotas and a reduced season length, neither the catch of chinook nor the effort was reduced. The catch exceeded the 1984 quota and the 1983 catch. Quotas severely restricted catches off Washington and Oregon. The 1984 troll catch of chinook in Washington was 40% of the 1983 catch. A reduction of over 70% in Alaska's fishing season resulted in only 30% reduction in catch (Vreeland 1989).

During El Niño of 1982-3 the salmon catch in 1983 off California, Oregon, and Washington was very poor. The catch off Alaska was a record high. The British Columbia catch was mixed. Historical data for Washington coho landings show sharp declines in 1942 and 1958-60. Chinook landings also dropped, but not as severely as coho. Oregon chinook were about 25% smaller than average, coho were about 50% smaller than average (Fluharty 1984).

MODELLING

A multiplicative, log-normal distribution is most consistent with the random variation seen in stock-recruitment relations (Peterman 1981).

Optimal harvest rates for mixed stocks can be calculated using stochastic dynamic programming (Hilborn 1976).

Classically defined maximum sustainable yield exploitation rates are close to the rates that would cause a drastic decrease in the population. Catastrophe theory is discussed with reference to harvesting multiple stock salmon systems (Peterman 1977).

Fish size and average age has generally declined due to selection by fishing gears and harvesting strategies. Coho and pinks are most affected, followed by chinook, then chum and sockeye (Ricker 1981).

Exploitation rates for maximum yield and stock collapse depend on a stock's maturity schedule. They are low for a late maturing stock and high for an early maturing stock. There is a probability of stock collapse in a fully exploited mixed stock fisheries. Management research should focus on obtaining better estimates of the Ricker a parameter. Female chinook, which mature at older ages, suffer higher cumulative fishery removal rates than males and decline in abundance more rapidly as exploitation increases (Hankin and Healey 1986).

A model suggests that the variability in the harvest of adult Hokkaido chum and Oregon coho is related to the number of smolts entering the ocean. The more smolts, the greater the variability in harvest. Previous inferences about density dependence may be incorrect (McCarl and Rettig 1983).

In determining Oregon coho smolt density independence, limiting factors regression technique gave the best results of several models tested (Clark and McCarl 1983).

The population dynamics of wild and hatchery coho were estimated using pooled time-series and cross-sectional data with Breverton-Holt and Ricker models (Anderson and Wilen 1985).

Biased parameter estimates for stock-recruitment curves can come from using time series data. Bias can be determined using Monte Carlo simulations (Walters 1985).

A simple population model questions the assumption in fisheries management that stocks have a natural persistence (Steele and Henderson 1984).

The limit-mean model is introduced to analyze Ricker, Fredin, and Cleaver models. A wide range of bias is observed. The limit-mean model performs best when offshore catch is known (Lander 1973).

Dynamic programming is useful for evaluating alternate escapements (Walters 1981).

SMOLTIFICATION

MIGRATION

Columbia River yearling chinook, steelhead, and coho showed migration peaks in early May at Jones Beach. Subyearling chinook showed three peaks in April, May, and July. Movement rates to the estuary generally increased with increasing river flow and fish size (Dawley et al. 1982).

Columbia River hatchery reared chinook, coho, and steelhead peaked in passing Jones Beach (river km75) during the first two weeks in May. Numbers of subyearling chinook were related to hatchery releases. Wild yearling chinook migrated past Jones Beach from late March to late June. Subyearling wild chinook migrated past Jones Beach from late May through September. Columbia River juveniles migrating past Jones Beach were actively feeding during migration (Dawley et al. 1981).

Coho smolt migration occurred during full moon during a period of maximum low tide between sunrise and sunset. No relationship with stream discharge or temperature was seen. Fry exhibited similar patterns (Mason 1975).

Coho salmon raised at a high rearing density showed a reduced plasma thyroid hormone level. There was no effect from water inflow rate. Rearing density and water inflow affected plasma cortisol and Na,K-ATPase with varying effects. Lowering the rearing density from high to low 2 weeks before sampling lowered plasma cortisol to levels seen for fish reared at low density, but with no effect on thyroxine or Na,K-ATPase (Patiño et al. 1986).

Coho reach the upper Columbia River estuary between late April and early June with peak numbers between May 6 to May 17. Large fish migrate before small fish. More migration occurred during daylight (Durkin 1982).

Pre-smolt coho transferred to seawater had parr-marks and lower condition factor than smolts. Pituitary gland prolactin cells were less active. Growth hormone cells were more numerous and filled with secretory granules. Thyroid and endocrine pancreas had regressed. Interrenal cells showed no difference. After 4 months in fresh water, pre-smolts recovered (Clarke and Nagahama 1977).

High streamflows enhanced survival of downstream migrating chinook in Green River, Washington. Mean travel time was 4.3 days to cover 13 miles (Wetherall 1970).

PHYSIOLOGY

For Willard NFH and Eagle Creek NFH 1976 coho releases, the total recovery of 'late' (higher ATPase) released fish was 2.8 times greater for Willard and 3.1 times greater for Eagle Creek than for 'early' releases. No geographic shift in recovery distribution due to 'delayed' release was seen. Fish may not migrate as rapidly if released before the peak in ATPase level. Later releases may have survived better due to increased food resource (Wahle and Zaugg 1982).

Fall chinook fed salt (7% vs 1.6% NaCl in control) six weeks before release showed 65% greater recovery in the fishery and to the hatchery than controls. Another supplemented fall chinook group (7.9% NaCl for over six months) had higher ATPase activity and higher survival when transferred directly to seawater net-pens. If fish are at their maximum salt regulation ability, then salt supplementation may not increase survival (Zaugg et al. 1983).

Seawater survival of coho at various salinities is a function of size, not age. Sea-water adaptation preceded migration by six to seven months (Conte et al. 1966).

ATPase activity of yearling coho increased during the last two weeks of March and remained constant until July, when it decreased. ATPase activity increased three to four days after coho were placed in salt water and continued to increase for 30 to 35 days (Zaugg and McLain 1970).

Gill Na,K-ATPase activity and T_4 levels are poor predictors for the release of juvenile coho and spring chinook to produce maximal adult returns (Ewing et al. 1985).

Spring and fall chinook possess similar osmoregulatory capabilities. The rate of development of osmoregulation is enhanced by prior conditioning and by high growth rates (Wagner et al. 1969).

In spring chinook at Leavenworth NFH, thyroxine level peaks were seen in mid-March and late April, with a prolonged peak from late May into June. ATPase peaks were similar to thyroxine, but were slightly later, and reached their highest levels in late May. Fish are normally released in April, about four weeks before these observed physiological events. Branding studies showed that fish released in April took longer to move downstream. Fish released later moved downstream more rapidly. It is surmised that thyroxine is the precursor to migration and ATPase levels peak during migration. Crowding elicited maximum stress response, more than netting, anesthesia, or branding (Weitkamp and Loeppke 1983).

Spring chinook in the Deschutes River, Oregon showed a higher ATPase in migrating fish than in non-migrants. In 1978, a peak ATPase level was seen in hatchery fish, no peak was seen in 1977 samples of hatchery fish. Caution is indicated for ATPase use as an indicator with hatchery fish (Hart et al. 1981).

Spring chinook entered the ocean in September and October at a length of about 10cm. Peak ATPase activity occurred in mid-September or October. A maximum change in activity also occurs at this time. Data were analyzed for Cole Rivers SFH spring chinook progeny of sub-yearlings, as adults from yearlings only constitute 10% of the return (Buckman and Ewing 1982).

EVOLUTION

Salmonidae evolved in fresh water. *Oncorhynchus* originated in brackish water. Schooling oncorhynchids are the most specialized of the seagoing salmonids while *Salvelinus* and *Salmo* are more primitive (Hoar 1976).

BEHAVIOR

Pink, chum, and coho in the Little Port Walter, Alaska estuary concentrate, sometimes in mixed schools, in the upper, least saline layers of water when they leave the stream mouth (Lagler and Wright 1962).

Pink and chum fry outmigrate at night. Strong lights are avoided. Pinks show a strong downstream swimming response. Both species swim at or near the surface. If still in the stream at daybreak, the fry bury themselves in the substrate. Once reaching salt water their behavior changes, perhaps due to the onset of feeding (Neave 1955).

Sockeye, coho, pink, and chum fry migrate downstream at night, regulated precisely by changes in light intensity. Pink fry are found throughout the water column, but mostly at middle depths. Pink and chum would migrate during daylight if they had long migration routes. Pink and chum were observed to school only at the end of their seaward movement. Some feeding of pinks was seen in natal areas, but more predominately as the sea was approached (McDonald 1960).

In fresh water chum and pinks form schools and are constantly active day and night. At night they lose visual contact with the bottom and are subject to downstream displacement. Active downstream swimming occurs only with unusually high temperatures. Coho fry are strongly territorial and are quiet at night. Coho smolts exhibit less territoriality and tend to aggregate. During the day they group in deeper water or under cover. At night they rise to the surface and are displaced downstream. All behaviors are modified by pronounced temperature changes. Increases in water level speeds downstream displacement (Hoar 1951).

Sockeye and chum fry school, respond positively to current and avoid shallow water. Of the two, chum form more active schools, travel faster, prefer stronger light, prefer shallower water, and have a less marked cover reaction. Sockeye smolts, contrasted with coho smolts, are more active, show little territorial behavior, and a stronger response to current. Sockeye fry move downstream after dark. Coho smolts move seaward more slowly than sockeye (Hoar 1954).

In seawater, juvenile pink and chum schooled closely and were in constant motion at ambient temperature. Juvenile chinook did not school strongly and moved slowly or were motionless. All species increased swimming rates and reduced schooling behavior immediately in response to a temperature change of less than 1 °C per minute (Bessey 1972).

Upon entering saltwater, chinook were observed to swim near the surface and orient to the shoreline. No fish were observed more than 300 yards from shore or deeper than five feet (WDF 1959).

Sockeye returning to freshwater will attempt to find their stream by swimming perpendicularly to the shore. If they fail, they head offshore and make another perpendicular attempt. This reduces wasted efforts of following the shoreline and potentially becoming lost in large bays and estuaries (Westcoast Fisherman (British Columbia) story on tracking adult chinook 1990).

GENETICS

Genetic destabilization is caused by too few parents inputting to the population. Genetic contribution to the population is limited by the minimum number of spawners used at the hatchery and subsequently retained for production (effective number in population). The problem can be remedied by increasing the number of parents used and retained (Simon et al. 1986).

An inverse relationship exists between the distance a fish is transferred from its natal stream and the survival rate to adult. Genetic adaptation to a specific river system is implied (Reisenbichler 1988).

Pooling of sperm, or sequential addition of multiple males, does not achieve an equal proportion of siring. Observations of 3% to 84% siring have been reported (Withler 1990).

More heterozygous rainbow trout have greater disease resistance to bacterial gill disease than less heterozygous fish (Ferguson and Drahushchak 1990).

Wild steelhead interbred with domestic rainbow trout increased their exposure to predation by foraging closer to a predator than did wild steelhead. Both types suffered equal mortality rates (Johnsson and Abrahams 1991).

DISEASE

Spring chinook smolts in the mid-Columbia River with chronic bacterial kidney disease infections disappeared from the migrating population before reaching McNary Dam, presumably due to mortality (Rondorf et al. 1988).

Vaccination against *Vibrio* did not increase the survival or growth of chum released to the ocean (Wertheimer and Martin 1986).

Vaccination against *Vibrio* did not increase the survival of Atlantic salmon released to the ocean. Investigators used an intraperitoneal injection of trivalent bacterin (Baum et al. 1982).

Vaccination against *Vibrio* increased the survival of steelhead released to the ocean. Investigators used an immersion in bivalent bacterin (Amend et al. 1980).

Vaccination against *Vibrio* increased the estuarine survival of coho released to Great Bay estuary, NH. The vaccinated survival was 1.2 to 15 times that of unvaccinated controls. Investigators used an interperitoneal injection (Deegan 1981).

More heterozygous rainbow trout have greater disease resistance to bacterial gill disease than less heterozygous fish (Ferguson and Drahushchak 1990).

HATCHERY PRACTICES

Bonneville SFH fall chinook fed Oregon Moist Pellet No. 4 (fish protein base) appeared to survive to the estuary at twice the rate as those fed Oregon Moist Pellet No. 2 (soy protein base). Smaller individuals released from hatcheries (Washougal chinook, Willamette steelhead) may not have survived as well as larger individuals during their migration to the estuary (Dawley 1981).

Rainbow trout fed a diet containing up to 12% salt for a month before transfer to seawater showed reduced mortality over trout fed normal diets (Salman and Eddy 1990).

Fall chinook fed salt six weeks before release showed 65% greater recovery in the fishery and to the hatchery than controls. Another salt-supplemented fall chinook group had higher ATPase activity and higher survival when transferred directly to sea-water net-pens (Zaugg et al. 1983).

Fall chinook fed salt six weeks before release contributed 49 to 64% more adults to the fishery than controls (Zaugg 1982).

Coho reared at stable water temperatures in March and April showed lower marine survival rates than coho reared on fluctuating water temperatures (Olson 1978).

Fall chinook were subjected to four treatments after common rearing in freshwater for 78 days:

1) 5 day conversion to 75% seawater,
2) direct release to seawater,
3) 8 day conversion to 100% seawater followed by 25 days pen rearing in seawater, and
4) 8 day conversion to 100% seawater followed by 60 days pen rearing in seawater.

Survival to adult was 0.75%, 0.47%, 0.26%, and 0.19% respectively (Ellis 1957).

Coho released from net-pens at Squaxin Island, Washington after some salt-water rearing had an average recovery rate (catch + escapement) of 17.1%, which was similar to that for other facilities releasing at about the same time (Rensel et al. 1988).

Coho experimentally trucked, then released at the hatchery of origin, upstream, or downstream averaged 76%, 83%, and 84% of ocean catches of untrucked fish. Coho transported to another system and acclimated for six weeks showed higher survival than fish released immediately (Johnson et al. 1990).

Coho were released at Bonneville Dam, the head of saltwater intrusion, the mouth of the Columbia River, the Columbia River plume, north of the plume, and 38km offshore in oceanic water. Over five years of releases were made with highest survival to fisheries seen for the fish released at the point of saltwater intrusion (1.6 to 2.5 times that of the Bonneville Dam release (control)). Other release groups did not differ significantly from the control. Straying increased as the release distance from shore increased (Solazzi et al. 1991).

Preliminary data suggest that hatchery fall chinook survival could be enhanced by increasing stamina, increasing size, increasing protein and energy reserves, and lowering disease incidence (Burrows 1969).

Coho reared in a semi-natural habitat on a partly natural diet showed lower returns than wholly hatchery reared fish. Four brood years and 17 tag groups were examined. Releases one month later than normal did not increase returns, as models predict. Distribution of catches in sport and troll fisheries were similar (Mundie et al. 1990).

The ocean survival of coho salmon was increased by reducing rearing pond density in 1979, but only weakly affected the survival of fish released in 1980. High rearing density fish showed decreased weight, length, and protein content, and increased condition factor and mortality. At higher rearing density, skewness in length distribution and correlation of condition factor changed from positive to negative. Larger smolts showed increased protein and lipid content and reduced moisture and ash content. Crowding stress particularly affects smaller fish (Fagerlund et al. 1983 and Fagerlund et al. 1981).

At a high rearing density coho salmon showed a reduced plasma thyroid hormone level, no effect was seen for water inflow rate. Rearing density and water inflow affected plasma cortisol and Na,K-ATPase with varying effects. Lowering the rearing density from high to low two weeks before sampling lowered plasma cortisol to levels seen for fish reared at low density, but with no effect on thyroxine or Na,K-ATPase (Patiño et al. 1986).

Coho with slime removed from 25% of the body had no mortality in fresh or sea water. Removal of slime and scales from 25% of the body caused no mortality in fresh water, but 75% mortality within 10 days in sea water. The 10 day median tolerance limit was 10% scale removal immediately prior to sea water entry. Mortality was highest when scales were removed from the ribcage area. 90% of fish descaled at lethal levels regained tolerance to sea water after one day of recovery in fresh water (Bouck and Smith 1979).

Fall chinook return rates to Spring Creek were related to fingerling releases. Survival rates since 1950 have dropped greatly. The high rates seen in 1958 and 1959 don't match rates seen in the 1940s. Responsible factors may be tuberculosis, coagulated yolk disease, fingerling crowding, and a change in diet (Junge and Phinney 1963).

SIZE AND TIME OF RELEASE

For the 1981 release coho from Big Creek SFH and the 1984 release from Coos Bay SFH survival was not related to size of fish. Survival increased with date of release for both hatcheries, regardless of fish size (Mathews and Ishida 1989).

Coho from the 1966 Big Creek SFH release at 10.7 fish per pound had an estimated catch of 2.21% and those released at 27.3 fish per pound had an estimated catch of 1.14%. No difference was seen in the percent males recovered, but female recovery rate was more than double for the larger smolts (Johnson 1970).

For Columbia River coho, at any given time of release, the greater the fish size, the greater the contribution. June is the best release time. Fish below a 'critical size' were absent in ocean sampling, suggesting they did not survive through the estuary (Mahnken et al. 1982).

Coho ocean survival increased with increasing smolt size. Small (9.4g to 11.1g) fish survival was much lower than for medium (12.5g to 13.9g) or large (16.2g to 18.0g) fish (Fagerlund et al. 1983).

Late summer releases of zero age coho produce the highest rate of return. The optimum production can be realized from 14cm to 15cm smolts released in August and September. Maximum returns should come from June releases of 12.5cm to 13cm fish (22g to 25g). Fish released in July should be 14.5cm to 15.5cm (35g to 42g) (Stohr and Parker 1982).

For British Columbia coho, the yield of jack biomass was positively correlated with smolt size. Larger smolts resulted in more jacks. Releases were made May 12, June 10, and July 7, 1975. Larger smolts produced larger jacks. Earlier releases produced more jacks than later releases. Maximum adult biomass came from moderate (20g to 24g) sized smolts released in early June. Highest jack biomass came from large smolts released in May (Bilton 1980).

British Columbia coho were investigated, with releases made April 20, May 10, May 30, and June 19, 1980. Triplicate coded wire tagged groups of graded small, medium, and large smolts were used. Mathematically derived, the maximum return would come from 15.7g smolts released June 4. The investigators recommended 20g though, since that was smallest actually tested. The highest predicted jack return would come from 30g smolts released May 8. Combined, the maximum biomass would come from 16.6g fish released June 3 (Bilton et al. 1984).

Larger British Columbia coho smolts did not generally show increased survival but large smolts did survive better in years when marine survival was relatively poor (Holtby et al. 1990).

There is no evidence that size-dependent mortality of Columbia River hatchery coho exists (Mathews et al. 1985).

Coho held at the hatchery for delayed release in June and July, as opposed to release in May, migrated seaward more rapidly and in greater numbers (Zaugg 1982).

Coho smolt survival is size dependent when smolt survival is poor and when herring abundance is low (Holtby 1989).

Puget Sound hatchery coho showed increased survival with increasing smolt size (Olson 1978).

Alaska chinook salmon from the 1977 and 1978 brood years were released at two sizes, 9.7 to 12g and 28.2 to 37g). The adult return rates were higher for large smolts in both years. At higher rearing density, 6.6 to 24.3 kg/m^3, there was no effect on survival during the culture period, there was a lower adult return rate, but more adults per unit volume were produced (Martin 1988).

Washington Department of Fisheries releases of fall chinook are typically smaller and later than US Fish and Wildlife Service or Oregon Department of Fish and Wildlife releases. This results in a shorter marine rearing period during the first year, which leads to later maturing, older fish (Vreeland 1989).

Juvenile salmon entering the ocean after the transition from winter to summer ocean conditions have enhanced survival. North of the Columbia River this is about May 1, south of the Columbia River about April 15. Upwelling and prey abundance is greatest after this transition. The transition has generally occurred later in the year since the middle 1970s (Anonymous 1990).

The number of sockeye smolts is negatively correlated with the return rate of adults. With more smolts there is a lower survival rate to adult. This condition is related to smolt size. If smolt size increases from 4 to 10 grams, survival is tripled. Smolt size and numbers account for about 60% of variation in survival to adult (Foerster 1954).

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