C C G E the California Geographer

Volume XXII 1982

MAN AND THE PACIFIC SALMON: A NEW ERA?

*Jerry C. Towle**

Those who teach courses in resource conservation are aware that what they teach and what occurs in the "real world" are often at odds. Even competent and authoritative texts are outdated by a year or more before dissemination, and the increasing backlog of articles makes professional journals ever less responsive. Where correction for time lag involves updating statistics which do not substantially alter general interpretations, the problem is not particularly important to most of us. If an erroneous interpretation, based on conditions of some years ago, persists, the disparity is more serious. One example of the latter situation is in the field of conservation. Most students of resource management are familiar with the Pacific Salmon; the history of human use of the genus is known in broad outline, if not detail. The most affluent of pre-European North American societies owed much of their economic success to the salmon. The fish effectively harvested the productivity of the sea and carried it back to their natal streams on the spawning journey. Northwest Coast peoples lived well in a land offering little in the way of terrestrial resources, mostly because they took large numbers of salmon. In spite of heavy predation extending over millenia, early written accounts testify to the astonishing abundance of the fish. That population levels remained high was probably because freshwater spawning areas were not damaged.

This era of balanced predation ended with European settlement. Large scale commercial fishing, associated with canneries, began in the Sacramento River in the 1850's. As the runs in the Sacramento dwindled, intensive commercial fishing moved northward, tapping the resources of the Columbia, the Fraser, and

**Jerry C. Towle is a member of the faculty at California State University, Fresno.*

A Faculty Research Grant from California State University, Fresno aided the development of this paper. A number of busy people graciously took time to answer my questions, chief among these Robert Hager of the Washington Department of Fisheries. Mr. Hager and Bill Hopley, also of the Washington Department of Fisheries, reviewed this paper and made many helpful comments.

finally, Alaskan rivers by the end of the century.[1] Early fishing methods emulated those of the Indian in that fish were taken as they entered the rivers to spawn. Unlike the Indian, commercial fishermen were working to supply a world market rather than local subsistence needs. As footloose entrepreneurs on a frontier, they paid little attention to conservation. In some cases, nets stretched entirely across rivers allowed no upstream escapement of spawners.[2]

At the same time that fishing pressure increased, freshwater habitat deteriorated. Dam construction blocked access to many miles of spawning beds. Some dams had no fishways to carry the salmon around the obstruction. If fishways were incorporated, the loss was not total; yet mortality of spawners, and of juveniles migrating downstream inevitably increased. A number of other activities stressed the salmon. Hydraulic mining blanketed spawning gravels in the Sacramento system with thick layers of silt. Water diversion for agricultural and urban use so reduced the volume of some streams that returning adults could not navigate the shoals to reach their spawning beds.[3]

Logging injures the fish in several ways. Storage of logs in estuaries produces an accumulation of toxic bark residues that can virtually eradicate marine life. Logging debris blocks upstream migration paths. Removal of trees alters erosion and sedimentation rates, so that spawning and rearing areas are subject to siltation or scouring floods.[4] Dredging, pollution, and the expansion of port facilities have all diminished the utility of the estuarine nursery areas. In short, virtually every activity associated with economic development of the Pacific drainage has damaged the salmon runs. Even in British Columbia, where the extent of environmental modification is not great by U. S. standards, the number of adult fish returning to spawn each year was halved between 1860 and 1960.[5] The losses experienced in Washington, Oregon, and California have been considerably more severe.

Current Assessments

The Pacific Salmon has come to epitomize the incompatibility of modern man and the natural order. Anthony Netboy notes that compared to the Atlantic Salmon:[6] "...Pacific Salmon are much more numerous, but this abundance is bound to diminish under present policies, despite conservation programs in existence." He concludes:[7] "Only a deceleration of industrial activity, coupled with something like the Indians' awe and veneration of the wondrous animals who supply us with food can ultimately save the salmon." A more recent text in the field of man-environment relationships states:[8]

> The Pacific Salmon is not ecologically extent, but is perilously close to endangered status....Salmon have already been reduced by overfishing. If their spawning territory continues to be disturbed by logging, pollution, increased water temperatures, power dam construction, and other human interference, they will certainly become extinct in an ecological sense, if not in a biological one.

These are representative of the pessamistic assessments available to the layman. Given the unlikelihood of an economic and spiritual metamorphosis such as that proposed by Netboy, there will be, it is suggested, a sad, inevitable decline ending in extinction. Balanced exploitation has been supplanted by a terminal era of destructive predation, the end of which will be the end of the salmon.

This vision of the future cannot be totally disregarded; yet, there is considerable optimism in professional circles that the salmon will not be a twentieth century successor to the bison or the passenger pigeon. In 1975, the Canadian government undertook a Salmonid Enhancement Program, the goal of which is to restore the salmon to their pre-European levels of abundance within fifteen years. If successful, this will involve a doubling of current numbers. Commitments to increase numbers have since been made in Alaska, Washington, and California. We are at a point when destructive predation may be supplanted by a new era, one in which man will not only arrest, but reverse, the long process of decline.

A question which occurs is, "Why now?" Salmon numbers and range have been shrinking for more than a century, so that concerted action has started quite late. One reason for change is that management of salmon populations--both production and harvest--has been, until quite recently, the exclusive domain of the state. Those who are charged with allocation of a public resource face a growing number of claimants demanding their share of a dwindling supply. This problem is especially severe in the state of Washington, where a federal court ruling in 1974 awarded up to half of the annual allowable catch to treaty Indian fishermen.[9] Government agencies confront the problem of mediating among trollers, net fishermen, sport anglers, and conservation groups, generally to the satisfaction of no one. Certainly, increasing the number of fish is the most obvious and important step in solving the allocation problem.

Economic considerations are also important. At a large scale, commercial salmon fisheries have been criticized as wasteful and inefficient, in that too many people have invested too much capital, when the harvest could be accomplished with far less effort and gear.[10] Yet the salmon, in most years, support North America's leading fishery by value. At the local level, fishing is the economic base of many small, isolated resource communities, particularly in Alaska and British Columbia. Saving the fishery by increasing numbers is, at present, more practical than finding alternative industries.

Biological Characteristics

The will to restore the salmon and the public concern over maintenance of the fishery are not recently developed attitudes. Ability to carry out enhancement projects is the second necessity, and this ability depends on recent advances in propagation technology. Some knowledge of the salmon's life history is necessary to the appreciation of these advances.

Although the salmon problem is often discussed as if there were only one species, the genus Oncorhynchus is represented by six species, five of which are native to North American waters. These are: the chinook, or king (O. tshawytscha), the coho (O. kisutch), the chum (O. keta), the sockeye (O. nerka), and the pink (O. gorbuscha). All species spawn in fresh water. All die after spawning. Juvenile salmon migrate downstream to the sea and attain their growth in salt water. As adults they return to their natal streams to perpetuate the process. All cease feeding upon entering fresh water.

There are, from a conservation and management prespective, significant differences among the species.[11] Length of time spent in fresh water and freshwater habitat requirements vary. Chum and pink salmon begin their migration to the sea almost immediately upon hatching; they make little demand on the food resources of the stream. Coho and chinook may spend up to two years in fresh water; sockeye, three. At some time during their stream residency, coho, chinook, and sockeye undergo a series of physical and behavioral changes which readies them for survival in the sea. This process is called "smoltification", and the downstream migrants are smolts. Sockeye reproduce only on rivers which have lakes along their courses. Upon emergence, the young migrate to the lake and remain there for up to three years before descending to salt water.

Oceanic life histories also differ. Pink salmon have an unvarying cycle in that all adults return to spawn after spending slightly more than a year at sea. The others show more variability. Chinook generally return after two or three years at sea but may remain in salt water for up to five years. Chum ocean life spans range from two to six years. Coho generally spend 1½ years and sockeye two or three.

Feeding habits vary; coho and chinook are carnivores while chum, pink, and sockeye are planktivores. This affects fishing methods because coho and chinook are taken by trollers and sport fishermen and the other three do not readily strike lures.

In addition to differences among species there is considerable genetic variation within each species. Because salmon have a strong (though not absolute) tendency to spawn in their natal streams, the fish of each river system comprise a closed reproductive population. It is estimated that the five species are thus subdivided into as many as 10,000 ecological subraces, or "stocks", which vary in such traits as size, time of spawning, or oceanic migration routes.[12]

Enhancement Strategies

Restoration of salmon populations, then, must depend on an array of techniques and strategies, each suited to species, stock, or environmental differences. Some are designed to rebuild natural stocks by improvement or expansion of freshwater spawning or rearing habitats, others to create artificial environments (Table 1).

Table 1
Major Facilities Considered for Canada's
Salmonid Enhancement Program

Type	Number	Maximum Annual Output (000)	Species
Fishway	4	347	pink
Lake Fertilization	9	1,815	sockeye
Spawning Channel	34	23,482	sockeye, pink chum, coho, chinook
Hatchery	28	4,882	chinook, chum, coho
Rearing Pond	8	264	coho, chinook
Box	22	2,419	chum, coho, pink, chinook

Source: Fisheries and Environment Canada, Fisheries and Marine Service, The Salmonid Enhancement Program (Vancouver: Salmonid Enhancement Program, 1978). This is a candidate list of projects, some of which may not be constructed.

Fishways and stream clearance projects aid migration of spawners by providing a route around barriers or removing obstructions in the stream bed. Where such barriers have denied access to otherwise suitable spawning grounds, salmon may colonize and extend their range in a stream system. In economic terms these projects are very practical; maintenance expenditures are low, and eighteen of the twenty fishways constructed on the Pacific Coast since 1954 have paid for construction costs by increased contribution to the fisheries.[13]

Flow and temperature controls can aid the salmon in several ways. Where water levels impede or delay upstream migrations, release of water from reservoirs at critical times reduces mortality of spawners. The same practice may aid downstream movement of juveniles. Stream temperatures can be modified by releasing water from different levels in a reservoir. During the upstream migration of adults, colder water is desirable because it can hold more dissolved oxygen. In streams where coho and chinook juveniles are resident, warmer water can, up to a point, increase growth rates.

Lake fertilization is a recent innovation applicable to sockeye enhancement. The lakes in which juvenile sockeye reside are typically nutrient-poor oligotrophic bodies. Addition of nitrogen fertilizer--a sort of mild, deliberate eutrophication--increases primary productivity of the lake, and ultimately increases salmon growth and survival rates. Ocean survival rates correlate positively with size of smolts, so that the fishery should harvest more adults. Testing this technique in British Columbia and Alaska indicates that large returns can be expected from modest investments.[14]

In-stream feeding is a variant of this technique used to increase carrying capacity for juvenile coho and chinook. In some ways, both lake fertilization and in-stream feeding are less manipulations than restoration of original conditions. The carcasses of spawners were an important source of aquatic nutrients, and helped to provide food for the next generation. Where salmon runs had declined, the productivity of lakes and streams likewise diminished. All of these strategies allow the salmon to spawn under natural conditions; humanity intervenes to increase survival rates of wild fish in fresh water.

Other techniques demand creation of new environments and more direct control of reproduction and early life. Spawning channels are, essentially, man-made streams in which ideal spawning conditions are maintained. The salmon spawn naturally, but control of gravel quality, flow, and the density of fish increases egg-to-fry survival by as much as four to eight times over natural settings.

Hatcheries involve complete human control of reproduction. A portion of the returning adults are directed to holding ponds where they remain until ready to spawn. Eggs and milt are taken and mixed artificially, and the fertilized eggs are kept on trays until hatching. After emergence, the young salmon are typically kept in ponds or rearing channels and fed until the optimal time of release. Length of retention time varies with the natural life history of the species; coho and spring chinook generally remain for over a year before release, fall chinook for about three months to a year depending on stock, and chum and pink anywhere from a few days to three months.[15] Few sockeye are produced in hatcheries, mostly because of persistent disease problems.

Hatcheries, though increasingly efficient, have some drawbacks; they are expensive to build, demand considerable labor, and require large amounts of water which, ideally, does not experience great seasonal fluctuations. A large expanse of level land is necessary for construction of facilities. The incubation box needs less space, water, and labor. Eggs are taken in the same manner as in standard hatcheries and placed in trays or in layers alternating with layers of gravel. Water enters the box at the base and percolates upward to flow out near the top. Upon hatching, the fry may follow the outflow and enter the stream. An incubation box measuring 12 x 5 x 5 feet has a capacity of 500,000 chum eggs and, under ideal conditions, will produce 400-450,000 fry.[16] Their greatest utility is in bolstering populations in streams which are too small, too remote, or lacking in level land sufficient for hatchery construction.

The problem of restoring the salmon, then, may be attacked in diverse ways; proposed major facilities in the Canadian Salmonid Enhancement Program employ most of these strategies. Rebuilding natural populations is an important aspect of all programs; however, because hatcheries represent the fastest (and most controversial) method, ensuing commentary focuses on hatchery technology.

Early Efforts

Hatcheries are not recent innovations. Artificial propagation of salmon on the Pacific slope dates back to 1872, and a number of hatcheries were constructed before 1900 in an effort to restore dwindling populations.[17] They were generally unsuccessful in arresting the decline. The reason for their inefficiency was that mortality rates at the egg and fry stages were equal to, or greater than, those in natural populations. Diseases related to temperature or density were common in hatchery ponds. Where young fish were held for a time before release diet was a persistent problem. Most commonly, juvenile salmon were fed ground fish scraps consisting largely of the caracasses of their parents. Whatever the economic efficiency of this arrangement, the diet was not only nutritionally inadequate, but probably helped to pass on diseases from one generation to the next. Decomposition of uneaten food lowered oxygen levels and further stressed the fish. Development of a satisfactory diet was not accomplished until 1959.[18]

In other cases, lack of knowledge of the salmon's life history or environmental requirements hindered restoration work. The first hatcheries were built at a time when it was not yet known that all Pacific Salmon die after spawning. Sockeye raised in early hatcheries were often released in places where they had no access to lakes; in these cases, mortality rates were probably 100 percent. Cannery operations in Alaska were, at one time, required by law to operate hatcheries of sufficient capacity to produce four salmon for each one caught.[19] Even if this law could have been enforced, it showed no understanding of the low survival rates of juvenile salmon; in some modern hatcheries, an adult return of five percent is considered adequate.

Early hatcheries often released fish as unfed fry immediately after emergence so that few survived the journey to salt water. In short, although most streams of any size had hatcheries along their courses at one time or another, and although large numbers of eggs were taken and young released, there is no evidence that all of this activity contributed much to the number of returning adults until about 1960. The fact that most public hatcheries were built only in response to specific losses of spawning water also lessened their effectiveness. Such mitigation projects, in theory, replaced the number of fish lost when, for example, a dam denied access to upstream migrants. Even if these facilities had been up to their stated task, they could not have kept pace with losses caused by overfishing, logging, or other less place-specific processes.

Modern Improvements

Modern hatcheries are not only more efficient than their predecessors but considerably more efficient than nature. The basis of success is greatly reduced mortality at the egg-fry stage. In Japanese rivers, egg-fry survival is about eight percent in natural spawning beds and 79 percent in hatcheries.[20] North American figures are comparable..[21] Although subsequent mortality rates are somewhat higher in the hatchery stock they are proportionately much less significant than the original tenfold gain.

Improved diet and the practice of feeding for extended periods before release have reduced early mortality and accelerated growth rates. Young coho and spring chinook are held at hatcheries until they become smolts and are physically equipped to enter salt water. The smolting process depends on time as well as size. Fish not released upon smolting tend to revert to the previous stage, and will then not readily migrate to the sea when liberated.[22] If the salmon attain a larger size before smolting, they will better withstand the rigors of their downstream migration and contribute more to adult populations. Ideally, fish released at the proper time and size will move quickly to salt water, avoiding the danger of stream predators and putting little pressure on food resources in the stream. Because egg-fry survival has probably reached the limits of improvement, current research is concerned largely with identifying optimal size and time of release.

Successful adaptation to salt water is dependent on release time, and survival of smolts could be increased if hatchery fish were released at the time of maximum readiness to migrate. Mortality rates of those which enter salt water before the optimum time may be as high as 50 percent, with many of the survivors stunted. A recent study has linked capacity for salt water survival of coho smolts with high levels of the hormone thyroxine. Further, the study indicates that maximum thyroxine levels occur within a day of a new moon in March or April. If this is correct, release time can be calculated precisely without time-consuming blood tests, and survival of smolts increased to well over 90 percent.[23]

In some cases smolts are transferred directly to the estuary by truck, completely bypassing the downstream migration. This is done if there is a critical barrier to migration, or if loss to predators is potentially very high. Chinook and steelhead stocks of the Snake River and its Idaho tributaries have declined precipitously in recent years. Juvenile migrants must negotiate eight dams and reservoirs on their way to the Pacific; the attendant high mortality at this stage is responsible for the decline. Survival of these stocks may depend on transportation of smolts past the obstacles. An experimental study indicates that survival rates measured by the number of returning adult spawners increased from 11 to 15 times as a result of transportation, and that there is no significant loss of homing instinct.[24] In California, a number of chinook smolts in the Sacramento River system are released in the estuary each year. Fish liberated upstream move down toward the sea at the same time that striped bass migrate upstream; the result is heavy predation on the young salmon. A more laborious means of accomplishing the same thing was attempted in Alaska; Arctic char, a major predator on sockeye juveniles in the Agulouok system, were netted and held in captivity until the seaward migration was completed.[25]

If all the techniques available to increase fresh water survival are applied, hatchery advantages over nature are enormous. In the Sacramento system it is estimated that 100,000 chinook, held for a year and released in the estuary, will yield the same number of returning adults as 40 million eggs in a natural spawning bed.[26]

Modern hatcheries date from approximately 1960. Those constructed much earlier either closed or adopted new methods. There has been considerable construction of new facilities since 1960, particularly of holding and rearing ponds (Figures 1 and 2). The number of juvenile fish released from hatcheries has likewise increased. Estimated releases from all hatcheries in the Pacific drainage of North America have grown from slightly less than 150 million fish in 1960 to more than 400 million in 1980[27]. Moreover, because of the widespread practice of holding juvenile salmon for extended feeding periods, the average size of the smolts at release is considerably larger than in 1960. The increase measured in pounds is more impressive.

Private Producers

Technological advances have been paralleled by other innovations in salmon production, chief of which is the re-emergence of private hatcheries. Facilities operated by individuals or corporations were among the earliest developed, but public agencies assumed control of propagation by the 1920's. The state of Oregon authorized private sea ranching operations in 1971 and has since issued twenty permits for release of salmon by private concerns. Maximum permitted releases total 180 million fish annually; actual numbers released are considerably less. In 1978, about 12 million juveniles were produced.[28] Sea ranching is a process in which private hatchery operators turn young salmon out to sea and are permitted to sell the adults which return to the release facility. The fish are common property while in the sea and may be taken by commercial and sport fishermen. Losses during the oceanic free-wandering phase are expected to be high; at current prices, however, an adult return of one to two percent is enough to insure a profit.[29] Sea ranching operations range from small

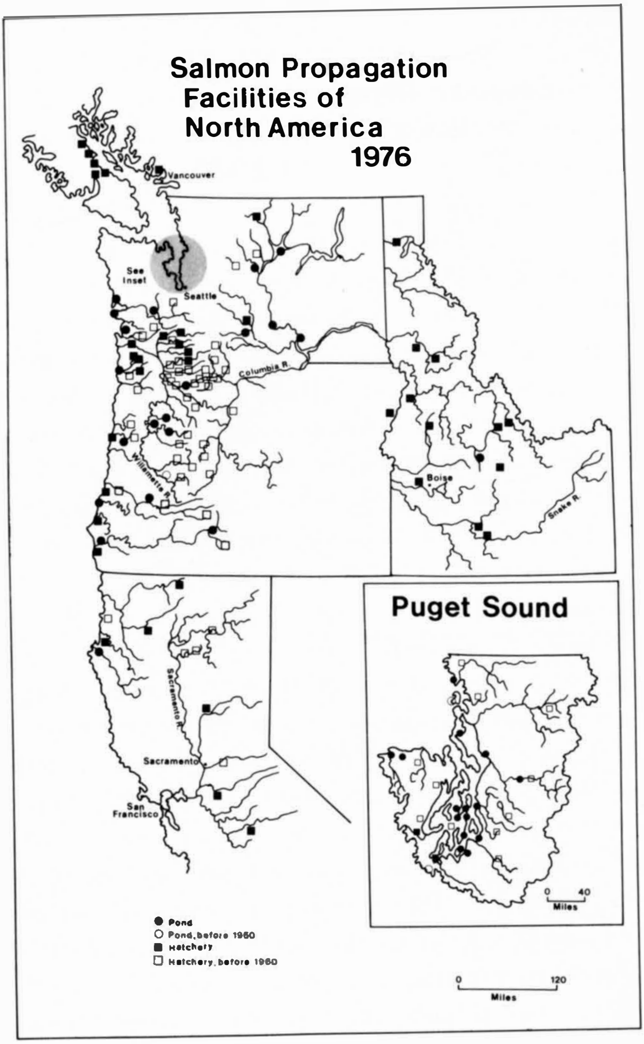
Salmon Propagation
Facilities of
North America
1976
Vancouver
See Inset
Seattle
Columbia R.
Willamette R.
Boise
Snake R.
Sacramento R.
Sacramento
San Francisco
Puget Sound
0 40
Miles
Pond
Pond, before 1960
Hatchery
Hatchery, before 1960
0 120
Miles

Figure 1

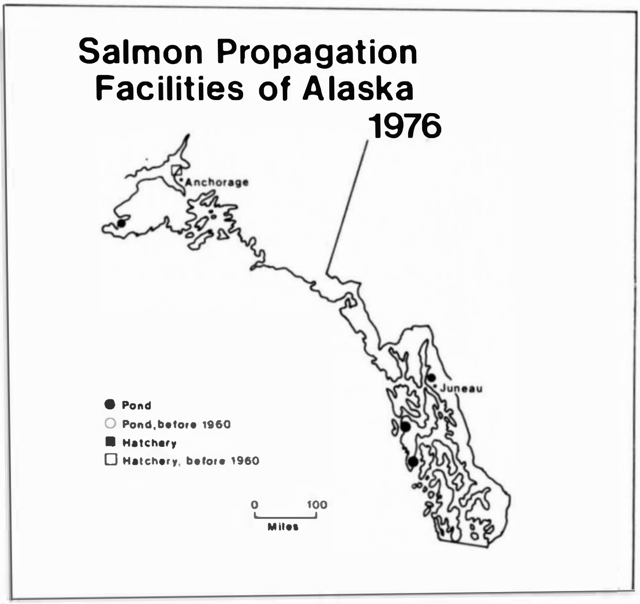
Salmon Propagation
Facilities of Alaska
1976
Anchorage
Juneau
Pond
Pond, before 1960
Hatchery
Hatchery, before 1960
0
100
Miles

Figure 2

individual endeavors to highly capitalized subsidiaries of major corporations; the largest, Oregon Aqua Foods (Ore-Aqua), is a part of the Weyerhauser Corporation. Ore-Aqua hatchery and rearing ponds are located well inland at Springfield, Oregon. Heated water from a Weyerhauser paper plant is mixed with cool river water to provide ideal temperatures. One benefit of temperature control is that the rate of maturation of coho may be accelerated; smolts are produced in six months rather than the customary fourteen to eighteen.[30] The smolts are then trucked to coastal release facilities and held for several weeks to habituate them to salt water. Chemicals added to the water in the holding ponds "imprint" the site on the fish so that they will return as adults. This operation represents the greatest degree of human control over salmon populations yet achieved. Even the need for a river flowing to the sea is eliminated.

However, sea ranching is not yet well established. Most of the authorized establishments have not released fish, and returns from the first large Ore-Aqua coho release occurred in the fall of 1979. This first return was disappointing; only about 0.5 percent of the smolts were recaptured as adults. Fall, 1980 returns improved to 0.8 percent, and 1981 to about 1.3 percent.[31] It is likely, however, that this low rate of return will not be a permanent liability. Accelerated smolts, whatever the advantage in feeding costs, do not survive well at sea compared to those which have spent the normal length of time in fresh water. The improvement in return witnessed in 1981 may well be due to release of fish in 1980 which had experienced a longer rearing period. Presumably, increasing precision of release timing will result in higher returns. Too, Ore-Aqua has been purchasing surplus eggs from Washington State hatcheries on Puget Sound, and introduced stocks generally have low survival rates for the first year of return. Development of indigenous stock will, in theory, also lead to higher returns.

Lack of eggs is an important limiting factor to expansion. At present, all private operations purchase surplus eggs from public hatcheries. State laws regulate importation of eggs from other regions so that diseases will not spread to wild stocks or so that hatchery fish will not endanger local stocks through competition or genetic contamination. Thus, Columbia River coho cannot be released along the Oregon coast because of genetic and disease concerns. Chum salmon are not yet raised in sufficient quantities in North America to permit large diversions to private hatcheries. Importation of chum eggs from the Soviet Union has been authorized but only small quantities delivered.

Chinook, the most valuable species, cannot be imported. Oregon coastal stocks are genetically different from those of the Columbia and Puget Sound so that accidental hybridization could reduce the fitness of wild populations. State authorities have encouraged a system which will develop sea ranching stocks from local wild chinook populations. Wild fish are captured and spawned in hatcheries. Some of the fingerlings are returned to their native streams; the remainder are reared in the hatchery. Because hatcheries have a much higher egg-to-fry survival rate it is possible to build wild populations and hatchery stocks at the same time. This procedure overcomes the problems of introducing foreign stocks but does not encourage rapid expansion.

Political opposition has slowed growth as well. Sea-ranching is essentially confined to Oregon; California has granted one special permit but there is no general authorizing legislation. Washington, British Columbia, and Alaska have not yet granted any permits. Opposition quite naturally comes from commercial fishing organizations who fear competition. In Oregon, an appeal from fisherman's groups effectively blocked plans of the Crown-Zellerbach Corporation to begin sea-ranching on Tillamook Bay. The court ruling stated that the company must first prove that release of salmon would not unduly alter the ecology of the bay.[33]

In 1980, the Oregon Department of Fish and Wildlife announced a five-year moratorium on granting new licenses and froze the release quotas of authorized firms. The basis of this decision was the observation that, after 1967, increasing numbers of hatchery produced coho did not result in increasing numbers of returning adults. One interpretation is that the carrying capacity of the oceanic feeding grounds has been reached and that further competition from artificially produced smolts will stress the already depressed wild stocks.

Alaska has encouraged the establishment of private non-profit hatcheries. These differ from sea-ranching operations; fish returning to the facility may be sold only if the money is used for salmon-related research or hatchery expansion. Profits stem from increased oceanic catches rather than recapture at the place of release. Native American groups and fishermen's co-operatives, long severe critics of state and federal policies, are thus involved in production as well as harvest.

In addition to large scale private projects, there has also been an increase in voluntary activity aimed at salmon restoration. Many small stream clearance and rehabilitation projects have been carried out by volunteer groups. Actual production of salmon by non-professionals has expanded since development of the incubation box. Scout troops, school science classes, and prisoner's volunteer work groups have all maintained incubation box projects in British Columbia. Although the total number of fish produced is small incubation boxes are valuable in preserving salmon runs in small streams. Too, public involvement is important in establishing support for restoration programs at a larger scale.

Pen rearing of salmon is another recent innovation although different in intent from the others. There is no free oceanic phase in this sytem; rather, the fish are confined in estuarine net enclosures and fed until they reach a weight of approximately 3/4 pound. They are then marketed to compete with pond-grown rainbow trout. There are currently three such operations in North America--two in Washington and one in British Columbia.

Humanity has been very successful over the past twenty years in increasing the survival rate of the salmon in fresh water. The sea life of the fish is still outside the realm of human control; short of slaughtering seals little can be done to protect salmon from predators. Yet, knowledge of oceanic migration routes and survival rates has grown appreciably. The coded wire tag, developed in 1963, was instrumental in allowing efficient tagging and retrieval of marked fish.[34] A short piece of wire marked with a unique color or binary code is inserted into the snout of the young salmon before release. The adipose fin--which has no role in swimming--is clipped to identify the fish as bearing a tag, and the tag is retrieved when the salmon is caught or returns to the spawning area. Analyses of returns are used to establish migration patterns of different stocks and to evaluate their contribution to the various fisheries. The results of experimental manipulation in hatcheries may be ascertained by tag recoveries; fisheries managers can learn the effect of, e.g., delayed release or dietary modification on oceanic behavior and survival rates.

In theory, then, the question of survival is answered affirmatively. Given the series of successful innovations summarized above, salmon will not become extinct and may well increase in numbers and range. Operations such as Ore-Aqua show that the genus can be maintained even if fresh water spwawning and rearing areas continue to deteriorate. At least one fisheries biologist is of the opinion that given the availability of fresh water rearing sites, the carrying capacity of the sea is the only remaining natural limit to restoration.[35]

Problems of the New Era

Although the possibility of extinction seems remote there are new problems which transcend the question of survival. The most obvious of these is preservation of wild stocks in an age of increasing hatchery production. An animal whose existence depends on human intervention, especially in reproduction, is at least on the way to being domesticated. As hatchery production comes to be a dominant mode some would argue that the salmon will be saved in the same sense that the aurochs lives on in modern dairy cattle. The effort to preserve wild stocks is essentially concentrated on the Pacific drainage of North America; Japan and the Soviet Union, both large scale producers of hatchery fish, place little importance on the restoration of natural runs.

Animal domestication is often followed by extinction of the wild form. This is a distinct possibility in the case of the salmon even with the best intentions of preserving wild fish. The very efficiency of modern hatcheries poses a threat to naturally spawning populations. Because of the high egg-to-fry survival rate in hatcheries few adult spawners are needed to maintain population levels. Hatchery stocks can withstand exploitation rates of 90-95 percent without serious difficulty. Presumably, if recent experiments to determine the optimum release time of hatchery smolts prove successful this figure would be even higher. Wild stocks, with much lower juvenile survival, need more spawners to produce the same number of adults. Maximum sustained exploitation rates are, accordingly, lower; 60-65 percent is the critical upper limit.[36] Under current fishing regulations most salmon are taken at sea when fish from many rivers and from both hatchery and wild origins are mingled. If the allowable catch is calculated to reach hatchery exploitation levels wild populations suffer fishing pressures heavier than they can bear. If, as is presently the case, catch levels are calculated to preserve wild stocks hatcheries are used inefficiently. Spawners often return to hatchery racks far in excess of the number needed to produce the next generation. These fish are not necessarily wasted; surplus eggs may be sold to private concerns or used to bolster populations in other streams. The adults may be sold on the market although physical deterioration suffered during the upstream migration reduces their value. Ideally, however, state agencies would prefer to leave harvest and marketing to the private sector. Too, relations between fishermen and management agencies became strained when fishing seasons are severly curtailed in the name of conservation and hatcheries retake huge surplus numbers of fish.

The biologically rational solution is to delay harvest until stocks have separated and entered their home streams. If this were done hatchery fish could be taken more efficiently and natural stocks protected assuming that there were no hatcheries on a wild-stock stream or that the hatchery stock returned to the river at a different time than the wild fish. Ocean fishing is the despair of fisheries managers. Even apart from the mixed stock problem critics point out that sea fishing takes salmon before they have reached maximum size and that imposition of size limits is no real solution; a high percentage of undersized fish die after release.

In economic terms, the expenditure of capital, energy, and labor is far greater than necessary; there is no need to pursue a fish that is, predictably, going to return to the river. One critic said:[37]

> The native people who preceded the Europeans on these Pacific shores had the good sense to build live traps in the river mouths and wait for the salmon to swim into them. Managing such a system is quite simple--so many for the cooking pot, so many released alive for seed to maintain the stock.
>
> It is time to take a tip from our predecessors on these shores and try to set up a management system that will allow us to handle this magnificent resource in a sensible manner. To do this, we must first recognize the foolishness of fishing for salmon on the high seas and agree to stop it!

The economic and biological rectitude of this argument seems unassailable; yet social and political pressures militate against abolition of ocean fishing. Resources are allocated to preserve ways of life as well as to promote economic efficiency. The right of Native Americans to take salmon in ways and places denied to other fishermen derives from ancient cultural and symbolic importance accorded the fish. Something of the same supra-economic legitimacy may be granted to a third or fourth-generation salmon troller. Too, trolling replaced a system where salmon were caught by net in rivers. Wealthy entrepreneurs gained virtual monopolies by purchasing land on both sides of the stream near the mouth.[38] The evolution of ocean fisheries democratized the industry by allowing more people to harvest the fish. A return to terminal fishing equates fishing rights with property rights, and once again allocates the resource to the wealthy.

Thus, while ocean fishing may be phased out gradually no one expects it to happen quickly. The problem of managing a mixed stock fishery and, therefore, the threat to wild populations will remain.

Conclusion

Advances in hatchery technology over the past two decades would seem to insure the survival of Pacific salmon in sufficient numbers to remain economically important. Presumably, hatcheries could go on producing if every stream became unfit for spawning. The crucial issue, at least in North America, is how to accommodate this increase in artificially produced salmon while retaining wild stocks. For many people the salmon is only secondarily a resource to be exploited and preservation a hollow victory if wild fish no longer ascend the coastal rivers.

NOTES

1. Rogers, George W., "The Alaskan Fishing Community and the Socio-Economic History of the Alaska Salmon Fishery", in Donald Rosenberg, ed., Proceedings of the Conference on Salmon Aquaculture and the Alaskan Fishing Community (Cordova, Alaska: Sea Grant Report 76-2, 1976) pp. 7-24.

2. Wahle, Roy J. and Robert Z. Smith, A Historical and Descriptive Account of Pacific Coast Anadromous Salmonid Rearing Facilities and a Summary of Their Releases by Region. 1960-1976, NOAA Technical Report NMFS SSRF-736 (Seattle: United States Department of Commerce, 1979), p. 21.

3. Fullerton, E. C., "Statement Made at the Joint Legislative Hearing Regarding SB547", Walnut Creek, California, October 24, 1979.

4. Netboy, Anthony, The Salmon: Their Fight for Survival (Boston: Houghton Mifflin, 1974), pp. 332, 354-55.

5. MacLeod, J. R., "Enhancement Technology: A Positive Statement", in Derek V. Ellis, ed., Pacific Salmon Management for People (Victoria: University of Victoria, 1977), pp. 137-47.

6. Netboy, op. cit., footnote 5, p. 533.

7. Netbory, op cit., footnote 5, p. 535.

8. Greenwood, N. J. and J. M. B. Edwards, Human Environments and Natural Systems, 2nd ed. (North Scituate, Massachusetts, 1979), p. 400.

9. An account of the events leading to this decision is found in American Friends Service Committee, Uncommon Controversy: Fishing Rights of the Muckleshoot Puyallup and Nisqually Indians (Seattle: University of Washington Press, 1970).

10. Crutchfield, James A., and Guilio Pontecorvo, The Pacific Salmon Fisheries: A Study of Irrational Conservation (Baltimore: Johns Hopkins Press, 1969).

11. Summaries of life history data are found in Netboy, op. cit., footnote 5 and Salmon Industries of the United States, The Pacific Salmon: A Unique Problem in Ocean Resource Management (Seattle: 1974).

12. Helle, John H., "Genetic Considerations for Salmonid Aquaculture: Biological Uncertainties", in Rosenberg, op. cit., footnote 1, pp. 171-90.

13. Fisheries and Environment, Canada, The Salmonid Enhancement Program (Vancouver: Fisheries and Marine Service, 1977), p. 21.

14. Stockner, J. G., Lake Fertilization as a Means of Enhancing Sockeye Salmon Populations: The State of the Art in the Pacific Northwest, Fisheries and Environment in Canada, Fisheries and Marine Service Technical Report 740 (West Vancouver: Research and Resource Services, 1977).

15. Fletcher, V., P. Coleman and P. Hall, 1978 Hatcheries Statistical Report of Production and Plantings (Olympia: Washington Department of Fisheries, 1979).

16. Fisheries and Environment Canada, Salmonid Enhancement Program, "Incubation Boxes", Salmonid Fact Sheet, no. 4., (n.d.).

17. Wahle and Smith, op. cit., footnote 2.

18. Wahle and Smith, op. cit., footnote 2, p. 33.

19. Wahle and Smith, op. cit., footnote 2, p. 4.

20. McNeil, Willian J., "Potential for Salmon Aquaculture in Alaska", in Rosenberg, op. cit., footnote 1, pp. 25-68; reference on p. 31. These are from 1966; egg-fry survival in hatcheries may be as high as 90 percent now.

21. Bams, Robert A., Evaluation of Gravel Incubators on the Third Cycle of Tsolum River Pink Salmon, 1972-74, Fisheries and Environment Canada, Fisheries and Marine Service Technical Report 871 (Nanaimo: Pacific Biological Station, 1979).

22. Demaris, A. J., Oregon Department of Fish and Wildlife, personal communication, June, 1980.

23. Portland (Oregon) Sunday Oregonian, August 9, 1981.

24. Ebel, Wesley J., "Transportation of Chinook Salmon, Oncorynchus Tshawytscha, and Steelhead, Salmo Gairdneri, Smolts in the Columbia River and Effects on Adult Returns", Fishery Bulletin, Vol. 78 (1980), pp. 491-505.

25. Alaska Department of Fish and Game, Division of Fisheries Rehabilitation and Enhancement, Annual Report (Juneau: Alaska Department of Fish and Game, 1980), p. 42.

26. Schafer, William, California Department of Fish and Game, personal communication, April, 1976.

27. Johnson, Philip, "Salmon Ranching", Oceans, Vol. 1 (1982), pp. 38-55.

28. Cummings, T. Edward, Private Salmon Hatcheries in Oregon (Portland: Oregon Department of Fish and Wildlife, 1979), p. 3.

29. Eugene (Oregon) Register-Guard, September 30, 1979.

30. McNeil, William J., Oregon Aqua Foods, Inc., personal communication, June, 1980.

31. Eugene (Oregon) Register Guard, November 16, 1980.

32. Lindbergh, Jon, Domsea Farms, personal communication, November, 1980.

33. Newport (Oregon) Log, June 20, 1980.

34. Bergman, P. K., K. B. Jefferts, J. F. Fiscus, and R. C. Hager, "A Preliminary Evaluation of an Implanted Coded Wire Fish Tag", Washington Department of Fisheries Research Papers, Vol. 2 (1969), pp. 63-84.

35. McNeil, personal communication, op. cit., footnote 30.

36. McNeil, op cit., footnote 20.

37. Joyner, Timothy, "Farming Ocean Ranges for Salmon", Journal of the Fisheries Research Board of Canada, Vol. 33 (1976), pp. 902-04.

38. Dodds, Gordon B., The Salmon King of Oregon (Chapel Hill: University of North Carolina Press, 1959).