MFR PAPER 1010

A modest hatchery program combined with saltwater rearing should generate a vigorous New England salmon sport fishery.

Part III: Developing a Coastal Fishery for Pacific Salmon

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INTRODUCTION

An examination of history shows that the effects of the growth and spread of Western civilization on the inshore fisheries have been disastrous. And today, even on the high-seas fisheries, its effects are becoming all too clearly evident.

Perhaps saddest of all has been the fate of the Atlantic salmon, *Salmo salar*. For centuries, salmon stocks which had flourished under the protection of royal decree in the preindustrial kingdoms of Great Britain and northern Europe, quickly disappeared as factories, sewers, and ship channels usurped their native habitats in the Thames, the Rhine, and the Scheldt. In France, overfishing proved equally detrimental. In the wake of the Revolution of 1789, an overeager population, freed of royal restrictions on the taking of salmon, destroyed the once considerable runs of the rivers flowing into the English Channel and the Bay of Biscay. On the western shore of the Atlantic, the story was much the same. The combination of habitat destruction and overfishing virtually eliminated the vast salmon resources which had been the delight of colonial Europeans in England and eastern Canada for two centuries and of the Indians for thousands of years before that.

In the Pacific Northwest, the development of an extensive system of hatcheries and vigorous management of the fisheries has slowed the decline of Pacific salmon, *Oncorhynchus* spp., populations that began as soon as the western spread of European civilization started taking its inevitable toll of that region's vast resources. And now, new developments in the technology for rearing Pacific salmon hold forth the promise that at last the historic trend can be reversed.

The first salmon hatchery on the Pacific Coast of North America was opened in 1872 on the McCloud River in northern California by the U.S. Fish Commission. From this simple beginning, salmon hatcheries in the Pacific Northwest have become the most highly developed of modern aquatic culture systems. Information on disease, nutrition, growth energetics, physiology, behavior, and life history—resulting from research at salmon laboratories—is plentiful and has been used as a starting point for research on other species of fish as well. In the State of Washington, hatcheries are operated by both the State and Federal governments. The first hatchery in the State was opened in 1895 near Kalama on one of the tributaries of the Columbia River.

Despite the development of extensive hatchery systems for rearing Pacific salmon from eggs to fingerlings, mortalities from natural causes during their downstream migration and at sea can be enormous. Added to this are increasing pressures from sport and commercial fishing. Recently, however, a significant advance in the culture of salmon has been brought about by extending their confinement. This was achieved by holding them in pens floating in saltwater so that instead of migrating to the sea, they could be kept under control from egg to maturity. Saltwater pen culture is the latest of several important steps in the evolution of hatchery management starting with the fry-release systems of early hatcheries. Following is a review of traditional and newly developed salmon culture systems in use on the Pacific Coast and a plan for applying some of them to the introduction of Pacific salmon in New England.

HATCHERY REARING SYSTEMS

At first, hatchery rearing extended only through the early fry stage when the tiny salmon were released into the streams. In 1895, the first year of operation of the Kalama hatchery, more than 4 million fry were planted. By the 1930's, as many as 189 million eggs were being taken for fry propagation (Washington Department of Fisheries, 1968).

At salmon hatcheries, the period of rearing has been gradually extended before the young salmon are released to migrate downstream to saltwater.

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Larger migrants are better able to cope with environmental hazards enroute to the sea and tend to return at a higher rate than earlier-released fry.

In 1970, the Washington Department of Fisheries planted more than 34 million large fingerling smolts. In addition, 80 million smaller fingerlings and nearly 12 million fry were planted (Washington Department of Fisheries, 1970). The high percentage of adult coho salmon, *O. kisutch*, of hatchery origin in Puget Sound sport and commercial catches (estimated at 40% in recent years) attest to the success of such programs. In 1972, an unusual year, 90% of the sport and commercially caught coho returning to home streams in Puget Sound were estimated to have been reared at hatcheries. The progressive loss of natural habitat places increasing demands on hatcheries to maintain valued stocks of fish.

In modern Northwest hatcheries, extended rearing is being applied to the rearing of coho salmon which, in 1970, made up more than 30% of the salmon released in the State of Washington.

Adult coho spawn in the fall and early winter. The juveniles remain in fresh water for a year or more before migrating downstream to the sea. Most coho mature in 3 years when, weighing between 2.7 and 5.4 kilograms (6-12 pounds), they return to their home streams to spawn (Hart, 1973). At the hatcheries, which substitute for their natural spawning environment, the salmon are reared on artificial diets in ponds or raceways until they are ready to go to sea 12 to 14 months after hatching.

Returning adults selected for spawning are killed. The eggs are stripped from the fresh carcasses and fertilized with sperm from selected males. The fertilized eggs are incubated in stacks of trays made of fiberglass or plastic. Water cascades from one tray to the next, welling upward around the eggs which are supported above the bottom of the tray by a screen, and flows over a lip into a channel along the edge of the tray down to the next. Each stack of 16 trays can hold 100,000 eggs or fry. The eggs are extremely sensitive to handling for 3 weeks after fertilization. Then, when the eyes become clearly visible, the eggs may be handled without injury and, if desired, shipped considerable distances.

The hatching period is dependent on water temperature. At 11.1°C (52°F), it will take 45 days for the eggs to hatch; at 5.5°C (42°F), it will take 90 days. After hatching, the alevins are nourished from the material stored in the egg sac, which lasts for 5-6 weeks. The rate of absorption of the yolk is dependent on the water temperature. When the egg sac has been absorbed, the young fry begin to search for food. Once they begin feeding, they are shifted to tanks, troughs, and ponds or raceways where they will have more room to grow. In some of the outdoor rearing areas at the larger hatcheries, 500,000 or more fry can be accommodated in each pond or raceway.

This kind of system affords control only over the freshwater phase of the life of the fish. When the young coho grow to a size of 15 grams (0.48 ounce) —about 14 months after hatching— they are released into the streams to face the rigors of predation and competition for food. Mortality is high. In hatcheries, about 90% of the coho reach the fry stage and about 75% survive to become yearlings. By the time they return from the ocean as adults, only about 1% of the yearlings are left (Washington Department of Fisheries, 1968). Despite this low percentage of survival, hatchery runs are increasing. From recent research, we now know that survival to maturity is increased when the fish are held longer at the hatcheries so that they are larger when released. In 1961, an increase in the size at release from 13 to 27 grams (0.46 to 0.95 ounce) improved the return of adults from 0.47 to 2.81% (Washington Department of Fisheries, 1968). Lack of additional space and water, however, would make it difficult to extend the rearing of coho salmon at most hatcheries.

SALTWATER REARING

At some state hatcheries in the Pacific Northwest, returning adults provide more eggs and sperm than are needed to maintain full production. These surpluses make it possible for private growers to purchase seed from the states for commercial sea farms or feedlots in which salmon are grown to pan size in floating pens made of netting. In such a system, the tide-driven flow of saltwater carries in fresh oxygen and carries out waste. The temperature of the water should be high enough to promote the efficient conversion of feed, yet low enough to prevent the proliferation of disease. For coho the best range of temperature is between 9° and 15° C (48.2° and 59.1° F), with an optimum at about 12°C (53.6°F).

Experiments at the National Marine Fisheries Service's Aquacultural Experiment Station at Manchester, Washington, on Puget Sound have shown that in saltwater pens it is possible to rear coho from 15 to 340 grams (0.53 to 12.0 ounces) in 6-8 months and to maturity in an additional 10-12 months, a full year ahead of fish reared and released at hatcheries (Mahnken et al., 1970; Novotny et al., 1971-72). During 1971-72, in a cooperative pilot experiment by the U.S. Department of Commerce and private industry, more than 200,000 pan-sized salmon were grown in 14 months. Freshwater growth was accelerated by heating the water at the hatchery and in the rearing ponds. Final growth was in a floating system of net pens (Figure 1).

ACCELERATED FRESHWATER GROWTH

In an effort to reduce costs, commercial salmon farmers on the West Coast are using new methods to improve the growth of salmon in fresh water. Shortening the freshwater growing period by careful control of water temperature has made possible economies in operations, maintenance, and labor. When the water is heated to 11.1-12.8°C (52-55°F), coho salmon will grow to 15-20 grams (0.48-0.64 ounces) in 8 months after hatching, compared to the 12-14 months at hatcheries where unheated water is used (Figure 2). Heated water systems also make it possible to stagger production for optimum use of hatchery space.

In Puget Sound, commercial growers have already begun selective breeding to improve their stocks. Rapidly growing salmon are selected for brood stock and kept in saltwater pens and fed special diets until they are ready to spawn, having lived out their entire lives in captivity.

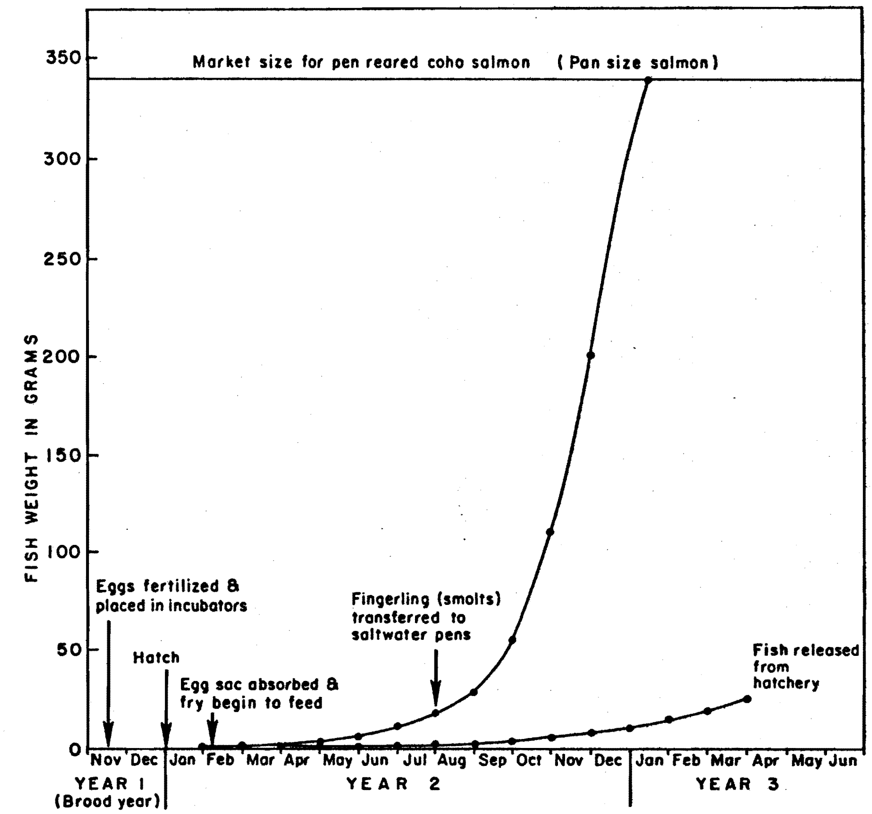

Figure 2.—A comparison of the early growth of coho salmon in normal and accelerated rearing systems.

DELAYED RELEASE AND ITS EFFECT ON MIGRATORY BEHAVIOR

Delaying the release of hatchery-reared salmon is being tested in the State of Washington as a means of improving returns. These experiments have produced unexpected results. In the past, the young salmon have been released at a time to coincide with their normal seaward migration from their home streams. Recent studies by the Washington Department of Fisheries have shown that delaying their release alters the normal migratory behavior. Continuous and extraordinarily high catches in the Puget Sound sport and commercial fisheries of "delayed-release" salmon show that these fish tend to remain near the site of release instead of migrating out to sea. The same sort of behavior results when salmon are delayed in saltwater pens beyond the time of their normal out-migration before being released. Not only do the salmon remain relatively close to the release site, but the mature fish run up streams in the vicinity of the site rather than returning to the hatchery stream to spawn (Figure 3). At the National Marine Fisheries Service's Experiment Station at Manchester, salmon have returned to Clam Bay on central Puget Sound where they had been held in saltwater enclosures before they were released. The mature fish ran into Beaver Creek, a stream that flows into Clam Bay, rather than to their hatchery stream at Minter Creek on southern Puget Sound.

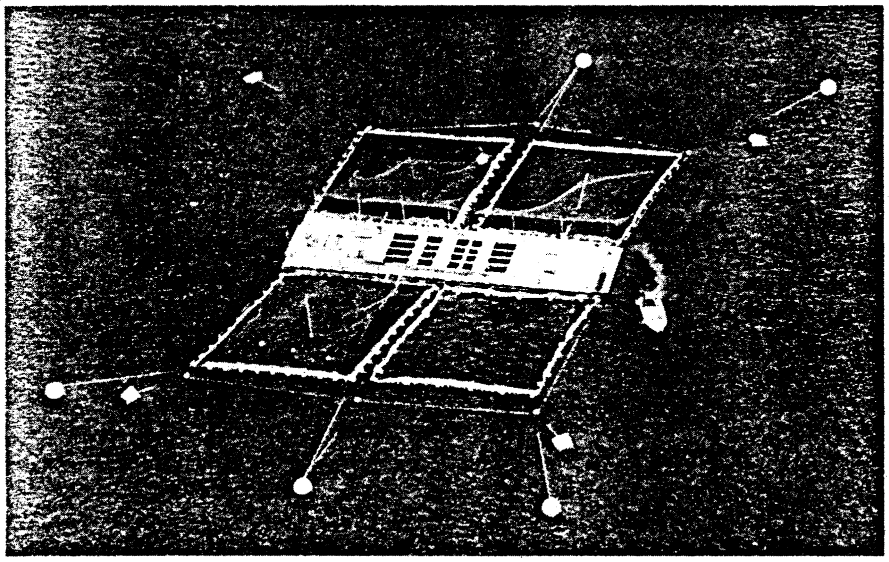

Figure 1.—Floating system of net pens used to rear coho and chinook salmon in Puget Sound (more than 200,000 pan-sized salmon were harvested from these four pens).

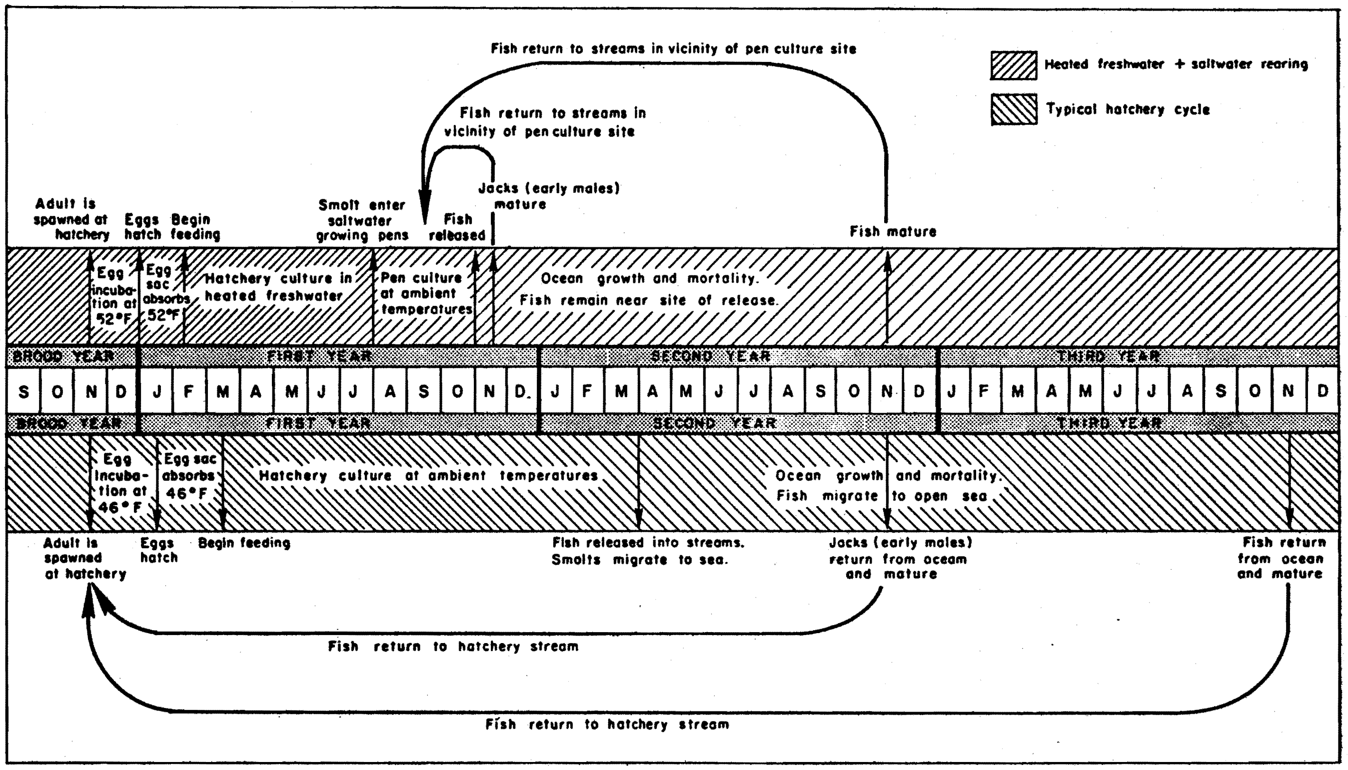

Figure 3.—A comparison of the life cycles of coho salmon in normal and accelerated rearing systems.

Delaying the release of young salmon, then, has the following advantages over normal hatchery procedures:

1. They tend to remain in the immediate locality and stay available to local fishermen.
2. When they are held in saltwater before being released, they do not return to the hatchery stream to spawn but move instead to a suitable stream near their point of release.
3. Survival to maturity is increased, with improved escapement and returns to sport and commercial fisheries.

The application of delayed rearing techniques should make it possible to manipulate migration patterns by inducing salmon to return to selected homing stations.

A PLAN FOR NEW ENGLAND

The streams of New England once teemed with Atlantic salmon. In the rush to carve a nation from the wilderness, little heed was paid to fish so numerous that they were often used as fertilizer. Fishing was unregulated, streams were dammed, and rivers were polluted by the wastes of industrial cities. As its freshwater environment deteriorated, the Atlantic salmon disappeared from most of its natural range. Today, there is growing concern for restoring the quality of the rivers and streams of New England, but it will take time. Over the past several decades, the efforts to re-establish natural runs of Atlantic salmon have not yielded much success.

Re-establishing large, natural runs of these fish, which are difficult to rear in hatcheries, will probably have to await the full rehabilitation of the rivers. Pacific salmon, however, are much easier to rear in hatcheries. With the new techniques for rearing hatchery-produced Pacific salmon in saltwater pens, the amount of freshwater rearing space for growing juveniles can be significantly reduced. A modest hatchery program combined with saltwater rearing should be able to produce enough Pacific salmon to generate a vigorous sport fishery along the New England coast.

The matching of the environmental requirements of donor stocks with appropriate conditions in the receiving waters can be critical. By paying attention to the greater latitudinal shift of ocean temperatures with the seasons in the North Atlantic, introductions of Pacific salmon can be timed so that ocean conditions match those of the North Pacific. With the hotter summers and colder winters of New England, it will be more difficult to find appropriate freshwater conditions. However, the urgency for precise matching in this respect can be relaxed if the early rearing is done in hatcheries in which the water temperature can be controlled. The ground water in much of southern New England remains close to 11°C (52°F) the year round.

In such water, coho salmon could be reared from eggs in the fall to smolts ready to migrate by late spring or early summer when ocean temperatures off New England would be appropriate for them. The smolts could

Table 1.—Predicted growth for coho salmon in fresh water at Quinebaug hatchery and in saltwater pens in Plum Island Sound (see text).

Date	Avg water temp °C	Avg water temp °F	Event	Body weight Grams	Body weight Ounces
Nov 1	11.1	52	Eggs taken	—	—
Jan 30	11.1	52	Eggs hatched	—	—
Mar 11	11.1	52	Sacs absorbed	—	—
Mar 31	11.1	52		0.9	0.032
Apr 30	11.1	52		2.0	0.071
May 31	11.1	52		4.2	0.148
June 30	11.1	52		8.6	0.304
July 31	11.1	52		18.2	0.642
Aug 4	11.1	52	Fish to salt-	20.0	0.706
Aug 15	14.5	58	water pens	26.3	0.928
Aug 31	14.5	58		39.0	1.38
Sept 15	17.0	63		60.3	2.13
Sept 30	17.0	63		93.0	3.28
Oct 1	13.5	56	Fish released	131.4	4.64
Oct 31	13.5	56	Fish released	189.7	6.70

then be trucked to saltwater rearing stations north of Cape Cod where they could be held through the summer for additional growth before releasing them. In this way the saltwater stations would provide capacity for extended rearing without taking up additional hatchery space, improving the chances for increased survival at sea and conditioning the mature fish to home on streams near the release sites.

There are many bays and sounds between Cape Cod and the Bay of Fundy that would be suitable for saltwater rearing. One of these is Plum Island Sound in Massachusetts.

We have prepared a model based on a hypothetical system in which coho would be reared, first in fresh water at a temperature of 11°C and then transferred early in the summer to a rearing station in Plum Island Sound. The projected growth in such a system is shown in Table 1. Release of the fish from the saltwater pens in October would take advantage of summer temperatures in the Sound which would favor the production of large, vigorous fish with a high probability of ocean survival and which, when mature, would return to Plum Island Sound. Mature brood fish would go into the Ipswich and Parker Rivers, small streams that flow into Plum Island Sound, where they could be readily trapped and the spawn taken to an appropriate hatchery. With such a system, a recreational fishery for Pacific salmon could be generated along the New England coast without the need for many large hatcheries or extensive natural river spawning.

Groundwater resources that can produce large volumes of water ideal for the accelerated freshwater rearing of salmon could be further developed in New England for use in hatcheries. The new State hatchery at Quinebaug in Connecticut is an outstanding example of how to build a fish-rearing facility around a superb source of ground water. The site of the new hatchery being built at Milford, N.H., was also chosen on the basis of a good source of ground water. Western Rhode Island has groundwater sources that have scarcely been tapped that would seem well-suited for the development of salmon hatcheries.

The geography of New England suggests that a regional system might best serve the development of salmon fisheries. Such a system, as we envisage it, would include freshwater rearing facilities centralized in a few, well-designed, large-volume hatcheries, primarily in southern New England where groundwater temperatures are optimum for rapid freshwater growth. Smolts of fall-running coho, reared at these hatcheries, could then be transferred to homing stations along the coast from Cape Cod to Maine to be released after a period of holding in saltwater pens to condition them to home on nearby streams. Spring-running chinook, *O. tshawytscha,* (Figure 4) and cherry, *O. masu* salmon could be released into the estuaries of streams flowing into Vineyard, Block Island, and Long Island Sounds to provide a salmon fishery for southern New England in the spring when the ocean temperatures are favorable for their homing migration.

Figure 4.—A chinook, largest of the U.S. Pacific salmon, returns to its hatchery.

Based on the evidence that we have briefly touched on in this paper, we believe that development of such a regional system for rearing salmon in New England could lead to the establishment within a very few years, of a vigorous, inshore salmon fishery that would not be readily accessible to foreign fishing fleets.

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MFR Paper 1010, from Marine Fisheries Review, *Vol. 35, No. 10, October 1973. Copies of this paper, in limited numbers, are available from D83, Technical Information Division, Environmental Science Information Center, NOAA, Washington, D.C. 20235.*