Part 1 of a two part series

Farming Pacific salmon from the "womb to the

The National Oceanographic and Atmospheric Administration (NOAA) has conducted research in marine aquaculture (or mariculture) for the last 2 years at its National Marine Fisheries Service (NMFS) marine research station on Puget Sound near Manchester, Wash. Function of the Manchester station is to conduct research in "farming" coastal waters and estuaries to enhance marine resources for sport and commercial fishing, and to study the influences of environmental change on marine and estuarine organisms. In addition, the Manchester station conducts cooperative research with state and local governmental agencies and with NOAA's Sea Grant programs which are affiliated with colleges and universities in the Pacific Northwest. This article introduces one aspect of our research in mariculture—sea farming of Pacific salmon, with the goal of developing techniques for commercial production. Since July 1969, when we put several thousand coho salmon fingerlings into a plastic meshed cage

PACIFIC SALMON MUST begin their lives in cold, fresh water, and will not tolerate salinities much above 9 parts per thousand during the egg incubation, hatching, and yolk-sac absorption stages. The embryos survive well and grow rapidly if the water temperatures can be held between 48° and 55° F. The time between egg fertilization and "swim-up" (or first feeding) of the fry should be about 60 days at those temperatures. Some of our experiments at Manchester were designed to test the effectiveness of different feeds at various stages of development of the fish in fresh and salt water.

Feeding of early fry: We found that all North American salmon species and the hybrids that we have thus far produced will begin feeding on the Abernathy formula or minor variations of it. Young fry are fed the mash for 7 to 12 days, after which divergence in the diet begins. Our experience has been that coho salmon will continue to do well on the presently tested dry foods and the other species do not. That's primarily because of apparent differences in feeding behavior of fish and palatability of food, however. We anticipate that economical dry foods may be developed that will be more acceptable and that dry foods someday may be used exclusively.

Feeding of post-fry: We have used the Oregon Moist Pellet in our studies of post-fry stages. OMP is a formulated, pasteurized, moist, pelleted diet that must be kept frozen until shortly before use. The OMP diet contains about 34 percent moisture compared with 8 percent moisture in dry salmon foods. The cost also is greater — about $320 to $380 per ton for OMP and $220 to $280 per ton for dry foods. Although storage of OMP is a problem and the cost is greater, its acceptance by all of the species and hybrids makes it an excellent food for comparative growth studies.

We have conducted growth experiments on all five North American species and several hybrids, but have concentrated much of our effort on coho and chinook salmon. Under proper conditions, those two species can be grown to fingerling size in fresh water at conversion rates of 1.1 to 1.4 pounds of food per pound of fish produced.

Once the fingerlings have begun their growth in the sea, the food conversions for all species range from 0.8 to 3.5 pounds of feed to produce a pound of fish. Food conversions of less than 1:1 are for small sockeye that eat natural food organisms attracted into the pens. The poorest food conversions are for fish held for brood stock development, because much of the food energy goes into the productions of sex products.

The practical and economical size for market production is fish of ½ to 1 pound. At those weights, feed conversions range from 1.4:1 to 1.8:1. We are continuously conducting experiments on commercial foods to determine the most economical rations for the various species in relation to water temperature. We found, for example, that the greatest OMP ration (4% of body weight per day) acceptable to small coho salmon could be fed only during the period of greatest available light and the highest temperature (58° F.). But fish fed a 4 percent daily ration were only slightly larger than fish fed a 2 percent daily ration by the end of the summer. The slight advantage in growth is attained at the

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in the sea:

tomb."

and floated it in Puget Sound, we have developed an economically feasible system for raising Pacific salmon from the "womb to the tomb" without ever letting them out "to pasture". The purpose of the first study was (1) to determine the rates of growth of coho salmon in the sea under specific dietary conditions and (2) to determine what difficulties would be encountered in culturing them in the sea. Surprisingly, we encountered few problems and answered many questions in the first experiments. Now, after 2 years of research, we believe that present and future efforts can be focused on (1) growth and nutrition, (2) genetics, (3) transfer to salt water, (4) diseases, and (5) floating pen design. Coming next in Part 2 of Farming Pacific Salmon in the Sea is: Recent progress in the operation of a large scale pilot farm. Watch for it in *Fish Farming Industries*. —The authors.

expense of food conversion.

During the winter months, when metabolism slows down, both the rate of growth and the food requirements (0.5 to 1.0 percent of body weight per day) decrease. Food conversions still are excellent, however, (approximately 1.5:1). Our lowest winter temperatures (45° to 48° F.) occur from late December through March.

Coho salmon were raised for the first time this year on a large scale (84,000 fish) on a commercial dry salmon food. These fish grew from a size of 22 per pound to 10 per pound in 77 days at conversions of around 2:1. Approximately 250,000 coho salmon for an experimental pilot farm now are being raised on the same type of dry pelleted food.

The transfer to salt water: The transfer of juvenile salmon from fresh water to salt water involves complex physiological changes in the fish. Some species, by natural adaptation, adjust more rapidly than others to the increased salinity.

Chum and pink salmon survive transfer to full sea water shortly after swim-up with 85 to 90 per-

Pacific salmon are well known to commercial and sport fishermen of the West coast and sport fishermen of the Great Lakes. The total United States catch averages more than 50 million fish per year. There are six species of salmon, all of the genus *Oncorhynchus*, in North Pacific waters, and our continent is "home" to five species.

Salmon returning to United States and Canadian waters are commonly called the sockeye, chinook, chum, pink and coho salmon. They are an anadromous fish; i.e., they spawn in fresh water and die, their progeny migrate to the sea shortly after hatching or after 1 to 3 years in fresh water (depending on species), and, as adults, return to fresh water to spawn. They may roam thousands of miles across the North Pacific ocean feeding and growing, and yet not only find the way home to their natal streams, but in some cases to the very gravel from whence they emerged as tiny fry.

Salmon are fished by several nations and are the subject of international treaties. They probably are the most studied fish in the world today. Yet we believe that we have just begun to probe into some aspects of their biological variability and adaptability.

Pacific salmon are unequaled on the diner's table. They are served all over the world smoked or cured, fresh or frozen, or from the millions of cans packed each year. Almost all salmon products come from adult fish weighing from 4 to 120 (a rarity) pounds.

The day is not far off when the household chef or restaurateur will be able to serve sea-farmed Pacific salmon, fresh or fresh flash frozen, white or red fleshed, at any time of the year.

cent survival, but grow much better if held in 50 percent sea water or less until they reach a size of about 400 per pound.

Coho salmon can be transferred from fresh water to sea water without acclimation when the fish have reached a size of 35 to 40 per pound. Chinook salmon can be transferred directly to sea water at a size of 80 to 90 per pound. Survival during the first month in the sea will be 95 to 99 percent if the fish are healthy when transferred and if the sea water temperature is below 50° F.

We do not have enough data on the sockeye, but we have been successful in acclimating them to full sea water (in stages) at a size of 200 per pound.

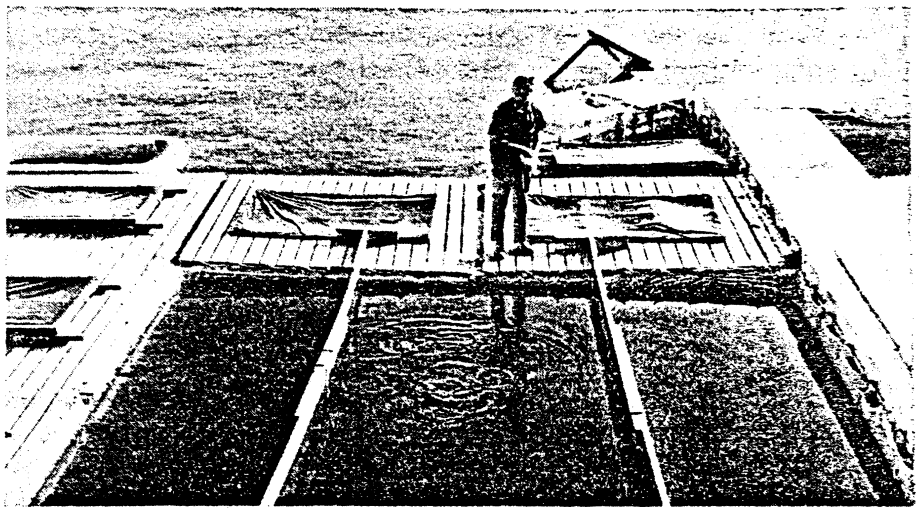
It is far better to acclimate any of the salmon species to full sea water in two stages. If the fish are first transferred to sea water of a strength of 25 to 50 percent, they will be stimulated physiologically, their feeding vigor will increase and they will continue to grow at a good rate. If the fish are held in the lower salinities for 10 to 15 days and then transferred to full sea water, both growth and feeding vigor increase uninterrupted. Unfortunately, adapting the fish to sea water in stages is not always practical on a large scale.

Genetics: The famous "super trout" developed by Dr. Lauren Donaldson of the University of Washington took 40 years of patient cross-breeding and dietary control. In December 1970, when we raised our first coho salmon to maturity in total captivity, we began breeding experiments with a similar goal — to produce improved strains under controlled conditions.

During the Christmas holidays, we spawned 30 female and 60 male coho salmon that we raised from the fertilized egg to maturity in exactly three years. These first fish were small, averaging around 2 pounds compared with about 8 pounds for wild stocks. The fecundity was low, from 500 to 1,500 eggs per female, whereas wild fish would have about 2,200 eggs. The eggs also were pale and fragile. We had felt that the OMP diet was not adequate for a maturing fish, and that proved to be true. Yolk from excessive egg breakage (10 to 15%) prevented sperm penetration, and only 3 percent survived through hatch. We now have a small number of coho salmon progeny, however, which soon will be ready for adaptation to sea water.

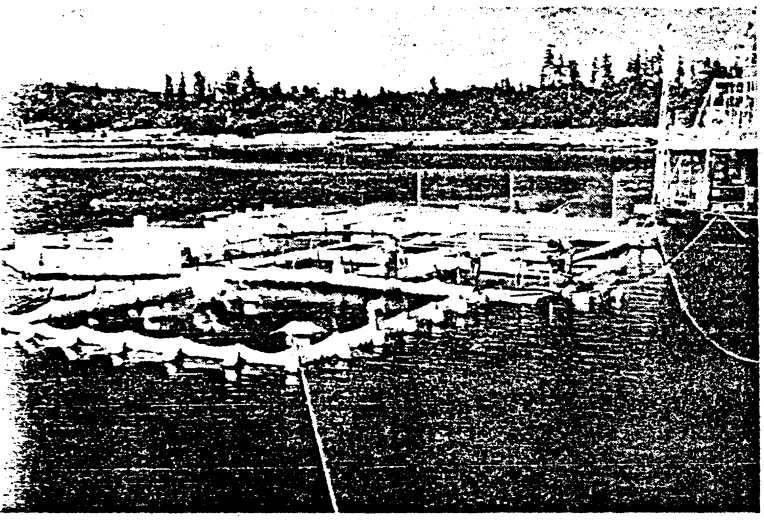
This year we have experimented with high protein and high carotenoid diets to improve the size and condition of maturing fish, and we feel confident that we will have much better success. Thus far, we have been able to bring our fish to maturity directly in the sea, spawn them directly from the pens and incubate the eggs in fresh water. The pre-spawning mortality of adults has been less than 10 percent.

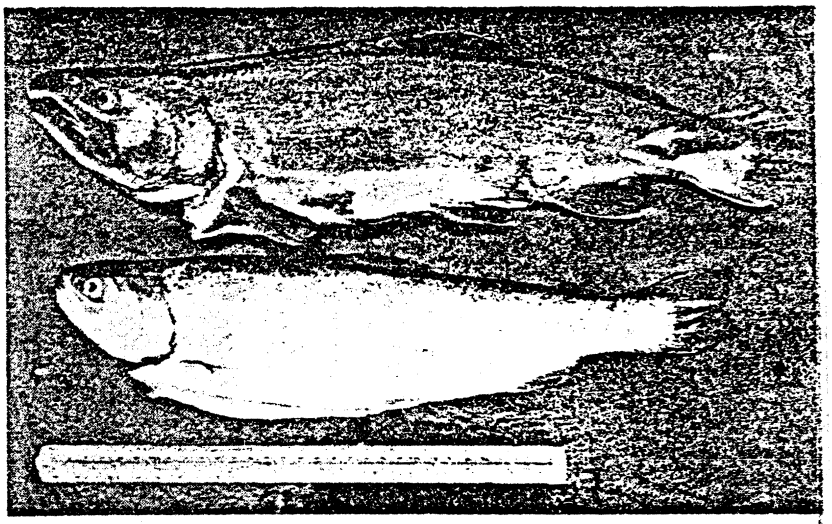
We also are conducting research in interspecific hybridization, or crossing species of Pacific salmon for specific purposes. Two of the

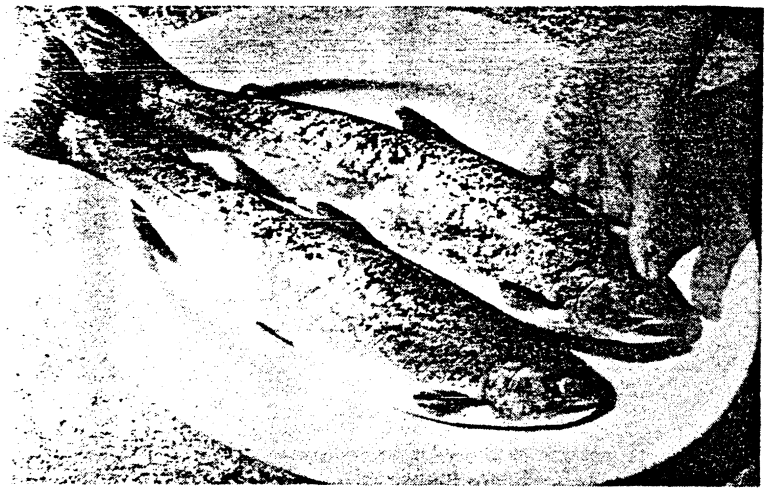


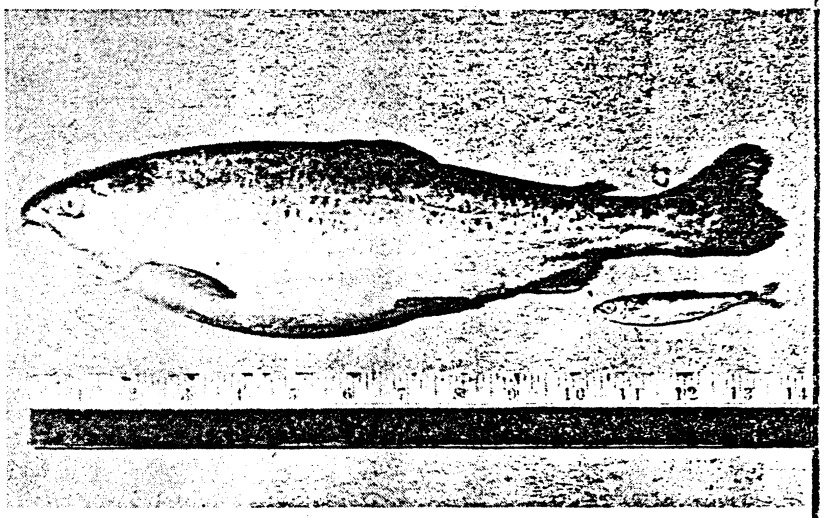
SPAWNED COHO salmon reared through their complete life cycle in captivity. Only a few individual Pacific salmon have been raised to maturity previously.

INDIVIDUAL nursery pens (under the plastic covers) are linked together to form the perimeter for hanging larger growing pens (foreground).









A VARIETY of floating enclosures are used for raising salmon in the sea. The largest pen (foreground) is 15 feet deep, and contains 395,000 chinook salmon fingerlings. The hexagonal pen (middle left) contains 140,000 coho salmon fingerlings.

COHO SALMON were raised to a marketable size in less than 12 months after they were placed in salt water pens as fingerlings (25 per pound).

THESE COHO salmon were reared completely in captivity for 3 years from fertilized eggs. The male (upper) was sexually mature. The female (lower) was not mature.

A CROSS between a male chinook salmon and a female pink salmon. The smaller fish is from the 1970 brood and weighs 1/100 pound. The larger fish, exactly 12 months older, weighs 1.2 pounds.

species, the chum and pink salmon, can adapt to full sea water as young fry. But the flesh quality is not as desirable as that of the chinook, sockeye, or coho, and they are more prone to disease.

By continual cross-breeding, we hope to develop a hybrid that (1) has a fast growth rate, (2) adapts to sea water quickly, (3) provides good food conversions, (4) is disease resistant, (5) has small scales, (6) has excellent flesh quality and appearance and (7) matures in 2 to 3 years.

That may take many years of research, but several hybridization experiments are under way. If we are fortunate, some of our male chinook x female pink hybrids will have spawned this fall as 2-year olds. If they are fertile, we will attempt to back-cross the male hybrids with 3-year-old female chinooks. In 3 to 4 years, we hope to have other hybrids maturing, such as the sockeye x chum and chinook x chum crosses.

One of the most promising hybrids is a cross between a male pink salmon and a female spring chinook salmon. A fast growing fish, the hybrid adapts to sea water rapidly and has been more disease resistant than our pink salmon. All our hybrid crosses are done by delayed fertilization; i.e., eggs and sperm are shipped separately and fertilization is accomplished at the research station. That enables us to draw from the many genetic sources along the Pacific Coast for 6 months of the year.

This story will be completed in the next issue of FFI