Aquaculture: Its Promise And Problems

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MAN HAS BEEN HARVESTING fish since before the beginnings of written history. Most of the methods we use today are conceptually similar to those of the ancients, and, in spite of the antiquity of basic concepts, these conventional fishing techniques are remarkably efficient. We are able to take as large a catch of the most valued fish as natural reproduction can replace. Only too often, we take still more.

If we are to further increase our supply of the most desirable fish, it will be necessary to supplement wild schools of fish with fish raised in captivity. In other words, we must now become fish farmers as well as fish hunters. The beginnings of an aquacultural revolution are already underway. The Chinese have been rearing carp since about 500 B.C. In the United States, trout have been extensively farmed for commercial markets since World War II. More recently, a whole new industry has sprung up in the South, around the catfish.

Carp, trout, and catfish are primarily freshwater fish. The creatures of the sea are not so easily tamed. Nevertheless, sea farming offers tremendous incentives. Almost three-fourths of the world's surface is ocean, and all but a minute part of the world's water is salty.

A Pilot Program

Some of us who live near Puget Sound began to look with interest at the Pacific salmon. To a fish farmer's eye, a salmon has much that is appealing. It has an old and esteemed name, the flesh is tasty, and customers are willing to pay a good price for it. But while salmon have been reared in hatcheries for close to a century, the fry had always been released to forage at sea. Little attempt has been made to cultivate salmon to a marketable size.

The National Marine Fisheries Service acquired coho salmon in 1969 and put them into floating net pens near Manchester, Wash. NMFS was curious to find out how well the salmon would survive and grow under captive conditions in salt water rather than foraging at sea. Some of us at Domsea Farms had the opportunity to follow the experiment. We concluded that the results were promising enough to indicate that if activities could be scaled up from a few hundred fish to a few hundred thousand fish, a viable business might follow.

The NMFS Manchester laboratory did not, at this time, have sufficient funds to carry out a research project of such magnitude. As a result, NMFS worked with Domsea to put together a joint government-industry pilot program. The pilot program applied to the Sea Grant Office of the U.S. Dept. of Commerce and was subsequently awarded a grant of $100,000. Our goal was to rear and market 400,000 Pacific salmon.

We picked the coho salmon *Oncorhyncus kisuch* as the primary fish for our pilot program for several reasons. Coho are a hardy species with good resistance to disease. They are voracious feeders and will accept a wide variety of feeds. Furthermore, the NMFS experiments had used coho, so we had good experience to rely on. We erected a small hatchery, purchased 700,000 coho eggs from the State of Washington, and the pilot program was underway.

The freshwater phase was carried out according to standard practices developed over the past 100 years. In one respect, however, we deviated. Generally, a coho must be about 18 months old before it is large enough to adapt to salt water. We did not want to wait that long. So, to accelerate growth, we added heat to our rearing enclosure. Other things being equal, a fish grows at a rate directly proportional to the temperature of the water. Our small hot water heater wasn't able to elevate the temperature in the fry pond as much as one degree, which was discouraging. However, the fish saved us by congregating in the warm water plume from the heater discharge pipe.

In June the coho salmon began to turn bright silver, and their instincts told them it was time to migrate to sea. Some became so agitated that they jumped into the grass surrounding the enclosures. We put them into a tank truck and hauled them to floating net pens near Manchester, Wash.

The floating net pen is the key to Domsea Farms' captive salmon aquaculture program. It is simply a nylon bag net supported by flotation that completely encloses the fish. Free-floating tidal currents renew dissolved oxygen and flush out metabolic wastes. The nets we use are weighted but have no rigid structure and yield in the face of currents. Nets may be, at times, partly collapsed, but the reduced volume is compensated for by high water exchange. Deep, continuously mixing waters of central Puget Sound act as a thermal buffer, with temperatures remaining between 7 °C and 14 °C year round. This temperature regime contrasts with that in isolated shallow inlets and diked lagoons where extremes are much more pronounced. Our floating net systems are secured to the bottom with conventional anchors, and they do not impose permanent changes on the ecology.

Spirits were high as hundreds of thousands of young salmon poured into brand new nylon nets, and at that moment success seemed in our grasp. But problems raised themselves quickly. A large dogfish (*Squalus acanthias*) was spotted in one of the nets. Diver inspection revealed several more, as well as numerous ragged holes in the netting. The shark-like predators attacked dead fish on the bottom of the net, and their small but very sharp teeth rapidly abraided the nylon. We sewed up the holes and picked up mortalities, but attacks continued. We were finally successful in foiling the dogfish only by completely enclosing grower nets with concentric predator nets.

Vibro anguillarum is a fish-disease bacterium found in temperate seas all over the world. It is lethal to salmon. Whenever our salmon were stressed or the population densities became high, epizootics of *Vibrio* flared up. Epizootics were controlled by administering antibiotics in the feed, but relapses threatened constantly.

Commercial salmon feed is prepared in pellet form. It contains about 50% marine protein with cereals, fats, and vitamins added. Feeding a half-million small salmon fry requires only a few kilograms of food per day. A half-million 250-gram salmon demand perhaps two and a half metric tons, and logistics became a significant problem. Domsea brought a surplus World War II amphibious vehicle to transport feed from the shore to the nets. While the old vehicle required an atrocious amount of maintenance, it did do the job.

In spite of dogfish and *Vibrio*, our salmon grew from 15 grams in July to 300 grams the following January. We selected a harvest weight of 300 grams, one salmon to a serving. The fish were seined out, processed, and placed in a marketing program. Acceptance in the market was quite good. The only complaint was that the reddish flesh color was not as pronounced as the color in large wild salmon.

Plunging into Commerce

The pilot program was deemed a success. Domsea graduated from the sphere of government support and plunged into a full-scale commercial venture. Historically, there has been in the United States a wide assumption that size is directly proportional to efficiency. You can follow the trend in automobile companies, transport planes, football players, and so on. So we built our second generation of grower nets several times larger than the pilot program nets. Each was 20 meters square, 10 meters deep, with a capacity of 250,000 salmon. Dozen of 15-K iron weights were hung on the bottom by divers to provide resistance to currents. To us, relative novices in the field of rearing fish, scaling up from a pilot activity to a commercial business had not seemed unduly difficult. The ocean, however, has ways of dealing with the brash.

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Violent tidal currents dragged and twisted our vast new nets. Floating timbers, only too often embellished with spikes, tore into the mesh. Rips appeared, and whole panels of the predator net simply disappeared. The best fishing in Puget Sound could be found right ourside our salmon farm! We rebuilt those nets with multiplied strength, and they held—for a while.

At the termination of the pilot program, we selected out the largest and fastest growing fish for brood stock. The eggs from those fish were placed into incubation as part of the commercial crop. We also took sperm from the male fish and used it to fertilize the bulk of the wild eggs we bought from Washington state. We reasoned that if agricultural animals have been selected through the years to build superior breeds, why not do the same with aquacultural stocks? The Domsea eggs were smaller than wild eggs and we suffered higher early losses with them, probably due to nutritional deficiencies. Once past the fry stage, however, these second-generation domesticated salmon grew about 10% faster than parallel fish from wild eggs.

In midsummer 1973, we were carrying 1,800,000 coho salmon in floating pens at our saltwater facility. They grew quickly and fish densities rapidly increased. *Vibrio* outbreaks became more and more frequent. Treatments were successful in controlling each outbreak, but no sooner had one died down than another started. We were medicating at least one group of fish, and sometimes all the fish, from July to November. Medication is expensive, and it seems to depress feeding and growth rates. We were also quite concerned that a strain of *Vibrio* would develop resistance to antibiotics and leave us defenseless. Attrition to our crop was chronic and in some cases acute. One net containing 135,000 fish lost 60% in three weeks. If we wished to survive economically, a new approach to *Vibrio* was crucial.

In spite of *Vibrio*, growth continued according to plan. Our first significant harvest began in November 1973. Fish were confined by seining the net, and then we pumped them out and across a fish grader. Those larger than 140 grams continued into a tank of cold brine, where they were killed and cooled to a temperature just above freezing. They were dressed, sorted into size increments, packaged, frozen, and stored for marketing.

Even before the 1973 harvest was complete, engineering failures began to crop up. Moorings became unstable and nets began to rip again. Marine fouling turned into a major problem. Algae, tunicates, and similar growth reduced water flow, but not to a critical degree. Mussels (*Mytilus edulis*) were more serious. A strong mussel crop in 1972 had flourished to the degree that it threatened to sink the floats holding up the salmon nets. That great weight caused an enormous increase in current drag and resultant stress to the net system. The only successful counter to the fouling problem was scrubbing by divers, but only at the expense of much time and effort. Selling mussels in a Seattle market did not cover the cost of sorting out the salable ones and transporting them.

In the face of mounting maintenance difficulties, personnel problems began to surface. One can take satisfaction in hard work if it is fruitful. To watch, time after time, a day's work nullified the following night is exceedingly frustrating, and morale drops. Personnel difficulties were compounded by the excessive need for divers. Having been a commercial diver for fifteen years, I can testify that divers are a cantankerous group. They work under difficult and sometimes dangerous conditions and hence are paid more. Jealousies began to develop. Furthermore, state safety officers inspected our saltwater facility and demanded that three, and preferably four, scuba divers be on hand for a diving task that two could easily have accomplished.

Bigger Is Not Better

Adding up the accumulating problems indicated only one outcome—a breakdown. We laid out plans for a staged redesign, but time ran out. On 18 June, 1974, a violent tidal eddy swept through the bay, and the mooring buoys were dragged completely underwater. A 1.9-cm mooring cable on the outer net complex parted, followed by several others in quick succession. The runaway net complex wheeled around and collided into our other complex. Destruction was almost complete; we were able to salvage only central walkways and some anchors. All fish escaped or were killed in the collapsing nets. Fortunately, most had already been harvested. We lost about 20,000 slow-growing runts, which we were best without. But we lost 5,000 second-generation brood fish, which would take three years to replace.

In the wake of the disintegration of the two net complexes, the affairs of Domsea Farms were in very shaky condition. We were beset by a host of problems, but two stood out prominently: *Vibrio* disease, and the structural inability of the net complexes. The outstanding question was simply whether or not to continue in the business. Our parent company, Union Carbide, had sufficient faith to ask us to lay out a plan of action leading to viable solutions to key problems.

The old maxim "the bigger the better" plainly did not apply to saltwater floating net pens. Our previous reasoning had been to the effect that small nets would be uneconomical per unit of volume. Experience, however, began to indicate that the reverse might be true. We designed a very simple net with dimensions of 14 meters long, 5.5 meters wide, and 5.5 meters deep. It was small enough to be moved by one person and did not need rope reinforcement. Instead of diver-installed iron weights, we suspended on the inside 4-liter plastic jugs filled with gravel. To deal with mooring failure, we replaced those 1.9-cm cables with 2.5-cm ship's anchor chains.

We have been agreeably surprised with the performance of this new design. The nets are easy to install and can be removed by two people with no diver assistance. Dogfish do not seem to be as prone to attack a small net, so we have stopped using predator nets. To harvest fish, we simply lift one end of the net and confine the fish to a pocket from which they can be pumped out. Marine fouling is controlled by pulling up the net and leaving it to dry. Fouling organisms die and they fall off when the net is returned to the water. After a year of experience with 64 nets, we have had no rips in the netting. Finally, capital costs are about the same as for the previous system in terms of fish produced, but labor costs are about half.

One may have excellent fish-rearing structures, but if the fish die of disease they are not of much use. John Fryer, of Oregon State University, developed a vaccine for *Vibrio*. Working with Fryer and NMFS, Domsea put together a program to immunize most of our crop of salmon against the disease. A line of technicians are provided with basins, vaccine, and semiautomatic syringes. Salmon fry are placed in a basin, anesthetized, injected, and released into a new enclosure. An experienced technician can inject about 9,000 fish per day, and the cost per fish is about one cent.

At the time of this writing, most of the first immunized crop of salmon are still in the saltwater nets, and no final data are available. The indications are that immunization will be successful, as we have had no significant outbreaks of *Vibrio*. Thus far, losses from *Vibrio* have been less than 2%, a figure that a fish farmer can live with economically.

At Domsea, we now believe that we have overcome the two most serious obstacles to success in the commercial culture of salmon in floating net pens. We can contain the fish in the nets and we can keep them healthy. Lesser problems, of course, remain to be completely solved. Saltwater nutrition needs further refinement, and we must learn to grow a higher percentage of coho that are ready to go to sea their first summer. These are problems we can accept and eventually solve. In 1976 Domsea Farms hopes to turn the corner to a profitable aquaculture company.

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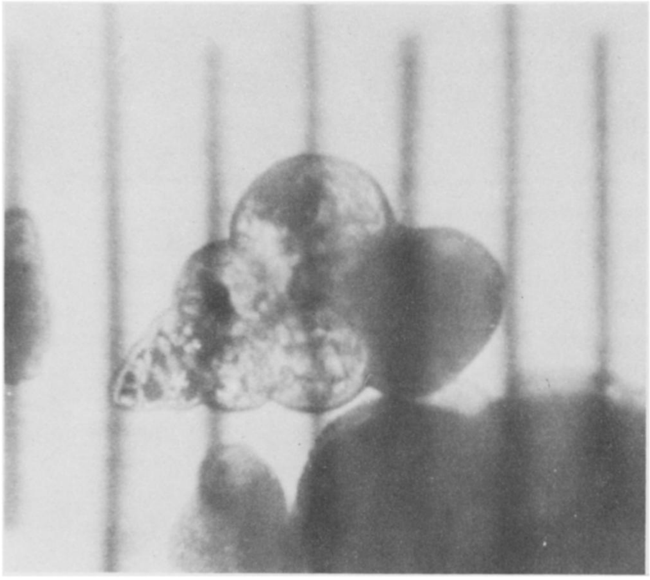

Fig. 1. The foraminiferan *Testularia* sp. is four subdivisions long. Each subdivision measures approximately 77 microns, thus the specimen is approximately 308 microns long. (Photo by author.)

camera setting for shutter speed and aperture with the light meter, and then overexpose the film one full f/stop. This will insure that the small white lines will be as black as possible and that the black background will be as clear as possible on the resulting negative. Develop the film normally. After the negatives are processed, cut the film into small square ocular micrometers. The ocular micrometers are now ready for calibration.

An ocular micrometer is placed on the small shelf of the microscope's ocular lens. Calibration follows the procedure set forth by Peleczar and Chan (1972): An inexpensive stage micrometer can be constructed by cutting a transparent metric rule into one-cm sections with millimeter divisions. These sections are mounted with Canada balsam onto standard student-grade microscope slides. The distance between the leading edge of one millimeter marker and the leading edge of an adjacent millimeter marker is 1,000 microns. Therefore, by counting the number of ocular micrometer subdivisions at low power (100X) between these two positions, one can easily calibrate the length of each subdivision. The method of calibrating at higher magnifications is to measure the width of one of the millimeter lines at low power and then count the number of ocular micrometer subdivisions across this same line at high power and divide.

Fig. 1 shows that the foraminiferan *Testularia* sp. is four ocular micrometer subdivisions long. Each subdivision of the ocular micrometer used measures approximately 77 microns; therefore, the specimen is approximately 308 microns long. Obviously, the measurements achieved by these inexpensive micrometers are not as accurate as the more expensive commercial kind, but they do allow the high school student to become familiar with the technique of calibration and measurements through the microscope with ocular and stage micrometers.

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If the mariculture of fish, shellfish, and plants is successful, what does this mean to the world of the future? Statesmen of note have pronounced that, between the farming of seafood and more efficient harvesting of what is found in the wild, the oceans are the answer to the population explosion. That is a shortsighted and most dangerous illusion. Wild harvests now seem to be close to their maximum sustained yield. Mariculture, in its infancy, is quite costly. It provides food for the gourmets, but not for the masses.

So, at present, mariculture provides a welcome addition to the diets of those who enjoy and appreciate seafood. As techniques and efficiency improve, it may provide lower-cost protein which may give us a little more time to learn to stabilize our world population. But to accept mariculture as a panacea to population expansion is simply to pass this most crucial of problems on to our children. Such procrastination is simply to encourage still more people to a day when there is no new ocean to exploit.

Education

Education is the instruction of the intellect in the laws of Nature, under which name I include not merely things and their forces, but men and their ways; and the fashioning of the affections and of the will into an earnest and loving desire to move in harmony with these laws.—*Thomas Henry Huxley*