Molluscan Mariculture

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Abstract

Man's long experience with molluscan species has taught him how to harbor and manage this resource and how to enhance or select the conditions of the environment so as to yield greater catches and harvests. Ultimately these practices, reinforced with the results of arduous scientific research, have led from the simple arts of seafarming to a new and burgeoning technology recently called mariculture.

Molluscan mariculture now enables the exercise of rather precise control in a hatchery over the spawning of selected parents; larval culture in which mollusk larvae are grown on carefully chosen and nutured unicellular algal feeds; spat or juvenile collection and culture in meticulously controlled conditions and finally the growth to market size. Environments are carefully selected and cautiously monitored to enable management of the grounds to avoid predation, competition, disease, pollution effects and other deleterious influences. Such good animal husbandry practices seek to provide optimum temperatures, water flow and gas exchange and salubrious environs for the mollusk to feed.

These cultural procedures are detailed and the economics of mariculture considered in light of the new business opportunities.

Phylum Mollusca, one of the largest, most diverse and successful animal groups, has been exploited by a great many other animals as a food resource throughout the span of our evidence of predation. It was man, however, the supreme predator, who in his vain audacity undertook to influence the molluscan environment so as to enhance the growth rate, to restrict competition and predation by other animals and to modify the very nature of some mollusks by selection and other genetic techniques, so that his nutritional and gustatory needs and appetites could be better served.

The Gastropoda, which form the largest and most successfully adaptive class of mollusks, express a great diversity of form and habitats from which man has selected several genera which are both desirable foods and are amenable to cultural practices. The most advanced of these practices is with abalone, but conchs, snails and other univalves have been garnered from at least partially controlled environments. The abalones feed on the large seaweeds and kelps, and thus when confined in a marifarm, require that their feed be provided to them.

Among the Cephalopoda, the shell-less squids and octopods are cultured in a pastoral sense, particularly in the Mediterranean and in Japan. Since they are all carnivorous, it is cheaper to allow them to catch their own food so that "rearing" entails essentially the provision of artificial dens, or lairs, in the form of clay pots, which are placed in selected regions of a heavily populated bay, enabling the octopuses to lay in wait to capture their natural prey of fish, snails and crabs. The harvest involves not much more than the collection of the octupuses from the pots.

The class Pelecypoda, the bivalves, including in its eccentric variety the oysters, clams, mussels, cockles and scallops, has not only yielded to man more abundant, tasteful food than all the other molluscan classes, but also the greatest opportunity to conduct controlled predation which has now advanced to a degree that warrants the name mariculture.

One of the primary reasons why the bivalve mollusks as a group have encouraged culture and control, is that they are for the most part sessile animals. Their natural habitat occurs in the inter-tidal zone of the estuaries and the coastal waters. Thus they have been readily available to man for harvesting from the wild and for observation. Man's long experience with this high protein food resource, and its desirable nutritional and gustatory character, have stimulated farming attempts. Even in our early records regarding man's food gathering practices, there is evidence of efforts to harbor and encourage such bivalves as oysters and clams.

Probably the most significant characteristic of this group of animals, in terms of ease of culture, is the filter-feeding habit which obviates one of the major burdens of animal husbandry, that of providing feed for rapid growth and fattening for market. Like the grazing terrestial animals, the bivalves are herbivores foraging on the primary productivity of the photosynthetic plants which utilize the sun's energy to fix carbon in nutritionally desirable forms. That is, they make a living off of the first trophic level at the bottom of the food pyramid. Thus, in terms of efficient utilization of the energy available to man on the planet the phytoplankton-eating filter-feeders of the sea are one of the most valuable, regenerative food resources available to man.

The total production of plant life in the ocean, although estimated to be at least equal in amount per year to terrestial production, has been vastly more difficult to utilize directly for human food. Harvesting the phytoplankton of the oceans would require filtering of 1 million pounds of water to recover 1 pound of plant material. Filter-feeding bivalves, however, feeding directly on this microscopic plant life, pump prodigious quantities of water, seeking out their appropriate food. According to Galtsoff (1), a single oyster may filter as much as 1000 pounds of water in a 24-hour period, and Chipman and Hopkins (2) report that in scallops the mean rate of water transport is 15 liters per hour which is only slightly less.

Although oysters, clams and mussels are essentially stationary animals, they can utilize phytoplankton production from very large areas of the sea, when tidal flushing rates and thus water circulation is appropriate. There are numerous reports in the literature of significant increases in bivalve growth rates with increase in current velocity in the estuaries.

A consequent advantage that accrues from the cultivation of the mollusks is the freedom from dependence on land raised feeds such as are likely to be required to support intensive culture of other aquatic forms. The crustaceans, and several of the economically important finfish, probably will require feeds that are in part produced on the land. Thus such an enterprise will compete for our land use and in turn compete with the conduct of terrestial animal husbandry enterprises. In the case of trout and catfish culture, which are developed aquacultural businesses, we are now feeding these fish with formulated rations comprised of crop fractions, oilseeds cake, animal offal and vitamin premix. Many of these components are those which are normally used in the preparation of rations for the culture of land animals. On the other hand, the culture of mollusks, consuming the productivity of the seas, which is otherwise unused by man, will result in a net gain in utilization of the resources of the planet.

Although each of the economically important bivalves has a somewhat different habitat, the ecological needs of all bivalves can be generally stated. These environmental requirements include, in addition to good water quality, appropriate sites for attachment, water movement to bring in food and oxygen, and to remove waste products from the growing zone, and adequate amounts of appropriate vegetable feeds. Control must be exercised over the deleterious influences in the environment, such as, predation; competition from other filter feeders including the fouling organisms, barnacles, bryozoans and tunicates; silting; pollution and inordinate fluctuations in temperature and salinity.

The physiology of the mollusks is understood to a degree that allows management (varying with the species) of the several production steps of culture, from maintenance of parent stocks, spawning and larviculture to rearing of juveniles to market size.

FIG. 1. Parent oysters being conditioned to induce gonad development in temperature controlled sea water.

Spawning can be controlled and induced in oysters, clams and scallops by an appropriate regimen of increase of water temperature from a low winter level. In these forms both the eggs and sperm are usually ejected into the water where fertilization takes place. The presence in the water of either of the sex products is known to stimulate the other, ensuring the simultaneous release of gametes required for fertilization. (In the *Ostrea* genus of oysters, the eggs are retained and are fertilized by the sperm which are carried in on the in-current water. The larvae are retained within the pallial cavity to be later released prior to metamorphosis.) In a commercial oyster hatchery, parent stocks are maintained in low temperature flowing sea water (Fig. 1) and then placed in conditioning trays where gonad development occurs. Water temperature is controlled so that mature oysters are induced to spawn.

The larval forms of the several bivalves can be cultured by similar techniques. After the first 24 to 36 hours when they require no food, they are fed on pure cultures through the early stages, and in latter stages on mixed cultures of nannoplankton (2-10 μ cells). The algae used most effectively include several naked flagellates and diatoms, including *Monochrysis lutheri, Isochrysis galbana, Dicrateria inornata, Cyclotella nana* and *Chaetocerus calcitrans.*

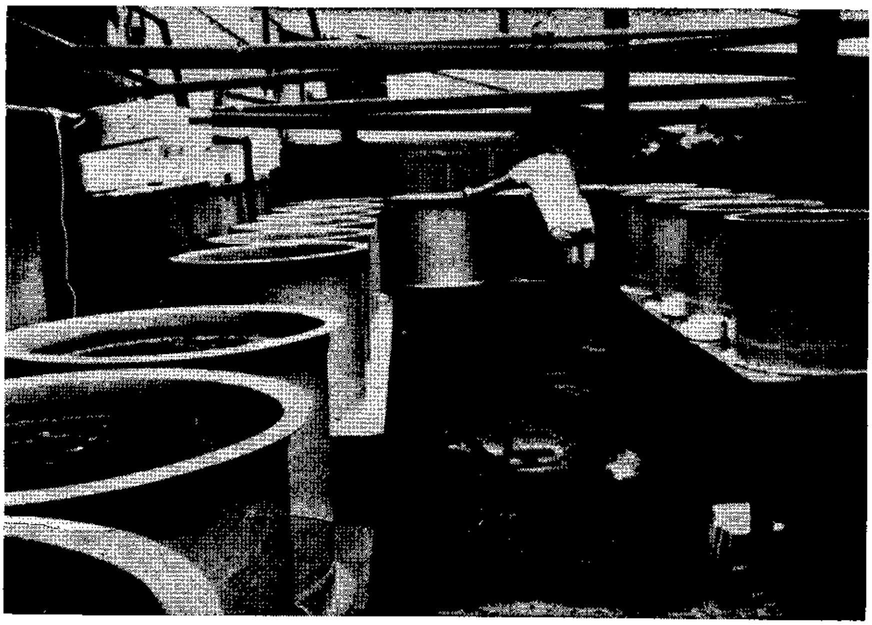

FIG. 2. Larval culture tanks into which cultured diatoms and naked flagellates are introduced daily as feed for oyster larvae.

During the larval stages which may last up to about 3 weeks the animals and the food organisms are kept in suspension by aeration of the constant temperature water in the culture chambers (Fig. 2). The water is changed frequently, maybe daily, to remove staling products, and to maintain optimum population densities. The tanks are emptied through fine screens of graded mesh which allows sorting by size and elimination of slow-growing individuals which provides a built-in mechanism for selection of the more vigorous individuals and a more uniform final product. In the case of the oyster, the selected larvae have reached a size of approximately 325 μ after 10 days and are ready to set (Fig. 3). These larvae are transferred to setting tanks, the bottoms of which are lined with cultch (oyster or scallop shell, or suitable artificial cultch material to which the larvae become attached, and, in nature, remain attached throughout their life span).

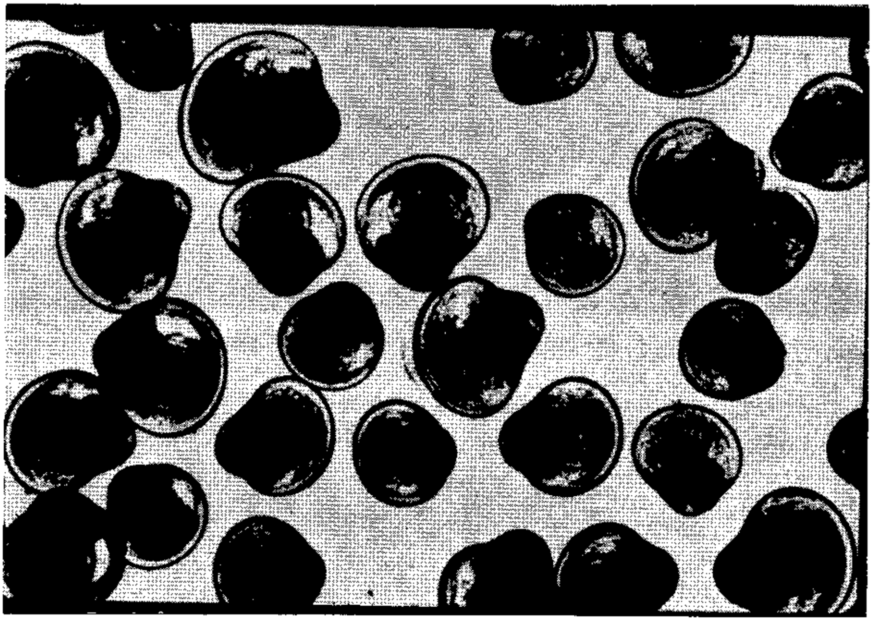

FIG. 3. Oyster larvae approaching umbo stage and about ready to set.

Other bivalve forms also attach themselves, at this time of metamorphosis, to a solid substratum by means of a byssal thread which is only temporary in the case of clams, but permanent in the mussel. Unless good management practices are exercised during the metamorphosis period, overcrowding can result in high mortality or subsequently in misshapen forms (Fig. 4).

The cultch with its attached spat, or "set" of juvenile oysters is transferred and suspended on racks in large concrete nursery tanks. Here, the juveniles can be protected through a stage when they are most vulnerable to competitors and predators. They are fed on mixed cultures of naturally occurring plankton which have been encouraged to bloom in enriched filtered bay water which is stored under a translucent polyester glass-fiber roof. The temperature of this water is gradually reduced to condition the juveniles to life in the "real world" of the open bay.

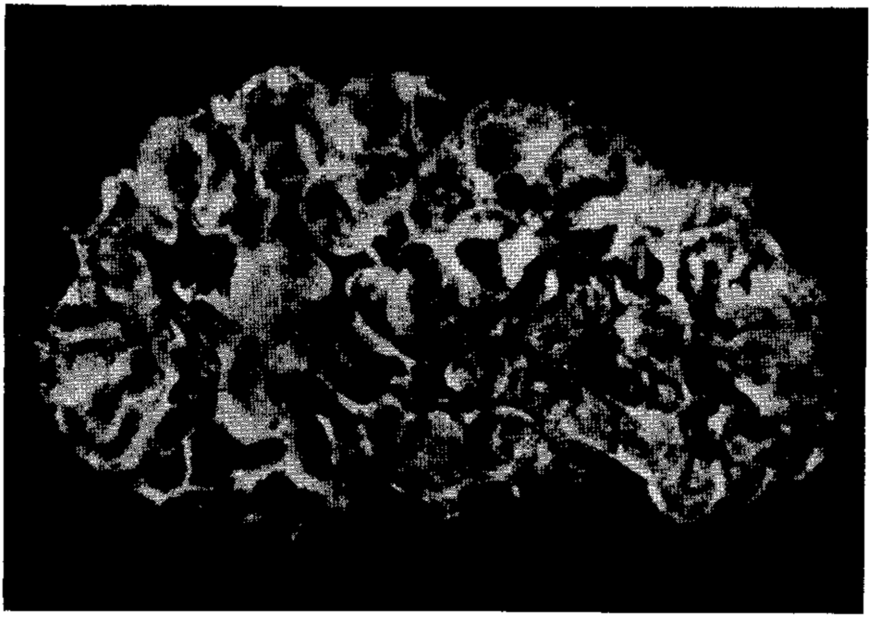

FIG. 4. Juvenile oysters set on oyster shell cultch.

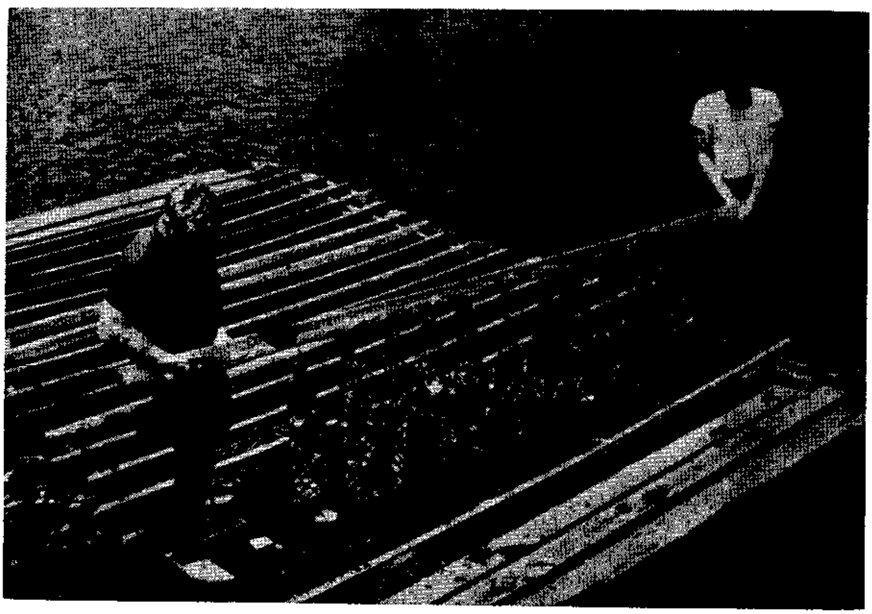

FIG. 5. Juveniles on oyster shell cultch in net bags are grown in suspended culture from rafts in heated seawater lagoon.

Under these almost ideal conditions, the juveniles grow rapidly for approximately one month, after which they are transferred to rafts in protected regions of the bay. The young animals have grown to about 0.5-inch in diameter and are becoming more hardy, but still require some protection from predators and silting. On the rafts they are also more available for monitoring. This nursery state is now also accomplished in a heated sea water lagoon receiving the cooling water effluent from a steam electric power plant (Fig. 5).

From this stage, the juveniles can be placed out in natural waters for a final fattening and hardening. This final location varies with the form, e.g. oysters require hard, smooth, relatively silt-free bottoms, whereas clams prefer a softer bottom in which they can burrow. In any case, the bottoms must be cleared of debris and silt and treated to remove predators and competitors such as starfish, drills and crabs. The oyster beds are monitored on a regular schedule by SCUBA divers who report the condition of the crop to enable prompt remedial measures to be taken so as to avert mortalities.

In some systems, suspended culture is carried through to the harvest of the mature crop. The choice of bottom vs. suspended culture is a trade-off on control of predation and competition. Depending on the variables in the ecosystem in which the animal is raised, as well as on the relative costs and availability of labor and automation, the choice of raised or bottom culture is made. Bottom culture, which requires chemical or other control of drill and starfish and control of silting, but provides better protection against wind and freezing damage and encourages less fouling by mussels, barnacles and bryozoans, may be more suited to our developed technology and capital intensive economy. On the other hand, suspended culture, while avoiding predation problems, requires the large labor force, for cleaning and stringing the cultch and for removing fouling organisms, which can be provided in the less developed parts of the world.

The coastal and estuarine waters where natural enrichment is high are, for the most part, the natural habitats of the molluscan forms which are most amenable to husbandry. Some specific waters have in certain instances proven to be inordinately productive. In the case of the Bay of Vigo in Spain, mussel culture is accomplished by hanging ropes from rafts in the highly eutrophic waters. I don't know the optimum population density in this particular environment, or in the case of Japanese suspended oyster culture in Hiroshima Bay of the Inland Sea, but this population is evidently receiving sustenance from a vast expanse of ocean. The high rate and volume of tidal exchange in these regions brings into the growing zones great quantities of phytoplankton which benefited from the sun's energy impinging on the oceans surface over large bays where the shallow waters are enriched by upwelling or terrestial runoff and where the sun's rays penetrate deep.

The current productivity of oyster culture around the world as recently reported by John Ryther (3) is given in pounds of oyster meat per acre per year in Figure 6. Public grounds in the U.S. yielding 6 pounds of meat per acre per year are pretty much unmanaged and the yield shows it. Private oyster farms where oysters are moved from setting grounds to appropriate growing ground, and some predator control is exercised, produce on the average of 170 pounds of meat per acre per year. On the other hand, in an instance of a well managed oyster mariculture business, we have records of 5,000 pounds per acre per year, and this number is now being exceeded.

YIELDS OF OYSTER MEAT IN POUNDS/ACRE/YEAR			
UNITED STATES			
	PUBLIC GROUNDS	(av.)	6
	PRIVATE GROUNDS	(av.)	170
	PRIVATE GROUNDS	(max.)	5,000
FRANCE			
	FLAT OYSTERS	(av.)	320
	PORTUGUESE OYSTERS	(av.)	740
AUSTRALIA			
		(av.)	120
		(max.)	4,400
PHILIPPINES		(max.)	10,000
JAPAN		(max.)	50,000
SPAIN (mussels)		(max.)	500,000

FIG. 6. Oyster meat productivity in pounds per acre per year in several major oyster producing countries. Spanish mussel productivity in the Bay of Vigo is presented for comparison. After Ryther, 1968.

In France, where there is a tradition of an oyster farming industry in which the spat are caught on limed tiles, and moved to "claires," which are specially prepared, rich growing grounds in shallow ponds, the yield of *Ostrea edulis,* the flat European oyster, averages about 320 pounds per acre per year, whereas the Portuguese oyster, *Crassostrea angulata,* managed in a similar system, has more than doubled this yield. In Australia, where oysters are grown in supported culture on racks and trays in the inter-tidal or shallow waters, intensive management can result in as much as 4,400 pounds per acre per year. In Asian waters where the species *Crassostrea gigas* is a rapid growing animal which is allowed to reach a larger size and where high labor intensive raft culture is practiced, yields are at a current maximum with 50,000 pounds being produced on the rafts in Hiroshima Bay, Japan. Finally, in a limited area in the Bay of Vigo, Spain, mussels, *Mytilus edulis,* are commercially produced on ropes suspended from very large rafts. Here the set of mussels is invariably dense and the abundance of phytoplankton feed results in the almost incredible yield of 500,000 pounds per acre per year.

Molluscan mariculture as a human endeavor is now undergoing a transformation from farming as an art to a more sophisticated technology where at least some of the essential limitations are understood through the systematic application of the biomarine sciences. As the new knowledge becomes more widely appreciated, the insertion of capital and competent management to exploit this advancing technology will result in a widespread maricultural industry.

It should be recognized that the motivation behind this investment appears not to be related to the alleviation of world protein hunger, but rather it is predicated on a cost benefit ratio that results in the generation of profit. In the economically developed portions of the world, mollusk meats are cherished as high-value foods, and when produced for this market and properly merchandized, command high prices with an attractive demand. This can be illustrated by comparing the cost in the marketplace of oysters produced in U.S. on public lands where very little, if any, management is expended, with those resulting from the kind of intensive mariculture to which I briefly alluded above. In the Gulf and Southeastern states the value of oyster meats ranged in recent years from 27 to 46 cents per pound. In the Chesapeake region where oyster farming is practiced, and considerable effort is devoted in the attempt to control the environments, oyster meats sold on the average of 69 cents per pound. In the New England and New York state waters, where oyster farming is an advanced industry, and where a large portion of the crop is sold for the half-shell market, oyster meats sold for better than $2.00 per pound.

We can expect to see these recently developed techniques in molluscan mariculture being applied over many of the coasts of the temperate, and eventually the tropical, seas. Ultimately, our expectation, and our basic goal, is that these techniques will find their application in generating acceptable high protein foods that will make a contribution to the freedom from hunger programs required to avert the famine of the billions in the next decades.

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