Potential for Penaeid Shrimp Culture in The Bahamas

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ABSTRACT

During the past 20 years, advances have been made in the culture of penaeid shrimps. Larval rearing has progressed to the point where commercial numbers of shrimp larvae may now be raised in artificially controlled environments to provide acceptable survival of healthy, vigorous post-larval seed stock from the hatchery. Grow-out studies in ponds have reached a point where seeding techniques, feeding regimens, predator control and water quality can be managed to produce significant yields at harvest in terms of growth rates and survival. Maturation of brood stock and captive spawning are beginning to show promise for providing larval shrimp hatcheries on a regular schedule. Genetic investigations offer the potential of an ideal commercially culturable shrimp that grows well, matures and spawns in captive environments. All of these advances open the door for commercial shrimp culture in areas heretofore thought unsuitable.

This paper outlines the recent developments in penaeid shrimp culture and discusses the environmental requirements for commercialization. With its clean, unpolluted water and tropical climate the Bahama Islands offer suitable sites for commercial ventures in shrimp mariculture. A stable, democratic government which encourages foreign investment makes The Bahamas even more attractive. By enumerating each of these issues and developing them as they relate to The Bahamas, I shall illustrate the potential for penaeid shrimp culture in The Bahamas.

Since 1934, when Dr. Motosaku Fujinaga first succeeded in spawning and partially rearing the larvae of *Penaeus japonicus* (Cook, 1976; Shigueno, 1975) commercial culture of penaeid shrimp has shown promise as a viable mariculture venture on a technical and economical basis. Japan and Southeast Asia are the traditional leaders in extensive shrimp culture. There, shrimp are raised in ponds, net enclosures, rice paddies and large concrete tanks.

In general, site selection for shrimp raising operations has been based on water quality and climate, and the presence of endemic penaeid species. The guiding philosophy has been, if shrimp occur naturally in an area, then controlled culture efforts had a reasonable chance of success. The most successful extensive or semi-intensive culture efforts have mainly focused on two species of Pacific penaeid shrimp. *Penaeus stylirostris* and *Penaeus vannamei* adapt well to pond environments and to the high population densities required for yields that will prove economically feasible. Their relatively fast growth rates coupled with recent successes in larval rearing and maturation/spawning procedures reinforce their suitability as mariculture subjects. *Penaeus japonicus* has also shown considerable promise of late in an operation in northeastern Brazil.

By reviewing various techniques and requirements for larval rearing, grow-out, maturation and spawning, and relating them to Bahamian environmental parameters, this paper demonstrates that the Bahama Islands hold a significant potential for commercial shrimp culture. Add to this the economic and industrial climate in The Bahamas of today, and it becomes apparent that investment in shrimp mariculture in this region makes sound financial sense.

HATCHERY TECHNIQUES

The larval development of penaeid shrimp involves a series of molts as the larva metamorphoses from nauplius to protozoea to mysis to post larva and finally to juvenile. The environment and nutritional requirements change as the animal develops, so hatchery design and operations must take these varying requisites into consideration. There are two basic hatchery strategies—the Japanese system (Shigueno, 1975) and the Galveston system (Mock et al., 1973).

First I shall describe larval development. When gravid female penaeid shrimp spawn, they generally produce 25,000 to 150,000 eggs dependent upon species, size, age and health of the parent (Aquacop, 1977). At 28°C, these eggs will hatch after 10-15 h in clean, gently aerated seawater, if not exposed to sunlight. The emerging nauplii are nourished by an attached yolk for 2-3 days as they begin to develop mouth parts and an intestinal tract. There are five (5) naupliar stages and each one displays different physical characteristics. In the last stage before metamorphosis into a protozoea, the nauplius can begin to feed on small phytoplankton (5-10 μ m). The protozoea undergoes three molts over a 3-4 day period, and feeds on phytoplankton, also. After the third molt, the larva is termed a mysis, which displays three (3) distinct stages and takes about 3 days to complete. Being somewhat larger than protozoeal larvae, they are able to feed on larger phytoplankton and zooplankton, such as rotifers and copepods. The mysis metamorphoses into a postlarva (PL) which swims suspended in the water column for 1-3 days, at which time it becomes benthic. Zooplankton provides nutrition for the planktonic stage, but once the PL settles to the bottom, its natural diet consists mainly of algal mat and associated organisms.

Due to the paucity of suitable endemic phytoplankton in Bahamian waters, the Japanese hatchery system does not lend itself to applications in this region. Fertilization can enhance the plankton bloom, but flagellates and copepods generally dominate the planktonic community that develops. A modification to the Japanese system using sterilized seawater and pure phytoplankton monocultures through innoculation may be possible, but owing to the large volumes of water that would have to be sterilized, it seems that the Japanese system would be quite arduous and expensive at Bahamian locations.

The Galveston hatchery system was developed at the NMFS Galveston Laboratory. This method utilizes conical-bottomed fiberglass tanks or raceways (Mock et al., 1973), relatively high larval population densities, and a closely monitored feeding regimen. The culture media is seawater filtered through fine mesh bags of 1-10 μ m and irradiated with ultra-violet light. Pure phytoplankton cultures are maintained in separate containers and are fed at regulated cell densities at intervals dictated by the feeding rates of the shrimp larvae. Cell counts are made frequently to determine the number of larvae and the number of food cells per milliliter. A hemacytometer is used for the algal counts and an eyedropper for the shrimp. *Skeletonema* is generally fed for the first 2-3 days after the nauplii have molted to become protozoeas. *Tetraselmis* or *Thalassiosira* is then introduced and fed as the main food organism until mysis larvae begin to develop. Then *Artemia* nauplii are added and are continued throughout the PL stage since the larvae are becoming increasingly more carnivorous.

The use of live food organisms has been identified as a source of problems in the hatchery tank environment. Metabolite build-up, undesirable plankton blooms, and competition for food cells all have detrimental effects on the shrimp, generally resulting in poor growth rates and reduced survival. Recently Mock et al. (1973) revised the method to utilize frozen phytoplankton, *Artemia,* and nematodes, as well as dried baker's yeast (*Saccharomyces* sp.). Inert foods are easier to prepare and to feed at the prescribed cell densities. Careful monitoring of water quality and food density can result in acceptable growth rates and survival using inert foodstuffs.

These aspects of the Galveston hatchery system seem to make it more suitable for the Bahamian environment. The clean Bahamian waters can be filtered and UV sterilized in necessary quantities and the utilization of inert food greatly simplifies the entire procedure. If yeast proves to be an acceptable substitute for phytoplankton, a significant and costly phase of the hatchery system, that of algal culturing, can be completely eliminated. Since both baker's yeast and *Artemia* cysts are readily available in dried and packaged form, food for the larval shrimp poses little or no problems for a hatchery based on one of the Bahamian islands and utilizing the Galveston system.

GROW-OUT TECHNIQUES IN PONDS

Raising post-larval shrimp through the juvenile phase to a size large enough to harvest in ponds is termed extensive grow-out. Owing to the rather high population densities most operations now use, perhaps a better phraseology would be semi-intensive culture. Intensive grow-out systems in raceways have been utilized with some success, but these have proven costly from a capital investment and operational aspect. Yields have been exceptional on a very limited scale, and when these yields are extrapolated to a reasonable commercial unit, the costs of constructing the physical layout become prohibitive. Coupled with the uncertainty of maintaining these high yields on a scale necessary for a commercial operation, these factors seem to indicate that intensive culture is not exactly a panacea for commercial shrimp operations at the present time. Therefore this discussion will concentrate on pond systems for grow-out.

The primary consideration in pond culture should be water quality and availability. The pond system should be located near an adequate source of unpolluted saltwater with a fairly constant salinity between 24 and 40 ppt. Optimum salinities for the commonly cultured penaeid species range from 28-38 ppt (Furness, 1978). Water temperatures need to be between 25°-30°C. during the growing season for best growth rates (Zein-Eldin and Aldrich, 1965), although this varies according to the species selected as the culture subject. Since growth rate dictates the number of harvests per year, and more harvests per year result in larger annual yields, water temperature is critical to the financial success of an operation. Well-managed ponds have produced market-sized shrimp in 120-140 days at 28°C. (Hutchins et al., 1981). Southern Bahamian waters range from 32-36 ppt. and 24°-30°C. for 8-10 months of the year at most locations. The islands south of New Providence located at 25° North latitude can generally be expected to maintain these temperatures and salinity ranges year round. The absence of any large population centers besides Nassau and Freeport and excellent flushing action due to ocean currents throughout The Bahamas minimizes any significant pollution factor. The waters of the Bahamian islands are world famous for clarity, and this is indicative of the pollution-free media available for mariculture. The absence of dense plankton blooms is not due to unsuitable water quality, but stems from the relatively low concentration of nutrients necessary to support dense phytoplankton populations.

The construction of shrimp ponds depends mainly on the local terrain, substrate and the method of harvest that will be employed. If, for example, the pond system is designed to take advantage of tidal action for water exchange, as opposed to pumping, different construction methods and elevations must be employed. By the same token, if the pond will be drained for harvest versus seining or using cast nets, the pond design must also take this into account. Soil type is important when selecting a site for a pond operation. High seepage rates are undesirable, as it will be difficult to maintain appropriate depths. Soils containing some clay offer the best material for dikes and pond bottoms. If clay-like material is limited, the dikes can be built with a central clay core to reduce lateral water losses. Soil quarried from the pond bottoms is usually used to form the dikes to minimize hauling costs. The coarsest material should be placed on the exterior of the dikes to minimize erosion due to wave action.

Tidal range in The Bahamas is generally less than 1 m. Therefore most pond operations will probably need to employ pumping stations to provide water exchange. This also offers a greater degree of control compared to tidal flow systems and reduces the threat of inundation in a locality subject to seasonal flooding caused by hurricanes. The geology of The Bahamas is basically $CaCO_3$ in a variety of forms. Although the occurance of clay is quite rare, clay-like aragonite mud is often available. This mud has been found to be suitable for sealing pond bottoms and coring dikes.

No definitive date is available on optimum pond size. It is suffice to say that ponds under 10 acres are easier to manage in terms of water exchange, feeding levels, circulation, predator control, population sampling and assessment and harvest methods. But the smaller the pond, the greater the ratio of dikes to surface area so construction costs increase disproportionately. Small ponds also tend to experience more variability in temperature and salinity, than larger bodies of water. These stresses can lead to disease problems in crustacean culture. A pond between 5 and 10 acres seems to offer the best trade-off when all aspects are considered. The depth of the pond is also somewhat subjective, but the water should be operated at a level that reduces the possibility of avian predation by herons, egrets and other wading birds as well as ducks and cormorants. Pond depths of 1 to 2 m seem to provide the best results.

The pond configuration is largely related to the harvest method. In some Ecuadorian locations, borrow pits are excavated around the inside perimeter of the pond. The material removed is then used to build the dikes. At harvest time, the water level is lowered until only the borrow pits are flooded. The shrimp tend to migrate from the high central plateau into these pits, and cast nets or seines are employed to capture them. If a pond is designed for drain harvesting (Parker and Holcomb, 1973), the pond bottom is sloped toward a drain pipe or gate and smooth-graded to eliminate puddles where the shrimp will congregate. At harvest, the pond is drained through the gate and a bag net is secured to the discharge end of the drainpipe. As the shrimp move with the receding water, they are captured in the bag net. Capture techniques using nets like the example from Ecuador, are more labor intensive and not as thorough as drain harvest methods. Some shrimp are always left behind in these ponds after harvest. In view of relatively high labor costs in The Bahamas, shrimp operations should probably design ponds for drain harvest. The carbonate substrate can be excavated to the desired elevations and the availability of sand allows inexpensive backfill techniques to establish the appropriate slopes.

In practice, post-larval shrimp are introduced into grow-out ponds after flooding with fresh seawater that has been screened to minimize predatory fish and crab species, and then fertilized to establish benthic and planktonic communities which provide a natural food source for the PL's. Some systems employ small nursery ponds which offer a greater degree of control in regard to water temperature and depth (Parker et al., 1974). These ponds are often operated at lower depths to allow increased penetration of sunlight for growth of algal mats and to increase temperatures. The small size of the postlarval shrimp allows the resultant increase in population density this technique requires, but after 20-40 days the juvenile shrimp can experience crowding stresses and need to be transferred to larger ponds. For the first 10-14 days water exchange and feeding levels are kept to a minimum. Thereafter, an exchange of about 5-25% is made daily. Care must be exercised to prevent escape of the small shrimp as they tend to swim along with the discharge water, so the effluent gates are usually screened. Here, again, the disadvantage of extremely large ponds is the increased water volume that must be provided and filtered to prevent the introduction of marine predators and the loss of shrimp.

Various feed and feeding strategies are applied at different locations. Natural food is either supplied via fertilization and growth of planktonic and/or benthic organisms or through the routine additions of processed protein sources, such as seafood processing waste, trash fish or bivalve meats. Artificial foods formulated from various grains and some source of protein are available from an increasing number of manufacturers. This material is generally extruded or pelletized to simplify handling. It is widely accepted that whatever food additions are employed, a large portion of the nutrition provided by these feeds comes from the increased natural productivity in the pond due to the availability of inert organic material suitable for bacterial colonization. Therefore, a food conversion ratio is an unsatisfactory index for the grow-out results from a shrimp pond. Artificial feed is normally administered at 5-10% of the shrimp biomass on a daily basis. This is generally estimated by population sampling to develop an idea of survival and average size. Cast net sampling (Hutchins et al., 1980) is often used for this purpose, but it is difficult to secure a truly representative sample by any means.

Although the sparsity of planktonic organisms in Bahamian waters would seem to indicate the need for additional food applications, with proper fertilization methods, a significant natural benthic and planktonic community can be established. This may reduce the requirement for processed food to a supplementary role.

Stocking densities are vital to the success of pond operations (Conte, 1975). If ponds are overstocked, growth rates will be depressed and survival will decrease. If the ponds are understocked, both growth rate and survival may appear good, but the total biomass will not provide acceptable yields. Feeding methods, whether natural availability or supplemental, have a bearing on the number of shrimp that a pond can support. Some shrimp species can tolerate higher densities than others. And nursery pond systems can support more individuals per unit area than final grow-out systems. There are obviously a number of factors to consider in determining stocking density. Presently various operations seed at densities ranging from 20,000 to 300,000 PL's per ha, with around 100,000 per ha as an average for systems relying on supplemental feedings. If all goes well, 30-50% survival can be achieved to harvest size, but higher densities generally result in reduced survival and smaller average size at harvest.

To summarize, one must conclude that grow-out pond-operations as they presently exist are more an art than a purely scientific technique. Experience is the key to success in ponds, and the operational designs will be modified as shrimp farming develops this experience.

MATURATION/SPAWNING TECHNIQUES

Perhaps the weakest link in manipulating the life cycle of shrimp under controlled conditions is the maturation of broodstock and spawning. To effectively utilize a hatchery facility at or near design capacity, broodstock must spawn to provide sufficient nauplii on a rather regular schedule. In some localities the practice of "mother shrimping" supplies spawners. This involves trawling for wild, gravid females and transferring them to hatching tanks where they spawn (St. Amant et al., 1966). Gravid females retain the ova internally (King, 1948) and a spermatophore is generally attached by the male externally in white shrimp and internally in pinks and browns (Farfante, 1975; Linder and Anderson, 1956). Rough handling can cause the spermatophore to become detached, especially with white shrimp. This, of course, prevents a successful spawn. If a culture operation's hatchery is located near penaeid spawning areas, "mother shrimping" can be a reasonable method of support. But weather, seasonal variability, and fishing success dictate the reliability of supply. Since there are no significant shrimp fleets operating out of The Bahamas, and since little is known about Bahamian spawning grounds, "mother shrimping" holds little hope for an operation located in this region.

Recently, some researchers have had limited success in captive maturation and spawning at several locations. This technique, although not too reliable at the present, seems to hold more promise for a Bahamian operation. By providing a high-protein diet with a liberal concentration of reproductive hormones, manipulating light levels and photoperiod (Duronslet et al., 1975), and ablating the eyestalks of females (Aquacop, 1975), several researchers have fostered successful ovarian development, copulation and spawning on a fairly reliable basis. The diets used have included shrimp heads, polychaete worms, bivalve meat, squid and adult *Artemia*. In Brazil, reproductive stage brine shrimp are fed to *P. japonicus* broodstock with considerable spawning success in ponds. Based on the habit of wild shrimp to spawn in deep sea environments, low light levels at various wave lengths may prove to be critical to promoting maturation in captivity. Photoperiod manipulations have also been demonstrated to be somewhat effective. Eyestalk ablation reduces the level of a hormone that originates in the eyestalk of most crustaceans. This hormone inhibits the production of the hormone ecdyson. Molting or ecdysis, is stimulated by ecdyson and ovarian development has been linked to ecdysis in female shrimp. Ablation or possibly reduced optical stimulii from lower light levels seems to play a major role in the maturation process (Caillouet, 1973).

If a Bahamian operation is designed with an indoor maturation unit where environmental conditions, such as light and feeding, can be controlled, the probability of successful maturation and spawning is enhanced. But at the present time, neither the predictability of maturation, nor the factors which control it, have been definitively managed at any location over a long period of time. Of course, adult broodstock would have to be imported to supply a Bahamian facility, but they are available in most cases from foreign wild stocks.

Artificial insemination has been tried using a technique developed by Dr. Paul Sandifer on *Macrobrachium* in South Carolina (personal communication). It entails ejaculating the spermatophores from the males by a slight electric shock. The sperm is then painted on the thelycum of a ripe female. As artificial insemination is refined, a greater degree of control can be exercised over the mating and spawning process. So, if broodstock can be maintained in a healthy condition and both males and females mature sexually resulting in spermatophores and ripe ovaries, a Bahamian shrimp culture facility may be able to rely on artificial insemination to provide fertilized eggs and nauplii for its hatchery. Appropriate environmental conditions can be provided in an indoor maturation laboratory, and the proper foods for the brookstock diet are readily available in frozen form. Several Bahamian locations even have large *Artemia* resources that are presently not being exploited.

PRODUCTION ECONOMICS

In the final analysis, the feasibility of developing a shrimp mariculture industry in The Bahamas depends upon economic results. Although the business may appear sound technically, profit margins and return on investment will ultimately determine its feasibility. Capital and operating expenses should be enumerated to identify the pros and cons of a Bahamian-based shrimp operation.

The capital portion of the costs associated with such an operation include ponds, buildings, land and equipment. Although construction costs are high in The Bahamas, the design for hatchery and maturation facilities is not extremely sophisticated. Land costs vary greatly according to location, but assuming most shrimp ventures would opt for one of the Family Islands, suitable properties should be available at reasonable prices. Bahamian ownership of the land would be advisable since annual real property taxes are quite high. The construction of ponds would depend on the pond design and local terrain and soil characteristics. High-volume, low-lift pumps are generally installed to supply cost efficient water exchange. Electrical power on Family Islands may present a problem. More than likely, a shrimp operation would establish its own generating facility. This can be quite costly, but if it can be associated with an already established residential or industrial consumer, the costs can be shared. A number of Family Island settlements are in need of a central power supply, so it's possible that in cooperation with the Ministry of Works an equitable arrangement may be formulated to provide electricity for a mariculture venture at a reasonable cost.

Operational expenses are dominated by labor and feed costs. A hatchery/maturation facility generally requires at least two professional biologists to supervise operations as well as several laboratory technicians. Pond management can be handled by skilled technicians with some experience in water movement and impoundment. Additional laborers are also needed to feed, clean screens and manipulate water flows along with regular maintenance of equipment. At harvest time the labor force needs to be increased for harvest and processing of the shrimp. Feed costs generally run 40-50% of the total operational expenses if formulated, supplemental feeds are utilized. The remainder of operating expenses include supplies, fuel, power, transportation costs and outside services.

The success of a shrimp culture venture located in The Bahamas appears to be technically and economically feasible. But the real key to the potential offered by such a business rests with the Bahamian government. The government issues business licenses, work permits for expatriots and permission to engage in various industrial activities. Duty rates on imported supplies and equipment are exorbitant and average over 35% of the original price plus freight costs. Under the Industrial and Agricultural Encouragement Acts, business may be granted duty-free bonded status allowing the free importation of goods to promote industrial and agricultural development. If this status is granted to a mariculture operation, production costs would be reduced significantly. Venture capital is available through the Bahamas Development Bank for mariculture business. Foreign investors would be well advised to seek suitable Bahamian partners to qualify for the various benefits offered by the government.

The need for new industry and employment opportunities, as well as for valuable export products, justifies a concerted effort on the part of the Bahamian government to encourage investment in mariculture in their country. Provision of some of the benefits mentioned above could assist shrimp culture operations in establishing a sound economic base from which to develop the mariculture industry. The potential for penaeid shrimp culture in The Bahamas, therefore, depends upon establishing professionally managed farms designed to take advantage of the Bahamian environment and utilizing state-of-the-art techniques for all phases of the operation: hatchery, maturation and grow-out. In conjunction with supportive governmental cooperation, penaeid shrimp mariculture stands an excellent chance of success in The Bahamas in the near future.

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