Biological and Economic Outlook for Hatchery Production of Juvenile Queen Conch

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ABSTRACT

The objectives of the queen conch research program at the Rosenstiel School of Marine and Atmospheric Science have been (1) to develop cost-effective methods for hatchery production of queen conch juveniles and (2), to investigate possibilities for intensive "grow-out" of captive queen conch populations and extensive restocking of natural queen conch populations. This paper summarizes progress made in the development of hatchery methods.

The quantities of juveniles produced by simple, small-scale hatcheries are likely to be highly variable making such hatcheries ineffective as aids to fishery management programs. But to be cost-effective, hatcheries must be capable of consistent production of juveniles without depending on expensive, advanced technologies. We have been attempting to resolve this problem by using technologically sophisticated research methods to understand the ecological and physiological requirements of queen conch larvae. A technologically unsophisticated experimental hatchery was developed to meet these specific requirements. Survival from eggs to juveniles of a size presumed suitable for restocking has been increased many orders of magnitude over natural rates of survival. Projections of hatchery production and costs are presented. Based on production costs of 1.6 to 5.6 cents per 5-month old 2-cm juvenile conch, a hatchery-based replenishment program will succeed if as few as 4% of released conchs are caught in the fishery as 2-year old adults.

While it remains to be shown conclusively that restocking natural conch populations with hatchery produced juveniles benefits the fishery, the biological and economic outlook for a large-scale queen conch hatchery is excellent.

Although the queen conch, *Strombus gigas*, as a species is not faced with extinction, conch fisheries throughout the entire range of the species are in trouble. Because the species is widely distributed in shallow waters of the Caribbean, northern

has made the species the second most important fisheries product of the Caribbean and at the same time, has threatened the conch's critical role as one of the most important subsistence-level fisheries of the Caribbean basin (Brownell and Stevely, 1981). The problem is one of regional over-exploitation of queen conch to meet demands for both commercial exports to the United States and local subsistence fisheries. In effect, the lucrative market for conch in the United States is successfully competing with the dietary requirements of many poor rural communities of lesser developed nations in the Caribbean. Solutions to these problems may be thought of as either regional or local in nature. Regional management (i.e. national scale) usually involves closed seasons, bag limits, size limits, limited entry, or cooperatives which work with catch quotas. All of these regional solutions require adequate catch statistics and effective enforcement, both of which are frequently difficult, if not impossible, to achieve in many areas where the queen conch is found. Local solutions to this problem usually focus on augmentation of natural stocks of queen conch. This may involve intensive culture of wild caught juveniles, redistribution of over-crowded natural populations, or hatchery production of juveniles. Queen conch hatcheries, as fisheries management tools, may be used in one of two ways: seed conchs can be extensively distributed to maintain overfished stocks or to establish new fishable stocks, or they may be intensively cultured to market size. Our field data indicate that intensive, captive culture to market size is not feasible at this time (Iversen, 1983).

The major objective and contribution of the Rosenstiel School's 3-year research program on the biology and fisheries of queen conch, funded by the Wallace Groves Aquaculture Foundation, has been the development of methods for hatchery production of juveniles. The work began in 1980 with background information from clam and oyster hatcheries, the early work on conch of D'Asaro (1965), Berg (1976), Brownell (1977) and the scientific literature on other marine snails. Our approach to the problem involved doing what universities do best; technologically-oriented basic research to derive a body of new information, in this case, on the environmental and biological requirements of queen conch eggs, larvae and juveniles. Areas of particular concern in this study involved investigations of water quality, temperature, salinity, oxygen and light regime. Biological factors which have been examined include types and quantities of food, interactions among larvae, bacterial and protozoeal problems and metamorphosis of larvae.

After early successes in 1980 and 1981, we developed an experimental production hatchery by eliminating the technology required as a research tool. The experimental hatchery is based upon low-technology methods to meet the environmental and biological requirements of conch eggs and larvae in an effort to mass-produce juvenile queen conch.

One might ask the question, "Why develop a hatchery for such a highly fecund animal as the queen conch, whose females commonly lay six to eight egg masses each season, each egg mass containing up to 500,000 eggs?" During the 3- to 4-week planktonic life of the queen conch larva, more than 99.9% mortality is experienced in the wild. The role of hatcheries is to eliminate the causes of such natural mass-mortality and improve the yield in terms of juveniles surviving per egg mass laid. The juvenile conch still faces at least 2.5 years of postlarval, juvenile and early adult life before reaching market size, and to date, we do not have reliable indications of age-specific survival rates from metamorphosis to adult size. However, the hatchery is the first step required both for experimentally determinating these survivalship curves of juvenile and adult conch and for initiating replenishment programs.

An understanding of our research approaches may be gained from a summary review of major results in defining these important environmental and biological requirements of eggs, larvae and juveniles.

An early problem confronted in our efforts to mass-rear queen conch larvae was protozoeal infestation in the larviculture tanks, primarily derived from protozoa (*Euplotes* sp., *Stylonchia* sp.) brought into the hatchery from the sand-covered egg masses of the adult queen conch. Several disinfection techniques were investigated. Dilute solutions of Clorox were found to be most effective in disinfecting egg masses and at the same time permitting very high percentage hatching rates. A series of factorial experiments were conducted examining the effect on hatching rates and disinfection of various concentrations of Clorox for various times of exposure. Response surface analysis (Siddall, 1979) was used to determine that exposure to 0.5% Clorox solution in seawater for 45 seconds would effectively disinfect egg masses yet permit 99% normal hatching to proceed. Such disinfection procedures are now routine in our experimental hatchery.

In an effort to obtain egg masses of the queen conch before and after the natural spawning season, we investigated the possibility for inducing egg laying activity using crude hormone extracts of the subesophagael ganglion (nerve mass) as have been used successfully in other gastropods (Ram et al., 1982). Hormone induction of egg laying in queen conch has not been a fruitful approach to date and further work will be required before the natural spawning season is expanded in captivity.

Therefore, we continue to collect eggs from actively laying females in the wild. We have experienced no shortage of egg masses collecting material from Florida, the Bahamas, Turks and Caicos, Puerto Rico and Bonaire. Egg masses are brought into the laboratory and incubated for 5 days in seawater containing the antibiotic Chloramphenicol (6mg·ℓ⁻¹). Antibiotics are not used in larviculture.

After hatching directly in 370-ℓ cone-bottom (15 degrees) larviculture tanks, the larvae are reared through their planktonic life of 20 to 25 days. Larviculture tanks are strongly illuminated from above to stimulate growth and reproduction of phytoplankton cells, cultured and added as food for larvae.

Much of our laboratory efforts have involved monitoring important environmental and biological variables with graphical and statistical computer analyses conducted on a daily basis if needed. We have been primarily concerned with aspects of water quality, especially as this factor relates to site selection for a hatchery. Using one of the School's oceanographic research vessels, R/V CALANUS, we collected 12 tons of Gulf Stream seawater from a depth of 10 m to supply our laboratory. Our routine hatchery operation was run for 3 weeks on Gulf Stream seawater during which time we determined that this type of high quality seawater actually decreased growth and survival rates, possibly because of very low levels of required nutrients in the water. This result loosens constraints on site selection as we are not obliged to seek seawater of such high quality.

Current water handling procedures call for 100% seawater exchanges each day on all larvicultures older than 4 days after hatching. To minimize this labor intensive exchange procedure, we have investigated flow-through systems. Engineering solutions may lead to the use of such systems in the future, but continuous flow of seawater through larvicultures resulted in continuous innoculation of the culture with microalgae which fouled the larval shell surface by the 15th day after hatching. Such fouled larvae cannot swim, do not feed effectively and hence do not grow.

For any conch hatchery to be cost-effective, it must practice high-density culture of larvae. High-density culture of such large larvae (2-3 mm across the velar lobes) is hampered by interlarval interactions, enhanced mucus production, elevated respiration rates and reduced ingestion and growth rates. Several physiological investigations were conducted to resolve some of the problems accruing from our needs to practice high-density culture.

Our research results support D'Asaro's (1965) report that the larval heart of the queen conch irreversibly ceases beating when the animal is disturbed sufficiently, as may happen during routine seawater exchanges. Four to 5 days after hatching, the adult heart has developed and has assumed the circulatory function from the larval heart (D'Asaro, 1965). The adult heart is not sensitive to handling and therefore our 100% seawater exchanges, which are a source of handling stress to the larvae, do not commence until the larvae are 4 days old when the stronger adult heart is functional.

We are continuing to investigate new methods for assessment of age-specific respiration rates using microrespirometry. Such refined measurements of respiration rates of individual larvae will be used to evaluate the physiological status, or fitness, of hatchery produced larvae and juveniles.

Radioactively labelled phytoplankton have been used to estimate maximum food density and maximum stocking density of larvae. At food densities above 50,000 cells·ml⁻¹ or at stocking densities in excess of 1,000 larvae·ℓ⁻¹ ingestion rates of food decline significantly. We currently use a graduated feeding regime starting at 1,000 cells·ml⁻¹ 2 days after hatching (larvae can feed 6 h after hatching) reaching 25,000-30,000 cells·ml⁻¹ 10 days after hatching and beyond.

Ten days after hatching, cultured larvae appear to have exhausted their lipid reserves (yolk) and are obliged to derive metabolic energy from planktotrophic activity. In an effort to provide a lipid-based diet as a replacement for natural phytoplankton diets, we investigated microencapsulated mollusc lipids as an artificial food. Details of this technique will be presented elsewhere, and the results were

Table 1. Cost estimates for queen conch hatchery

Item	Cost ($)
CAPITAL EXPENSES:	
Open-sided hatchery building; 4,000 sq ft	$160,000
Seawater supply and gravity fed plumbing system	25,000
Larviculture tanks; 40-730 liters	24,000
Technical supplies	20,000
Boat	17,500
Vehicle	15,000
TOTAL	261,500
10% allowance for cost overruns	26,150
TOTAL CAPITAL EXPENSES:	$287,650
ANNUAL OPERATING EXPENSES:	
1 Technical staff member (including benefits)	$ 26,000
4 Hatchery staff @ $18,000 (including benefits)	72,000
Electricity (50-65% for pumping seawater)	5,000
Supplies, repairs, maintenance	15,000
Depreciation of capital items (10% per year)	26,000
Cost of capital investment (12% per year)	34,400
TOTAL ANNUAL OPERATING EXPENSES:	$178,400

encouraging in that growth was reduced only 15% for larvae exclusively fed a microencapsulated lipid diet when compared to our best phytoplankton diet (Tahitian *Isochrysis*, *Nannochloris oculata*, *Dunaliella tertiolecta*). Although the culture of phytoplankton to feed conch larvae is not prohibitively expensive, alternate artificial diets may eliminate considerable efforts spent in phytoplankton culture.

We have developed a substantial line of evidence that phycoerythrins and related protein conjugants found in red macroalgae cause onset of metamorphosis in queen conch larvae. Our routine procedures for uniformly inducing metamorphosis of all larvae in a culture involves collection of competent larvae (20 to 25 days after hatching) on a Nitex screen, exposing them to a very dilute seawater solution of extracts prepared from red macroalgae (*Laurencia obtusa* usually) for 2 to 3 h, then placing them in shallow, submerged trays fouled with fine, filamentous macroalgae (often *Ceramium* sp.). Within 12 h of this treatment, 90-95% of all larvae complete metamorphosis with nearly 99% survival through what has been considered a critical period for most other cultured species. Early estimates of survival during the nursery grow-out phase from 2 mm metamorphosed postlarvae to 2-3 cm juveniles for reseeding are as high as 90%.

Several other research groups have been examining hatchery methods for queen conch including the University of Puerto Rico, the Carco Project of Bonaire, and the Foundation for PRIDE in Turks and Caicos. Based on the new information developed in these projects and our 3-year research program, the biological outlook for hatchery production of queen conch is excellent, although continued biological research will be required if any facilities are to be scaled up to a production hatchery approximately 10 times larger than our existing experimental facility.

To evaluate the economic outlook for hatchery replenishment, I have prepared cost/revenue estimates for such a full scale production hatchery. The operation and estimated production of this facility is based on our current hatchery practices, the details of which will be published elsewhere. Initial costs, or capital expenses, and annual operating expenses are summarized in Table 1. All amounts are in U.S. dollars. No allowance has been made in the operating expenses for (1) cost of leased or purchased land for a hatchery site because such costs are highly variable and site-specific and (2) for the "time value" of money invested in the hatchery for the year before any juveniles are produced and sold.

Both conservative and optimistic estimates of production are given in Table 2. Only two factors — the number of successful larvicultures at a given time and the stocking density of larvae per liter — vary between the conservative and optimistic estimates of production. It is assumed that supplies of egg masses are not limiting. Based on the results reported by the Foundation for PRIDE from their egg farm (Davis and Hesse, 1983), this is a reasonable assumption. While artificially expanded spawning seasons may be possible in the future, we assume a relatively short 24-week spawning season for these calculations. In 1982 the spawning season for queen conch in Florida was 34 weeks long.

In the conservative case, only 30 out of a possible 40 larviculture tanks are occupied with healthy cultures at any time. This figure is raised to 35 out of 40 in the optimistic estimate. Out of 50 experimental cultures handled in our 1982 season, 44 were successful.

While we have successfully metamorphosed larvae from cultures stocked as high as 300 larvae/ℓ, I have assumed in these calculations that only 20 (conservative) or 60 (optimistic) larvae per liter may be reared successfully. In this respect, even the optimistic estimates of production are conservative.

Net production of 3.15 million juveniles divided into the $178,400 annual operating expense gives a production cost per juvenile of 5.67 cents in the conservative case. Net production of 11.0 million juveniles in the optimistic case yields a production cost per juvenile of 1.62 cents. Gross margins and return on investments for different selling prices per juvenile are listed in Table 3.

Table 2. Production estimates for queen conch hatchery

	Conservative	Optimistic
Number of larviculture tanks which hold "successful" cultures at any time (out of 40 available)	30	35
Length of spawning season	24 weeks (May-Oct)	24 weeks (May-Oct)
Time required for each culture	3 weeks	3 weeks
Stocking density of larvae per liter	20 larvae/ liter = 14,600 larvae/tank	60 larvae/ liter = 43,800 larvae/tank
Larvae/tank X number of tanks X 8 batches/season	3.5 million postlarvae	12.3 million postlarvae
90% survival during nursery grow-out to 2-cm juveniles	3.15 million juveniles	11.0 million juveniles

If we pose the question, "What minimum recovery rate of hatchery produced juveniles is required to break even at some arbitrary cost per conch?", we may look to these cost and production estimates for an answer. Several assumptions are necessary; (1) 5 months are required to produce a 2 cm juvenile conch, (2) each juvenile costs between 1.62 and 5.67 cents to produce, (3) acceptable meat yields will be obtained at an age of 2 years and (4) the mean ex-vessel price of one 2-year old conch is 40 cents. If we release 5-month old 2-cm juveniles, they must survive 19 months (total of 24 months or 2 years) before recovery.

Table 3. Estimated revenues from one season of operation of queen conch hatchery

Production costs/ juvenile (¢)	Selling price/ juvenile (¢)	Gross margin ($)	Return on investment (%)
5.67	5.67	-0-	-0-
(3.15 million)	6.00	$10,560	6
	8.00	73,560	41
1.62	1.62	-0-	-0-
(11.0 million)	2.00	41,560	23
	4.00	261,560	147
	6.00	481,560	270

The answer to the question is a function of the cost of each juvenile. At 5.67 cents per juvenile, at least 14% recovery is required to break even at a cost of 40 cents per harvested conch, while only 4% recovery is required to break even if production cost for juveniles are reduced to 1.62 cents each. These simplistic calculations do not consider cost of the fishing effort, and clearly are not the ultimate evaluation of the hatchery's role but they are promising and call for further work.

Based on these preliminary estimates, the economic outlook for queen conch hatchery production is quite good. However it must be borne in mind that these are tentative projections subject to revision as a production hatchery is actually operated. The returns on investment of Table 3 are merely indications that a conch hatchery is economically feasible. In fact, unless the released queen conch juveniles are returned from the fishery as market-sized adults, the hatchery is not a useful aid to fisheries management programs. That a queen conch hatchery can benefit a fishery in the long term is yet to be demonstrated, largely because no one has had the opportunity to build and operate a production-scale hatchery and attempt extensive reseeding of conch populations.

To profit from mass-production of juveniles should not be the major objective of the first queen conch hatcheries to be built and operated. We view the conch hatchery as a tool for fishery management rather than an end in itself. However, the hatchery eventually may play a role in a vertically integrated approach for mariculture of queen conch from eggs to retail product.

Hatcheries should not be looked upon as a panacea for the entire region's problems with managing conch resources. The socio-economic and biological diversity of the queen conch fisheries of the Caribbean precludes a singular regional solution. Levels of fishing activity range from subsistence-level for family consumption to individual fishermen supplying local markets to both informal and sophisticated cooperatives contracting for extensive export sales. Biologically, the fisheries are similarly complex. Estimates of annual survival rates range from 1% to 93%. Mean age at market size ranges from 2 years to more than 4.5 years. Yield varies from 3 to 18 adult conchs per kg of cleaned meat. Levels of predation on conchs are highly variable from area to area, as are densities of natural populations. There is a wide range of habitat types of varying accessibility to fishermen, each associated with different natural diets for the conch.

Development of properly scaled, low-technology overseas hatcheries operated by local personnel to augment local conch populations with juveniles purchased by governments or fishing cooperatives may be most appropriate. Such facilities should benefit from close association with universities whose specialized research and training capabilities will support successful hatchery operations. Until such programs are undertaken, we emphasize the exciting potential for conch hatcheries to help resolve the conflict between subsistence-level fishing activity in the Caribbean and demand for conch meat by a profitable market in the United States.

ACKNOWLEDGMENTS

None of our queen conch research program would have been possible without the insight and support of Mr. W. Groves and our objectives could not have been met without the abilities and efforts of those in our research group: Dr. E. S. Iversen, R. L. Creswell, L. FitzGerald and R. Mianmanus. Thanks are also due Mr. J. Brown, National Marine Fisheries Service, Southeast Fisheries Center, Charleston, for his review of the economic analyses.

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