Integrating Aquaculture into Caribbean Development: Selection of Marine Species

PETER VAN WYK and MEGAN DAVIS
Harbor Branch Oceanographic Institution
Aquaculture Division
5600 US 1 North
Ft. Pierce, Florida 34946 USA

ABSTRACT

Many Caribbean nations have recognized the potential of mariculture to help meet local demand for fish and other marine products and to relieve pressure on fisheries. Governments and investors are especially interested in culturing species that are traditionally associated with the Caribbean, such as the spiny lobster, queen conch, and Nassau grouper. Commercial feasibility needs to be reviewed for these species and other candidate species. In some cases, the hatchery technology may be a major constraint, while in other species problems may exist in the nursery or growout phases of production. There are also candidate species for which the culture technology is well developed, but market prices are too low to allow for profitable production in the Caribbean. Expansion of Caribbean mariculture is critically dependent upon the identification of species with highest commercial potential.

To assist in determining commercial feasibility of a species, a scoring system was developed based on a mixture of technological, economic, and market-related factors. This system was used to rank nine species commonly considered as candidates for Caribbean aquaculture in order of their commercial feasibility. The species were rated in five different categories:

i) Hatchery technology,
ii) Nursery technology,
iii) Growout technology,
iv) Environmental impacts, and
v) Marketability.

Species rankings were highly dependent upon the culture technologies selected, as well as on individual marketing opportunities. The top five species ranked in order of their aquaculture commercial feasibility in the Caribbean were: cobia, sponge, shrimp, spiny lobster and queen conch. This ranking system is a tool that can assist in identifying species with the best commercial potential. However, investment decisions should also be based on detailed economic analyses.

KEY WORDS: Aquaculture, Caribbean development, marine species

Acuacultura que Integra en el Desarrollo del Caribe: Selección de la Especie Marina

Muchas naciones del Caribe han reconocido el potencial del acuacultura de ayudar a resolver la demanda local para los pescados y otros productos del mar y a relevar la presión en industrias pesqueras. Los gobiernos y los inversionistas están especialmente interesados en cultivar las especies que se asocian tradicionalmente al Caribe, tal como la langosta espinosa, el caracol de la reina, y el grouper de Nassau. La viabilidad comercial necesita ser repasada para las estas especies y la otra especie del candidato. En algunos casos la tecnología del criadero puede ser un constreñimiento importante, mientras que en la otra especie los problemas pueden existir en las fases del criadero o de maduración. Hay también las especies del candidato para las cuales la tecnología de la cultura se desarrolla bien, pero los precios de mercado son demasiado bajos para permitir la producción provechosa en el Caribe. La extensión del acuacultura del Caribe es críticamente dependiente sobre la identificación de la especie con el potencial comercial más alto.

Para asistir a determinar viabilidad comercial de una especie, un sistema que anotaba fue desarrollado basó en una mezcla de factores tecnológicos, económicos, y relacionados con el mercado. Este sistema fue utilizado para alinear nueve especies consideradas comúnmente como candidatos a acuacultura del Caribe en orden de su viabilidad comercial. Las especies fueron clasificadas en cinco diversas categorías: tecnología del criadero, tecnología del cuarto de niños, tecnología del maduración, consecuencias para el medio ambiente, y comerciabilidad. Las graduaciones de la especie eran altamente dependientes sobre las tecnologías de la cultura seleccionadas, así como en oportunidades individuales de la comercialización. Las cinco especies superiores alineadas en orden de su viabilidad comercial de la acuacultura en el Caribe eran: cobia, esponja, camarón, langosta espinosa y caracol de la reina. Este sistema de graduación es una herramienta que puede asistir a identificar especie con el mejor potencial comercial. Sin embargo, las decisiones de la inversión se deben también basar en análisis económicos detallados.

PALABRAS CLAVES: Acuacultura, desarrollo del Caribe, especie marina

INTRODUCTION

Many Caribbean nations have recognized the potential of mariculture to help meet local demand for fish and other marine products and to relieve pressure on fisheries. Mariculture also has the potential to create jobs and much needed export income. Expansion of Caribbean mariculture is critically dependent upon the identification of species with highest commercial potential. To assist in determining commercial feasibility of a species, a scoring system was developed based on a mixture of technological, economic, environmental, and market-related factors. This system was used to rank eight species commonly considered as candidates for Caribbean aquaculture in order of their commercial feasibility. The candidate species considered in this analysis were:

queen conch (*Strombus gigas*), spiny lobster (*Panulirus argus)*, marine shrimp (*Litopenaeus vannamei)*, Nassau grouper (*Epinephelus striatus*), cobia (*Rachycentron canadum*), red drum (*Sciaenops ocellatus*), Florida pompano (*Trachinotus carolinus*), and sea sponge (*Hippospongia spp*.)

METHODS

Species were scored in five different categories: hatchery technology, nursery technology, growout technology, environment impacts, and market considerations. Within each category a variety of criteria were identified that provided a basis for judging the commercial feasibility or potential for the different species. For each criterion rated, a score was given ranging from 1 to 4, where: 1 = Poor; 2 = Fair; 3 = Good; and 4 = Excellent. Average scores were calculated for each category.

Scoring Criteria

The criteria used for rating the hatchery technology for a given species included:

i) Maturation facility capital cost,
ii) Larval rearing facility capital cost,
iii) Reliability of egg production,
iv) Larval rearing survival rates,
v) Year-round availability of seedstock,
vi) Hatchery labor costs,
vii) Hatchery energy costs, and
viii) Expected cost of seedstock.

No hatchery score was given for sponge culture because hatcheries are not required for sponges. In the case of spiny lobster, seedstock (pueruli) would be obtained from the wild. Therefore, no scores were given for many of the spiny lobster hatchery criteria. However, scores were given for year round availability of seedstock and cost of seedstock, as these criteria also relate to wild seedstock collection.

The criteria used for rating the nursery technology for a given species were: nursery facility capital cost; survival in the nursery phase; nursery labor cost; nursery energy cost; and, nursery feed cost. Nurseries are not required for sponges, so no score was given for sponges in this category.

Growout technologies were rated based on:

i) Growout facility capital cost,
ii) Survival in the growout phase,
iii) Growout labor cost,
iv) rowout energy cost, and
v) Growout feed cost.

The criteria for scoring the environmental impacts associated with the aquaculture of a given species reflect the different ways that aquaculture activities can impact the environment. Environmental impact scoring was based on:

i) Habitat impacts,
ii) Natural resource depletion,
iii) Non-native species impacts,
iv) Effect on bio-diversity, and
v) The effectiveness of available mitigation procedures.

In this category higher scores were awarded to culture systems with lower degrees of environmental impact.

The market potential for each of the candidate aquaculture species was rated based on the following criteria:

i) The degree of processing required,
ii) Whether or not the product has a Caribbean identity,
iii) Availability of niche markets,
iv) Size of niche markets,
v) The degree of competition in the marketplace,
vi) The difference between wholesale price and production cost, and
vii) The difference between retail price and production cost.

Weighting of Category Average Scores

The relative impacts of the different categories on the economic feasibility of the aquaculture of a species are not all equal. For example, the growout stage of production will usually have a greater impact on the economics of producing a species than the nursery stage. A weighting factor was used to adjust for the relative importance of the different categories to the species selection process. The weighting factors, which are entirely subjective, provide a way to give additional weight to those categories deemed most important in the species selection process and less weight to categories deemed less important. Weighted category average scores were calculated by multiplying the category average scores by the weighting factor associated with the category. The following weighting factors were used for the different categories:

Category	Weighting Factor
Hatchery technology	8
Nursery technology	6
Growout technology	10
Environmental Impacts	10
Market considerations	10

In cases where no category average score was given (e.g., no hatchery or nursery average scores were calculated for sponge culture), the weighting factors for the hatchery and nursery were added to the weighting factor for the growout. In effect, the growout score received all of the weight associated with the production process. Thus, the average score for the sponge growout was multiplied by a weighting factor of 24 (8 + 6 + 10).

Composite Scores and Species Rankings

The resulting weighted ratings for each of the four categories were then summed for each species to yield a composite score. The composite score is a single number that is derived from all of the different criteria that were used to rate the commercial feasibility for a given species. The eight species considered here as candidates for Caribbean aquaculture were ranked based on the composite scores. Species receiving the highest composite scores should have the greatest potential for commercial success.

RESULTS

The scores given for each of the aquaculture feasibility criteria to the eight candidate species for Caribbean aquaculture are presented in Table 1. This table also shows the average scores for each of the five feasibility categories. Weighed category average scores and composite feasibility scores are presented for each of the eight species in Table 2.

Based on the results of this scoring system, the eight candidate species were ranked according to their feasibility for commercial aquaculture in the Caribbean. Species receiving higher composite feasibility scores should have the greatest potential for commercial success. The species are listed in Table 2 in order of their commercial feasibility ranking.

DISCUSSION

Sea Sponge

Based on the species ranking system, the best candidate for commercial aquaculture in the Caribbean is the sea sponge. While this result might be surprising to some, sponge culture has many favorable attributes. Foremost among these is the low capital cost associated with sponge culture. Adams et al. (1995) estimated the initial capital costs for establishing a 0.4 ha sponge farm to be under $3,000. Operating costs for sponge farming are also very low. Labor is the primary input. Because sponges are filter feeders and no feeding is required, the environmental impact of a sponge farming enterprise would be minimal. The technology for culturing sponges is relatively simple and reliable. The major factor limiting the commercial feasibility of sponge farming is the relatively small market for bath sponges. However, there may be opportunities for culturing sponges for biomedical and pharmaceutical applications (Duckworth 2001).

Sponge farming has potential as a means of providing supplemental income for artesanal fishermen. The low initial investment and operating costs makes entry into sponge farming feasible for individuals with low income. Marketing cooperatives would probably be required for small-scale sponge farmers to gain access to markets.

Table 1. Aquaculture feasibility scoring matrix for eight candidate Caribbean aquaculture

Feasibility Scoring Criteria	Species							
	Queen Conch	Spiny Lobster	Marine Shrimp	Grouper	Cobia	Red Drum	Pom-pano	Sponge
Hatchery Technology								
Maturation capital cost	4	NA	2	3	3	3	3	NA
Hatchery capital cost	3	NA	2	2	2	2	2	NA
Reliable egg production	3	NA	4	2	3	3	3	NA
Larval survival	3	NA	4	1	2	3	2	NA
Year-round seed supply	2	2	4	2	3	4	3	NA
Hatchery labor cost	3	NA	3	2	2	2	2	NA
Hatchery energy cost	3	NA	3	2	2	2	2	NA
Expected seed cost	3	1	3	1	2	2	2	NA
Average Score	**3.0**	**1.5**	**3.1**	**1.9**	**2.4**	**2.6**	**2.4**	**NA**
Nursery Technology								
Nursery capital cost	2	3	3	3	3	3	3	NA
Survival in nursery	2	3	3	3	2	3	3	NA
Nursery labor cost	1	2	3	3	3	3	3	NA
Nursery energy cost	1	3	3	3	3	3	3	NA
Nursery feed cost	2	2	3	2	3	3	2	NA
Average Score	**1.6**	**2.6**	**3**	**2.8**	**2.8**	**3**	**2.8**	**NA**
Growout Technology								
Growout capital cost	1	3	2	2	3	2	1	4
Survival in growout	2	2	3	2	2	3	3	3
Growout labor cost	2	2	3	3	2	3	1	2
Growout energy cost	4	3	3	3	3	3	1	4
Growout feed cost	4	1	3	2	3	3	2	4
Average Score	**2.6**	**2.2**	**2.8**	**2.4**	**2.6**	**2.8**	**1.6**	**3.4**
Environmental Impacts								
Eutrophication potential	3	2	2	2	2	2	3	4
Habitat impacts	3	3	2	2	3	2	3	4
Natural resource deple-	4	4	3	3	4	3	3	4
Exotic species impacts	4	4	2	4	4	4	4	4
Effect on biodiversity	3	3	3	3	4	3	4	3
Mitigation effectiveness	3	3	3	3	3	3	4	4
Average Score	**3.3**	**3.2**	**2.5**	**2.8**	**3.3**	**2.8**	**3.5**	**3.8**
Market Considerations								
Processing requirement	2	4	4	3	3	3	3	1
Caribbean product	4	4	2	4	3	2	3	3
Niche market potential	4	4	2	4	3	2	3	2
Size of niche market	4	3	4	4	4	2	4	2
Market competition	4	4	2	3	4	3	4	2
Wholesale Price-Total	1	2	2	2	4	1	3	1
Retail Price-Total Cost	1	4	3	2	4	3	3	2
Average Score	**3.0**	**3.5**	**2.5**	**3.2**	**3.7**	**2.2**	**3.3**	**2.0**

Table 2. Weighted feasibility and composite scores for eight candidate Caribbean aquaculture species. The eight species are listed in order of their feasibility ranking, based on composite feasibility scores.

Species	Hatchery Weighted Average Score	Nursery Weighted Average Score	Growout Weighted Average Score	Environ. Weighted Average Score	Market Weighted Average Score	Composite Feasibility Score
Sponge	0.0	0.0	78.2	26.8	18.6	123.6
Cobia	16.6	16.8	26.0	23.3	35.7	118.5
Marine Shrimp	21.9	18.0	28.0	17.5	27.1	112.5
Queen Conch	21.0	9.6	26.0	23.3	30.0	109.9
Red Drum	18.4	18.0	28.0	19.8	22.9	107.1
Pompano	16.6	16.8	16.0	24.5	32.9	106.8
Spiny Lobster	10.5	15.6	22.0	22.2	35.7	106.0
Grouper	13.1	16.8	24.0	19.8	31.4	105.2

Cobia

Cobia received the second highest commercial feasibility ranking. Because of its astonishing growth rate (cobia can grow to 6 kg in one year) and excellent market potential, cobia has tremendous potential as a commercial aquaculture species. Cobia can be grown in ponds (Weirich et al. In press) or in submerged offshore cages (Benetti and Orhun 2002). The cage culture system would offer greater profit potential because the capital and energy costs are much lower than those associated with a pond culture system. In addition, better water quality can be maintained in cages, and the potential for disease outbreaks is likely to be significantly lower than in a pond culture system. Overall production costs for cobia reared in offshore cages are expected to be low, due to the relatively low capital investment requirement per kg of annual production capacity, and low expected FCR (Benetti and Orhun 2002).

The primary constraint for the commercialization of cobia aquaculture is the lack of availability of fingerlings. Any new cobia aquaculture venture would likely have to operate their own hatchery. Hatchery production of cobia fingerlings is technologically feasible (Arnold et al. 2002, Benetti et al. 2003, and Kilduff et al., 2002), but reported survival rates have been low (Schwarz 2004). Supplying enough live feed to the rapidly growing larvae appears to be the biggest challenge. There are environmental concerns related to the cage culture, including the potential for eutrophication of surrounding waters, and escapement of hatchery-reared fish and their impacts on wild populations. Proper site selection is critical to mitigate the pollution potential of these cages. Submerged cages should be situated in locations where the water depth is at least 25 m and currents are between 1.5 – 2.5 km/hr. Cages should also be situated over a sandy bottom, away from any coral reefs or other sensitive habitats.

Marine Shrimp

The marine shrimp *Litopenaeus vannamei* received the third highest commercial feasibility score. The commercial feasibility of penaeid shrimp culture is well-established. However, the fact that this species is not indigenous to the Caribbean means that a high degree of biosecurity is required to prevent introduction of shrimp or exotic diseases into the wild. A hatchery capable of producing specific pathogen free (SPF) postlarvae would be required to prevent the introduction of shrimp viruses. The technology for production of SPF seedstock using has been described by several authors (Lotz, et al. 1995, Ogle and Lotz 2001, Wyban and Sweeney 1991). The environmental sensitivity of the Caribbean islands and the surrounding oligotrophic marine habitats also presents special problems for a marine shrimp farming operation. Lined ponds would be required to prevent saltwater contamination of freshwater aquifers. Offsite discharges would be eliminated either by managing the system as a Belize-style aerated suspension pond (McIntosh et al. 1999) or by recirculating the effluent from the shrimp ponds through a settling pond and a system of seaweed biofiltration ponds (Van Wyk and Davis Unpubl. report). Zero-exchange production systems have been demonstrated to be commercially feasible but are more capital intensive and require a higher degree of management expertise than traditional extensive and semi-intensive production systems. It is likely that the production costs for a Caribbean shrimp aquaculture venture would be relatively high, due to the high cost of importing the required inputs. Caribbean shrimp producers will need to identify marketing strategies that will allow them to compete with cheaper imported shrimp.

Queen Conch

Queen conch (*Strombus gigas*) received the fourth highest feasibility score. It is assumed that hatchery, nursery, and growout technology used for queen conch production is the system described in Davis (2000). The past 20 years have witnessed major advances in techniques for egg mass production, larval rearing, induction of metamorphosis, nursery production of juveniles, and growout of juveniles to market size in enclosed off-shore pastures. Although most of the technical problems associated with conch culture have been resolved, conch culture has met with limited commercial success due to the high cost of hatchery and onshore nursery production of juveniles. Conch grow slowly, requiring approximately 12 months to reach a size suitable for stocking in offshore growout pastures (7 - 9 cm shell length). As a result, the labor and energy costs associated with the nursery phase are quite high. Growout to market size in the offshore pastures is also quite lengthy, requiring another 18 months. Predation in the offshore growout can be a major problem. Known predators of queen conch include fish, sharks, rays, octopus, spiny lobsters, crabs, and other gastropods. An exclusion fence is necessary to contain the conch, as well as to exclude predators. While the exclusion fence may effectively exclude pelagic predators, benthic predators must be trapped and removed. Conch growout requires enclosing large areas. At the typical stocking density (1 conch/m^2), one hectare is required for every 10,000 juveniles planted. The environmental impact of excluding pelagic predators from such large areas is an issue that needs to be addressed. From a market standpoint, the demand for queen conch is excellent. However, due to the high production costs, farm-raised conch are more expensive than wild-caught conch. A conch farm in the Turks and Caicos has developed markets for smaller conch (< 9 cm SL), which are cheaper to produce since the offshore growout phase is eliminated. Wild conch in this size range are not available in the marketplace because they are difficult to find in significant quantities.

Red Drum

Red drum received the fifth highest commercial feasibility ranking. From a technical standpoint, red drum culture is well-established. Red drum can be induced to spawn continuously over a period of months or even years using temperature and photoperiod controls (Arnold 1988). Fingerling production can be carried out either intensively in tanks (Holt et al. 1990) or extensively in ponds (Davis 1990a). In the U.S. commercial growout of red drum is usually carried out in ponds, with juveniles reaching a market size of 1 - 1.5 kg in about 16 months (Davis 1990b). The nutritional requirements of red drum are relatively well-known, and suitable growout diets are commercially available. A red drum pond culture operation in the Caribbean would have to be managed to minimize discharge of untreated effluents.

Despite the technological feasibility of red drum culture, there are only a few commercial red drum aquaculture facilities in operation. The reason for this is that the commercial red drum fisheries are supplying enough fish to meet the current demand. As a result, the wholesale market price for whole red drum is very low relative to the cost of aquacultural production of red drum. However, if markets can be identified that will bring significantly higher prices, then aquaculture of red drum could be commercially viable.

Florida Pompano

Florida pompano has attracted considerable attention as a candidate species for aquaculture. Because of its delicate flavor, pompano has a very high market price. In addition, Florida pompano grow very fast, reaching market size (1.5 lbs) in one year or less. The technology required for spawning, larval-rearing and nursery production (Hoff et al. 1978) of this species is similar to that required for other marine finfish, such as red drum. While there is certainly room for improvement in this technology, it does not represent a major obstacle to commercial aquaculture production of this species. Pompano are susceptible to infestations by external parasites, which can cause high rates of mortality. Recirculating tank-based culture systems appear to be the best system choice for pompano because parasites can be controlled with ultraviolet filtration and/or ozone. However, the capital and production costs of recirculating production system are much higher than for cage or pond production systems. Another barrier to the development of a successful commercial pompano enterprise is insufficient knowledge about the nutritional requirements for this species. Very high feed conversion ratios have been reported for pompano reared on high protein, high energy diets (Lazo et al. 1998).

Spiny Lobster

Spiny lobster (*Panulirus argus*) was ranked seventh in terms of its commercial feasibility. Entrepreneurs have long been interested in culturing spiny lobsters due to the high market demand, and concerns about the sustainability of the commercial fishery. However, aquaculture of spiny lobsters has been limited by the lengthy, difficult larval rearing process, lack of suitable growout diets, and the high cost of land-based culture systems. In recent years, the development of techniques to collect seedstock (pueruli) from the wild (Phillips and Booth 1994), and the demonstration of the potential for growing spiny lobsters in cages (Jeffs and James 2001) has resulted in renewed interest in Caribbean spiny lobster culture (Jeffs and Davis 2003). Nevertheless, the reliability of collecting pueruli from the wild in sufficient numbers to support a commercial aquaculture operation has yet to be demonstrated. While cage culture appears to hold promise as a production system, information on the performance of Caribbean spiny lobsters in floating cages is still lacking. Suitable feeds for spiny lobsters must also be developed before this species can be cultured commercially.

Nassau Grouper

Nassau grouper (*Epinephelus striatus*) received the lowest commercial feasibility score. Like queen conch and the Caribbean spiny lobster, many people are interested in culturing Nassau grouper because of its strong Caribbean identity and because the wild population has been over-exploited. Unfortunately, the technology for culturing Nassau grouper has not yet been demonstrated to be commercially viable. The principle constraint is the difficulty in producing grouper fingerlings in commercial quantities. Techniques for maturation and spawning of Nassau grouper (Tucker 1999) are similar to those employed for other marine finfish. Grouper can be induced to spawn naturally, but hormonal induction of spawning has thus far proven more reliable. The main barrier to a successful grouper aquaculture enterprise lies in the larval rearing phase of production. Grouper are among the most difficult marine fish species to rear in the hatchery due to the fragility of the larvae and their requirement for extremely small prey items (Tucker 1999). In the nursery phase, cannibalism is a major concern. Due to the lack of fingerlings, few growout production trials have been conducted with Nassau grouper. In Asia, other grouper species have been successfully grown out in ponds and in floating sea cages. Research is needed to identify the optimal production system for Nassau grouper.

CONCLUSION

A scoring system such as reported here can be a useful tool to help rank the commercial aquaculture potential of multiple aquaculture species. The scoring system is a means of systematically examining the many factors that affect the feasibility of culturing a species, including technological, environmental and economic and marketing factors. Close examination of the scores received in the different categories can help illuminate both the strengths and weaknesses of a particular species as an aquaculture candidate.

Our analysis indicates that, of the species considered in this study, sea sponge, cobia, and marine shrimp have the best potential for commercial aquaculture development in the Caribbean. However, the rankings presented here are not the final word. A scoring system similar to the one presented here can help narrow the field of candidate species, especially if scores are adjusted to reflect the realities of a particular project. Ultimately, the decision whether to proceed with a given project should be based on a thorough feasibility study that takes into account location, site characteristics, available technologies, financial and human resources, environmental impacts, market opportunities, and risk factors.

This is Harbor Branch Oceanographic Institution Contribution Number 1577.

LITERATURE CITED

Adams, C., J.M. Stevely, and D. Sweat. 1995. Economic feasibility of small-scale sponge farming in Pohnpei, Federated States of Micronesia. *Journal of the World Aquaculture Society* **26(2)**:132–142.

Arnold, C.R.. 1988. Controlled year-round spawning of red drum *Sciaenops ocellatus* in captivity. Pages 65-70 in: *Red Drum Aquaculture*. Proceedings of a Symposium on the Culture of Red Drum and Other Warm Water Fishes. *Contributions in Marine Science* **30** (supplement).

Arnold, C.R., J.B. Kaiser, and G.J. Holt. 2002. Spawning of cobia *Rachycentron canadum* in captivity. *Journal of the World Aquaculture Society* **33** (2):205.

Benetti, D.D., J.F. Alarcon, O.M. Stevens, B. O'Hanlon, J.A. Rivera, G. Banner-Stevens, and F.J. Rotman. 2003. Advances in hatchery and growout technology of marine finfish candidate species for offshore aquaculture in the Caribbean. *Proceedings of the Gulf and Caribbean Fisheries Institute* **54**:473–487.

Benetti, D.D. and M.R. Orhun. 2002. Aquaculture of pelagic fish: IV. Cobia (*Rachycentron canadum*). *Global Aquaculture Alliance Advocate* **5**(1):61–62.

Davis, J.T. 1990a. Red Drum: Production of Fingerlings and Stockers. Southern Regional Aquaculture Center (SRAC) Publication No. 324. 4 pp.

Davis, J.T. 1990b. Red Drum: Production of Food Fish. Southern Regional Aquaculture Center (SRAC) Publication No. 322. 4 pp.

Davis, M. 2000. Queen conch (*Strombus gigas*) culture techniques for research, stock enhancement and growout markets. Pages 127 – 159 in: M. Fingerman and R. Nagabhushanam, (eds.). *Recent Advances in Marine Biotechnology – Vol. 4: Aquaculture.*

Duckworth, A. 2001. Farming sponges for chemicals with pharmaceutical potential. *World Aquaculture* **32**(2):14–18.

Holt, G.J., C.R. Arnold, and C.M. Riley. 1990. Intensive culture of larval and post larval red drum. Pages 53-56 in: G.W. Chamberlain, R.J. Miget, and M.G. Haby (eds.). *Red Drum Aquaculture*. Texas A&M University Sea

Grant College Program No. TAMU-SG-90-603, College Station, Texas USA..

Jeffs, A.G. and M. Davis. 2003. An assessment of the aquaculture potential of the Caribbean Spiny Lobster, *Panulirus argus*. *Proceedings of the Gulf and Caribbean Fisheries Institute* **54**:413–426.

Jeffs, A.G. and P. James. 2001. Seacage culture of the spiny lobster *Jasus edwardsii* in New Zealand. *Marine and Freshwater Research* **52**:14191424.

Hoff, F.H., J. Mountain, T. Frakes, and K.R. Halscott. 1978 Spawning, oocyte development, and larvae rearing of the Florida Pompano (*Trachinotus carolinus*). *Proceedings of the World Mariculture Society* **9**:279–297.

Kilduff, P., W. DuPaul, M. Oesterling, J. Olney Jr, and J. Tellock. 2002. Induced tank spawning of cobia, *Rachycentron canadum*, and early larval husbandry. *World Aquaculture* **33**(2):35–39.

Lazo, J.P., D.A. Davis, and C.R. Arnold. 1998. The effects of dietary protein level on growth, feed efficiency and survival of juvenile Florida pompano (*Trachinotus carolinus*). *Aquaculture* **169**(3/4):225–232.

Lotz, J.M., C.L. Browdy, W.H. Carr, P.F. Frelier, and D.V. Lightner. 1995. USMFP suggested procedures and guidelines for assuring the specific pathogen status of shrimp broodstock and seed. Pages 66 – 75 in*:* C.L. Browdy and J.S. Hopkins (eds.). *Swimming Through Troubled Waters: Proceedings of the Special Session on Shrimp Farming*. World Aquaculture Society, Baton Rouge, Louisiana USA .

McIntosh, R.P., D.P. Drennan, and B.M. Bowen. 1999. Belize aquaculture: development of an intensive sustainable, environmentally friendly shrimp farm in Belize. Pages 85 – 99 in*:* B.W. Green, H.C. Clifford III, M. McNamara and G.M. Montano (eds.). 5th Central American Symposium on Aquaculture, August 18-20. ANDAH-WAS-PDACRSP, San Pedro Sula, Honduras.

Ogle, J.T. and J.M. Lotz. 2001. A zero-exchange maturation system for marine shrimp. Pages 76 – 83 in: C.L. Browdy and D.E. Jory (eds.). *The New Wave: Proceedings of the Special Session on Sustainable Shrimp Culture, Aquaculture 2001*. World Aquaculture Society, Baton Rouge, Louisiana USA.

Phillips, B.F. and J.D. Booth. 1994. Design, use, and effectiveness of collectors for catching the puerulus stage of spiny lobsters. *Reviews in Fisheries Science* **2**(3):255–289.

Schwarz, M. H. 2004. Fingerling Production Still Bottleneck for Cobia Culture. *Global Aquaculture Advocate* **7**(1/2): 40 – 41.

Tucker, J.W., Jr. 1999. Species profile: Grouper aquaculture. *Southern Regional Aquaculture Center (SRAC) Publication* **721**:11 pp.

Weirich, C.R., T.I.R. Smith, M.R. Denson, A.D. Stokes, and W.E. Jenkins. [In press]. Pond culture of larval and juvenile cobia, *Rachycentron canadum*, in the southeastern United States: Initial observations. Journal of Applied *Aquaculture* **16** (1/2):27–44.

Wyban, J.A. and J.N. Sweeney. 1991. *The Oceanic Institute Shrimp Manual*. Oceanic Institute, Honolulu, Hawaii USA. 158 pp.