MFR PAPER 1113

Culture of the Bay Scallop, *Argopecten irradians*, in Virginia

MICHAEL CASTAGNA

Michael Castagna is Scientist in Charge, Eastern Shore Laboratory, Virginia Institute of Marine Science, Wachapreague, VA 23480. This paper is Contribution No. 589 from Virginia Institute of Marine Science. It was originally presented at the symposium Aquaculture in the Americas held at the Inter-American Scientific Meeting, "Science and Man in the Americas," jointly sponsored by the American Association for the Advancement of Science (AAAS) and Consejo Nacional de Ciencia y Tecnologia (CONACYT), México 18, D.F., México, 20 June to 4 July 1973.

INTRODUCTION

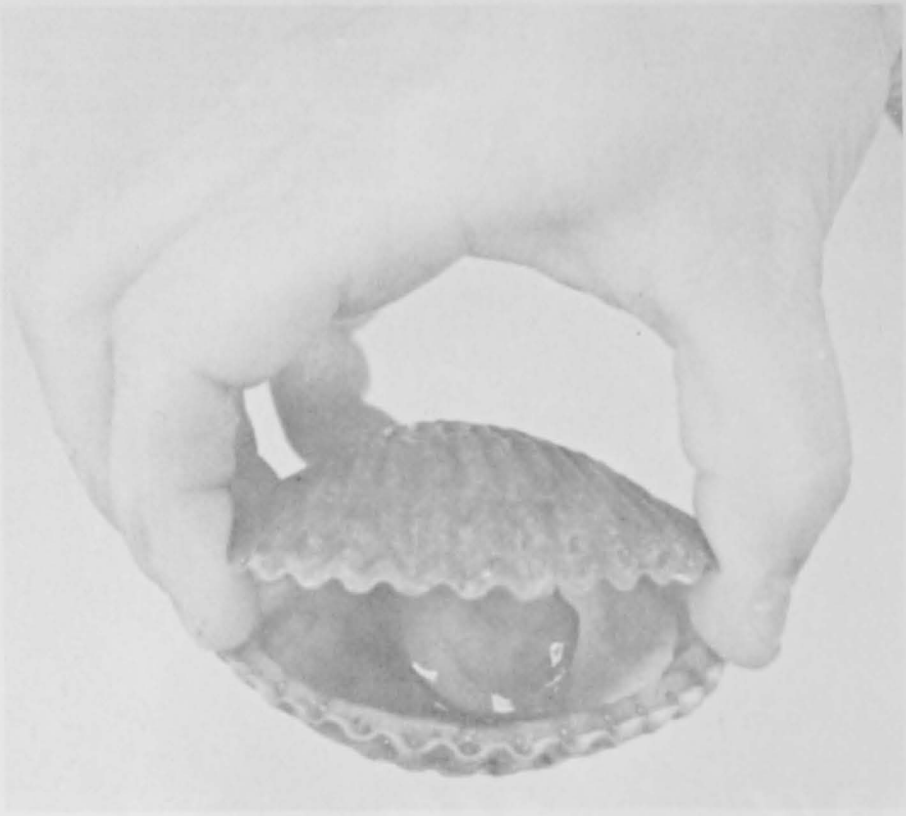
In recent years there has been an increased interest in the development of marine aquaculture or mariculture. Techniques for growing many traditional species, such as oysters and quahogs, have been developed, and considerable effort has also been made to test the feasibility of culturing new, less traditional species (Loosanoff and Davis, 1963; Iversen, 1968; McNeil, 1970; Price and Maurer, 1971; and Milne, 1972). This paper reviews the natural history of the bay scallop, *Argopecten irradaians* Lamarck, and presents a review of the Virginia Institute of Marine Science's (VIMS) continuing research on this species which began in 1968.

The bay scallop has several characteristics well suited for mariculture. It is fast growing, easy to condition and spawn, and is relatively hardy throughout all life history stages. Most important, it has a good market demand and commands high prices. Many species are biologically amenable to mariculture, but economics dictate the use of gourmet species which command high prices to defray high costs of culture.

Only adductor muscles of scallops are utilized. Yields vary, but approximately 1-1¼ bu of scallops produces 1 gal (9 lb) of adductor muscle. The price of shucked scallops rose to $38 per gal (for adductor muscles) in 1973, or over $4.20 per lb, certainly qualifying scallops as a gourmet food.

Utilization of shell and viscera would not significantly change the price or the demand. A mechanical

Bay scallops *(Argopecten irradians)*, top photo, grew from 16 to 57 mm in size in pen in Assateague Channel from 9 July to 24 November 1970. Shucked, lower photo, 247 of these scallops yielded approximately 1 qt adductor muscle.



Scallop, showing developing gonad.

shucking and eviscerating machine developed for the calico scallop fishery along the southeast coast of the United States could be used on bay scallops (Webb and Thomas, 1971). This would markedly reduce manpower and cost problems associated with hand shucking.

Bay scallops retain the ability to swim at all sizes, making it necessary to confine them in suitable enclosures. Although this necessity increases expenses, it is partially compensated by reducing the cost of harvesting expenses.

NATURAL HISTORY

The natural history of the species has been described by Belding (1910), Wells (1927), Gutsell (1930), Loosanoff and Davis (1963), Sastry (1965), and Castagna and Duggan (1971). Bay scallops in the mid-Atlantic area spawn from mid-April through early September (Chanley and Andrews, 1971). Spawning in New England occurs when water temperatures reach 22-26°C (Belding, 1910). Although the scallops are hermaphroditic, self-fertilization is uncommon in nature (Belding, 1910; Gutsell, 1930). They usually release sperm first, followed by eggs (Loosanoff and Davis, 1963), which encourages cross-fertilization. Fertilized eggs develop into straight-hinge veligers in a few hours, and the larvae are planktonic for about 5-8 days. Longer larval periods are common when environmental conditions are less than optimum. The total length of the straight-hinge stage ranges from 85 μ minimum to 140 μ maximum (Chanley and Andrews, 1971).

Juveniles attach by byssal threads to eelgrass or other epibenthic support. They usually maintain attachment until 20-30 mm size is reached, after which most scallops drop to the bottom. Marine plants or other suitable cover is quite important to scallops. Small scallops (under 10 mm) do not survive well when exposed to silt. By attaching to the leaves or stems of submerged plants, they grow large enough to survive the more rigorous existence and greater exposure to silt on the bottom. Further, grass beds reduce current velocities. Work by Kirby-Smith (1972) indicates that scallops grow faster in slow currents. Maximum growth rates were achieved in 1-5 cm/sec, and a flow volume of 4 liters/hr/scallop the slowest current velocities tested. Scallops apparently retain their ability to form byssal attachment throughout their lives, but are seldom found attached when fully grown. They are active swimmers at all sizes and apparently use this ability to avoid predators such as starfish and crabs. Davis and Marshall (1961), studying the filter feeding of bay scallops, found an abundance of benthic and tychpelagic diatoms in the stomachs. They considered this an indication that much of the food is microflora, detritus, bacteria, and organic matter that is common in the water immediately adjacent to the bottom.

The bay scallop has a relatively high pumping rate, probably correlated with its rapid rate of growth. The average rate for small scallops, 38-44 mm in length, was 3.26 liters/hr. The larger scallops, 64-65 mm in length, averaged 14.72 liters/hr, with a maximum rate of 24.4 liters/hr (Chipman and Hopkins, 1954).

The average lifespan is about 12-16 mo with a few individuals surviving to 18 mo and rarely even to 24 mo (Belding, 1910). The scallop, typical of animals with short life cycles, exhibits great fluctuations in abundance.

MATERIALS AND METHODS

The procedures used by VIMS scientists for conditioning and spawning scallops and handling larvae were similar to those used by Loosanoff and Davis (1963). Stocks of spawners were collected from the seaside of Eastern Shore and from North Carolina. Scallops were grown in pens and floats built of plastic screen stretched over wooden frames. Measurements of scallops were from hinge to lip.

Seawater used in the laboratory was pumped from an adjacent creek by cast-iron pumps. All pipes and containers were plastic or glass. The seawater used for larvae and early juveniles was clarified by centrifugation in a Sharples[1] clarifier, Type AS-14, or a Westfalia separator, Model KDD 605. The average salinity for

[1]Reference to trade names does not imply endorsement of commercial products by the National Marine Fisheries Service, NOAA.

the experimental area was 29.5 ‰ with seasonal temperatures ranging from 3 to 28°C.

CONDITIONING FOR SPAWNING

The scallops were conditioned by placing them in aerated standing seawater at temperatures of from 18 to 22°C for 3-6 wk depending on food, temperatures, and the initial gonadal condition of the scallops (Castagna and Duggan, 1971). The conditioning was usually done on scallops taken from ambient-temperature seawater, which dropped as low as 3°C in winter. While held in standing water, the scallops were fed mixed algal cultures. The maturation of the gonads could be seen by holding the valves slightly open. The gonad is a triangular bulbish organ lying alongside the adductor muscle. When ripe, it is usually a red-orange color (often covered by a black epithelium). The testis comprises the white anterior border of the gonad (Castagna and Duggan, 1971).

SPAWNING

Spawning was accomplished by placing one or two adult scallops in a 1-liter Pyrex container filled with filtered seawater. A number of these containers were placed in a water table. By flooding the water table with hot or cold water, the scallops were subjected to temperature changes sufficient to induce spawning. Temperatures of 24-26°C induced maximum pumping activity. Temperatures were usually raised to 30°C for a few minutes and then dropped back to 24°C. Spawning usually took place at 28-26°C.

A sperm suspension (either stripped or spawned) was added to further stimulate scallops to spawn. Various chemical stimulants have been tested with little or no success. Both sex products are often released by the same scallop but usually not simultaneously.

After spawning the scallop was removed from the dish and the egg suspension was poured through a screen, to remove dirt and fecal material ejected by the spawner, into a calibrated container of filtered seawater. Eggs were counted by stirring the contents of the container and subsampling several 1-ml samples. An estimate of the number of eggs was made by averaging the counts and multiplying by the total volume.

Scallop in foreground (left) is spawning.

FERTILIZATION

Fertilization was initiated by adding approximately 6 ml of sperm suspension per liter of egg suspension. Fertilization was nearly 100 percent successful even when sperm and eggs from the same individual were used. The addition of too much sperm suspension can cause larval deformities, probably due to polyspermy.

DEVELOPMENT

Survival and development were usually enhanced by holding developing eggs above 20°C. Optimum temperature for development appeared to be 26-28°C. A minimum salinity of 22.5 ‰ was necessary for development to straight-hinge stage. At near-optimum temperature in 28-30 ‰ salinity, the blastula stage was reached in about 4 hr, trochophore stage in 8-12 hr, and straight-hinge stage in 16-24 hr. The embryonic stages preceding the straight-hinge stage were most vulnerable to environmental conditions, but with proper maintenance approximately 60 percent survival can be expected. Larvae from self-fertilized eggs usually appeared normal in the F_1 generation. Subsequent generations often had larval deformities and poor survival.

The larvae were grown in 60-liter plastic containers. Three times a week the water was siphoned from these containers through a fine nylon screen

to retain larvae. These were concentrated in calibrated containers of filtered seawater, subsampled, and counted by the same procedures previously described. Measurements of a small sample were taken using an ocular micrometer, and the general condition of the larvae was ascertained. The larvae were then redistributed to containers of clean filtered seawater containing food and, if necessary, antibiotics.

LARVAL DENSITY AND LARVAL ENVIRONMENT

Larval density, although not critical, influenced the success of a group of larvae. Since labor and space were often in short supply, it was tempting to crowd as many larvae into as few containers as possible. This practice increased the number of failures, perhaps by increasing chances of disease transmission or because of competition for food or space. To avoid these problems, cultures were started at maximum densities of 40 eggs per ml. As the larvae grew, their densities were reduced with each water change until densities of 5 per ml were reached when larvae were ready to set.

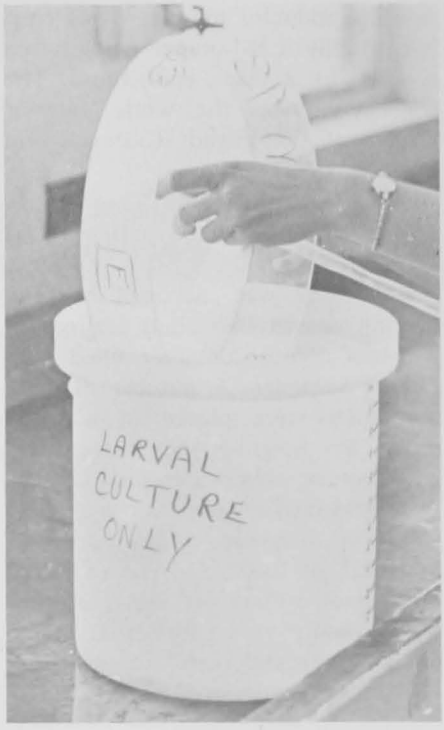
Aeration was not necessary for survival at the densities stated above. Gentle aeration enhanced growth rate and survival of late larval stages but made little or no difference in small or early larvae. Since scallop larvae set at a relatively small size, aeration was not used routinely.

FOOD

Several unicellular cultures of marine flagellates or diatoms were tried as larval food with varying degrees of success. In all trials, mixtures of two or more species worked better than one species. No artificial food mixture was found that gave comparable results.

Some successful species used were *Monochrysis lutheri, Isochrysis galbana, Phaeodactylum tricornutum, Dunaliella tertiolecta,* and *Nanochloris oculata.* Even though food was added, the water was changed periodically to cleanse cultures of metabolic wastes and dead larvae.

When raising large numbers of scallops (or any other cultured filter feeder), the logistics of growing sufficient unicellular algae become a serious problem. An excellent method of growing quantities of food is the solarium method, often referred to as the Glancy method. (Joseph Glancy, Sayville, N.Y. was the biologist responsible for introducing this method.) This method consists of clarifying and holding seawater in aerated vats in sunlight in a solarium or greenhouse. The stored water develops a bloom of diatoms and flagellates which can be used as food.



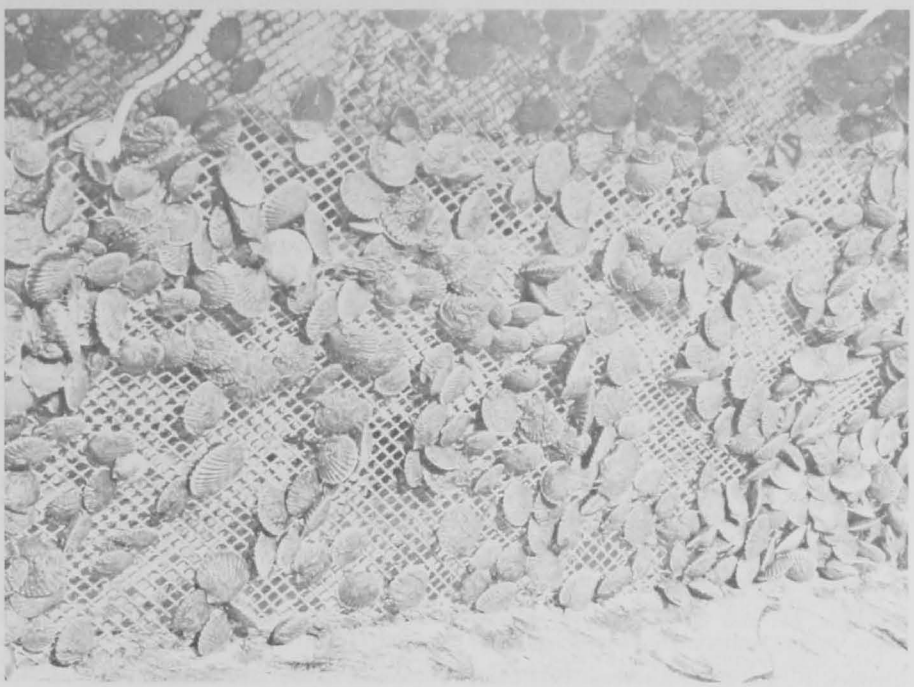
In top photo, a technician washes scallop larvae into container for counting and measuring. A technician grades scallop larvae in the lower photo.

The greenhouse method was used successfully at VIMS. Seawater was run through an AS-14 Sharples clarifier, which spins the water at 15,000 rpm in an 8-in diameter tube exerting 13,200 × *g*. Essentially a clarifier separates heavier particles by centrifugal force instead of gravity. The clarified seawater was then stored in 4 × 8 × 4-ft fiberglassed plywood tanks in a solarium and was continuously gently aerated. The clarified seawater retains small diatoms, flagellates, and protozoans. Heavier and larger forms, including zooplankters and diatoms with dense or heavy tests, are left on the wall of the clarifier tube. When stored in a solarium, the water temperature in the large aerated ranks rises, and the small diatoms and naked flagellates reproduce in a bloom that eventually colors the water. Seawater treated in this manner was referred to as cultured water and was used as a medium in which to grow larvae and early juvenile stages. No additional food was required. The cultured water was normally held 24 hr before use. This was sufficient time for a bloom to occur. If stored water was not used in 48 hr, it was usually discarded, since new cultured water resulted in faster growth and better survival of the larvae. Fertilization or inoculation was not necessary to attain dense blooms of useful food organisms.

Mixed wild algal cultures that grow in this system (Glancy method) were better foods than any combination of unicellular algae tested. Growth and survival were usually better than in larvae fed unicellular cultures.

LARVAL DISEASES, PREDATORS, AND COMPETITORS

Diseases, predators, and competitors were controlled by maintaining clean conditions. No physical, chemical, or prophylaxis treatment was used routinely except when water temperatures were over 28°C. Then, water was subjected to ultraviolet



Scallops in growing container.

light treatment. This treatment is reviewed by Loosanoff and Davis, (1963).

The most common disease problem was bacillary necrosis. This was treated with streptomycin (50 mg per liter) or with a wide spectrum antibiotic such as chloromycetin or polycillin. Care was taken in estimating dosage since antibiotics often caused the larvae to stop feeding for several days, and overdoses caused mortalities.

Arthropods often appeared in the larval cultures. These were controlled with tetraethyl pyrophosphate. Four drops in 60 liters of culture would usually kill all arthropods in less than an hour. Obviously this is a potent chemical and should not be used indiscriminately. Arthropods were also removed by screening. This method was preferred over chemical control.

Protozoans often appeared as a symptom of bacterial contamination. They were controlled by reducing the number of bacteria with an antibiotic.

As always, labor and space were considered as in a commercially-oriented culture practice. Therefore, it was usually more expedient to discard poor or sick cultures and start over rather than attempting treatment.

SETTING

Setting took place in 5-7 days, depending on food, temperature, and probably other environmental and genetic factors. The most obvious indication of spat stage was attachment by byssal threads to the culture container. The early juveniles have a well-developed foot with a heel-like byssal gland. The shell measures 175-200 μ at metamorphosis (Chanley and Andrews, 1971). This period, when the scallops were undergoing metamorphosis, was probably the most critical, and often heavy mortalities occurred.

Through early metamorphosis or setting, the scallops were kept in clarified water or in slowly flowing raw seawater. At this time vertical surfaces for attachment were presented to the setting scallops. These were panels of wood, mylar, or fiberglass that the juveniles fastened to by their byssus. Juveniles apparently preferred vertical surfaces and most were found clinging to the sides of the containers or the panels. As food requirements increased, flowing raw seawater was introduced. A screen of suitable size was placed at the overflow to retain scallops that were sucked into the overflow pipe while swimming. Juveniles were held in this manner until they reached 10-13 mm size, large enough to stay in ¼-in plastic screen.

When the juvenile scallops were moved into the field, they required confinement to prevent them from swimming away. A variety of enclosures were used. Floats anchored at the surface had severe fouling problems which reduced the flow of water. Additional problems of boat wakes and wave action, washing the scallops about in the floats and often causing a concentration in a corner with some loss due to smothering, were also encountered. Floats placed on the bottom had fewer problems but the scallops did not grow well.

The most successful growth and survival was in pens constructed of poles placed into the bottom with ½-in mesh plastic screen tacked around the outside of the poles. The pens were 10 ft square and 7 ft high. They were constructed in shallow subtidal areas.

Bay scallops grown in pens were brought to market size in 5-7 mo. Further, the adductor muscle was considerably larger than in scallops grown in floats. This may be due to

Juvenile scallops tagged and ready to be released.

the opportunity of scallops in pens to make vertical swimming excursions. The size of the adductor muscle is important since it is the only part of the scallop which is sold.

A series of tests were completed to assess the best depth to grow scallops. Little difference was found between depths if fouling, silting, and washing could be controlled. Experiments were also run to find the maximum optimum number of scallops per unit area that can survive and grow. Optimum growth and survival were found at 25 per sq ft of bottom area. However, the data suggest that 60-65 scallops per sq ft would be optimal economically, even though growth rates were less than optimum (Duggan, 1973).

PREDATORS

Although smothering is definitely the main cause of death, there are some serious predators. The rough oyster drill *Eupleura*, starfish, crabs (especially the blue crab, *Callinectes sapidus*) and various fish species are known predators of this species. No predator control methods were used in these experiments, but they should be considered in any commercial venture.

ACKNOWLEDGMENT

Grateful thanks are due to Nancy Lewis, Sharon Schneider, Mike Peirson, and Rick Karney for their assistance in carrying out these experiments. My special thanks to W. P. Duggan for his collaboration and help in much of this work and for carrying out most of the work on enclosures, densities, and depth experiments. I also wish to thank J. D. Andrews whose suggestions and review were greatly appreciated.

LITERATURE CITED

Belding, D. L. 1910. A report upon the scallop fishery of Massachusetts, including the habits, life history of *Pecten irradians*, its rate of growth and other factors of economic value. Mass. Comm. Fish. Game, Spec. Rep., 150 p.

Castagna, M., and W. Duggan. 1971. Rearing the bay scallop, *Aequipecten irradians*. Proc. Natl. Shellfish. Assoc. 61:80-85.

Chanley, P., and J. D. Andrews. 1971. Aids for identification of bivalve larvae of Virginia. (Germ. and Fr. summ.) Malacologia 11:45-118.

Chipman, W. A., and J. G. Hopkins. 1954. Water filtration by the bay scallop, Pecten irradians, as observed with the use of radioactive plankton. Biol. Bull. (Woods Hole) 107:80-91.

Davis, R. L., and N. Marshall. 1961. The feeding of the bay scallop, *Aequipecten irradians*. Proc. Natl. Shellfish. Assoc. 52:25-29.

Duggan, W. P. 1973. Growth and survival of the bay scallop, *Argopecten irradians*, at various locations in the water column and at various densities. Proc. Natl. Shellfish. Assoc. 63:68-71.

Gutsell, J. S. 1930. Natural history of the bay scallop. Bull. U.S. Bur. Fish. 46:569-632.

Iversen, E. S. 1968. Farming the edge of the sea. Fishing News (Books) Ltd., Lond., 304 p.

Kirby-Smith, W. W. 1972. Growth of the bay scallop: The influence of experimental water currents. J. Exp. Mar. Biol. Ecol. 8:7-18.

Loosanoff, V. L., and H. C. Davis. 1963. Rearing of bivalve mollusks. Adv. Mar. Biol. 1:2-130.

McNeil, W. J. (editor). 1970. Marine aquiculture. Ore. State Univ. Press, Corvallis, 172 p.

Milne, P. H. 1972. Fish and shellfish farming in coastal waters. Fishing News (Books) Ltd., Lond., 208 p.

Price, K. S., and D. L. Maurer (editors). 1971. Artificial propagation of commercially valuable shellfish. Univ. Del., 212 p.

Sastry, A. N. 1965. The development and external morphology of pelagic larval and post-larval stages of the bay scallop, *Aequipecten irradians concentricus* Say, reared in the laboratory. Bull. Mar. Sci. 15:417-435.

Webb, N. B., and F. B. Thomas. 1971. Influence of mechanical processing on the quality and yield of bay scallop meats. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Spec. Sci. Rep. Fish. 624, 11 p.

Wells, W. F. 1927. Report of the experimental shellfish station. N.Y. State Conserv. Dep., 16th Annu. Rep., p. 113-130.

MFR Paper 1113. From Marine Fisheries Review, *Vol. 37, No. 1, January 1975. Copies of this paper, in limited numbers, are available from D83, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235.*

MFR PAPER 1114

Crustacean Aquaculture in Middle America

HAROLD H. WEBBER

INTRODUCTION

This paper is designed to inform the reader regarding the technical and economic feasibility of establishing a profitable aquaculture venture in certain specific locations on the west coast of Central America.

The recommendations made here are predicated on the following basic premises:

1) The continuing paucity of high-value crustacean aquafoods in the expanding world markets demands that new sources of supply be developed.

2) An aquacultural production technology is maturing which will enable us to generate large volumes of shrimps at favorable cost.

3) The risks and rewards of a vertically integrated aquafood enterprise have been evaluated, and the business projections reveal an advantageous return on investment.

MARKETS

There exists a market for high-value crustacean aquafoods, including marine and freshwater shrimps, lobsters, and crabs, which is now unsatisfied and is likely to remain supply-constrained for the remainder of the century. This is a consequence in part of an increasing affluence in the highly developed industrial societies in the north temperate latitudes. This elevated economic status