Southern Regional Aquaculture Center

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Species Profile: Sea Urchins of the Southern Region

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Sea urchins are important species affecting community structure in many marine ecosystems. Sea urchins are members of the phylum Echinodermata and share taxonomic class (Echinoidea) with such popular ornamental organisms as sand dollars and sea biscuits. Sea urchin species inhabit a wide variety of marine habitats in the southern U.S. including rocky shores, hard bottoms, coral reefs, and shallow water seagrass beds. Many scientists have referred to sea urchins as "keystone species", suggesting that their absence could cause a major change in those ecosystems. Sea urchins common to the southern U.S. include the genera *Arbacia, Eucidaris, Echinometra, Diadema, Tripneustes,* and *Lytechinus.*

Sea urchin gonads, often referred to as uni or roe, have been widely consumed by human populations since pre-historic times. In more recent years, several species of sea urchins throughout the world have been commercially fished, processed, and sold for human consumption. Sea urchin roe is a valuable seafood item in Japan, China, France, Chile, Canada, United States, United Kingdom, Barbados, and the Mediterranean region. The commercial fishery for sea urchins throughout the world is so widespread that over-fishing, dwindling natural populations, and ecological damage is common.

A large and profitable sea urchin fishery has existed on both the east and west coast of the U.S. The green sea urchin *(Strongylocentrotus droebachiensis)* was fished heavily from the northeastern coast until overfishing decimated populations in the last two decades. The red sea urchin *Mesocentrotus* (formerly *Strongylocentrotus) fransciscanus* and purple sea urchin *(Strongylocentrotus purpuratus)* continue to be heavily fished from the west coast though populations have stabilized at reduced levels since 2003. The landings for the red sea urchin peaked in 1993 at over 34,000 metric tons with an estimated value of nearly 60 million dollars and has since greatly decreased to an average of less than 7,000 metric tons and a dockside value of around 13 million dollars (Fig. 1). Decreasing natural populations, increased consumer demand, and continued high prices for the

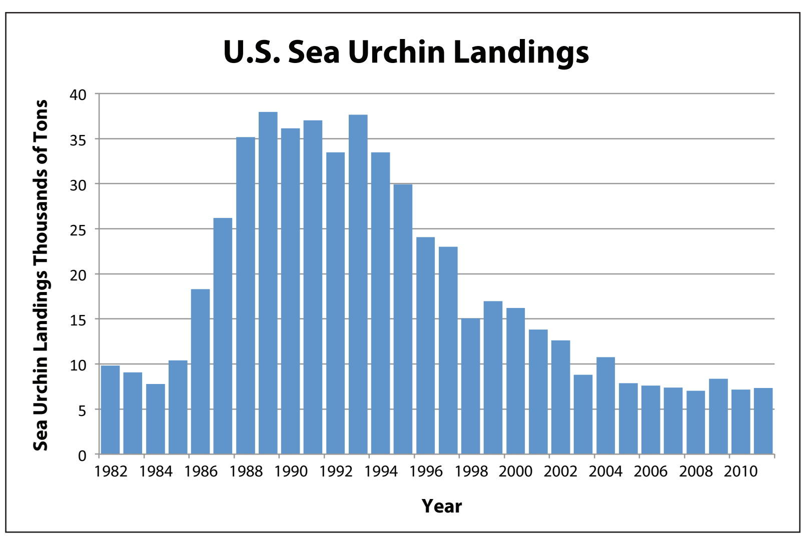

Figure 1. U.S. fisheries landings for all states and all sea urchin species from 1982 to 2011. Data obtained from NOAA Commercial Fisheries Database.

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processed roe have sparked an interest in the aquaculture of sea urchins.

The southern region of the U. S. has two native species of edible sea urchins, *Lytechinus variegatus* and *Tripneustes ventricosus* that have strong potential for aquaculture based on rapid growth rates, high fecundity, hardiness, and acceptable roe quality. *Tripneustes ventricosus,* commonly referred to as the sea egg, has been commercially fished for many years in Barbados. There were early attempts to manage the fishery that failed and eventually led to the collapse of the fishery in the 1980s. *Lytechinus variegatus,* commonly called the variegated urchin, has been fished and consumed by local populations in the Caribbean for many decades but is not commercially fished to any large extent at the current time. Recent aquaculture research with *L. variegatus* at the University of Alabama at Birmingham (UAB) has brought attention to the species and the roe was featured on a popular TV cooking show (Bizarre Foods America) in the summer of 2013.

Sea urchins have four prominent organs: test (spiny shell), gut, gonad, and Aristotle's lantern (jaw or feeding apparatus; Fig 2). The outermost covering called the test is a hard shell that protects the internal organs of the urchin. This test is covered with hard spines which can protect the organism from many predators. Small suction cup-like tentacles called tube feet are used for adhering to surfaces and locomotion. The mouth features a unique feeding apparatus with five pyramid shaped teeth held within a bony structure called the Aristotle's Lantern. These hard teeth are used to scrape food from surfaces and to consume seagrass. As food passes through the mouth and Aristotle's lantern it moves to the gut for digestion. Five gonads are suspended within the inside of the test (Fig. 3).

Figure 3. Two small *L. variegatus* with the oral side of the test removed to show the five gonads suspended from the inside of the test.

The sea urchins *L. variegatus* and *T. ventricosus* are common inhabitants of a wide variety of habitats in shallow water marine ecosystems including hard bottoms, sand bottoms, shell covered bottoms, coral reef flats, and seagrass beds. *Lytechinus variegatus* has the larger natural distribution of the two species and is commonly found from the Atlantic coast of North Carolina to Brazil including much of the Gulf of Mexico and Caribbean. The distribution of *T. ventricosus* overlaps with that of *L. variegatus* from the Atlantic coast of Florida to Brazil including the Florida Keys and much of the Caribbean but is absent from the Gulf of Mexico.

Both species occur in relatively high densities. *Tripneustes ventricosus* has been reported in densities ranging from 0 to 0.9 urchins/square yard. (0.75/m^2) *Lytechinus variegatus* has been reported in much higher densities

Figure 2. The four prominent organs of a sea urchin: from left to right gonads, gut, Aristotle's Lantern, and test.

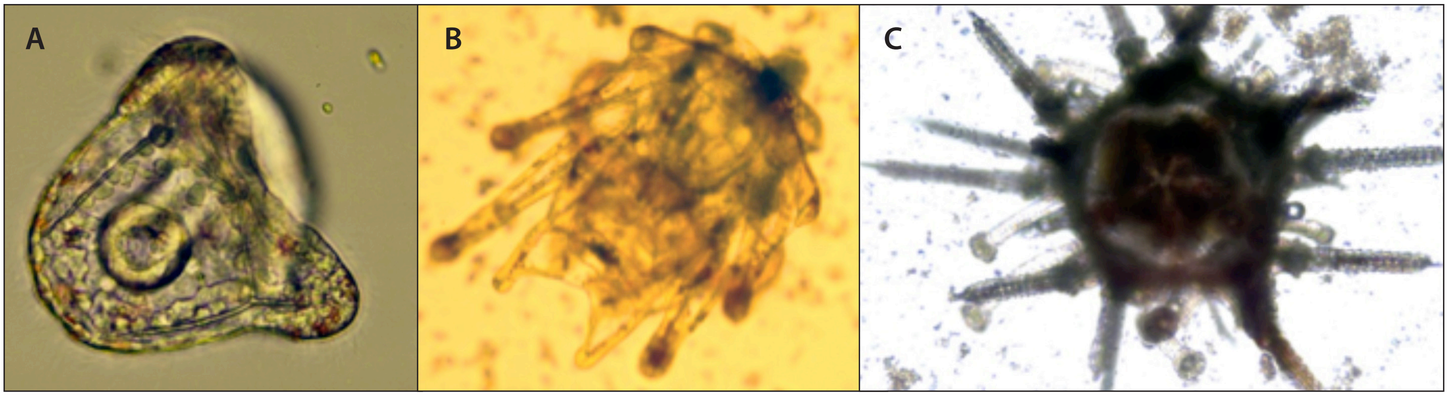

Figure 4. Photos of sea urchin larvae from under a dissection microscope: day 2 echinopluteus (ca. 0.15 to 0.2 mm) (A), day 9 echinopluteus (ca. 0.8 mm) (B), and newly metamorphosed juvenile (ca. 0.5 mm) (C).

ranging from 0 to 48/square yard (40/m^2). An unusual occurrence has been described several times in the scientific literature where *L. variegatus* is found aggregating in very high densities (300 to 720/square yard, 250 to 600/m^2) called urchin fronts. As these fronts move through the seagrass beds, the urchins graze the seagrass down to sand leaving little seagrass behind.

These sea urchins are widely regarded as omnivores that feed on a wide variety of organisms eating just about anything they can ingest. In the laboratory sea urchins have been observed consuming a wide variety of plastics, electrical wire covers, and even Styrofoam.

Sea urchins have separate sexes; hermaphrodism has been observed in some species but is relatively rare. Sea urchins are broadcast spawners that release gametes (eggs or sperm) into the water column where fertilization occurs. The reproductive cycle varies widely by species, season, and region but is typically influenced by seasonal environmental conditions. *Lytechinus variegatus* and *T. ventricosus* appear to be seasonal spawners at higher latitudes, reproducing primarily in the spring, but may reproduce year-round at lower latitudes. Prior to spawning, most species show an increase in nutrient storage leading to a pronounced increase in the size of the gonad. As the urchin gets closer to spawning the gonads appear to shift from primarily nutrient storage to gamete production. Gonad size, nutrient storage, gamete production, and reproductive success appear to be strongly related to nutrition and food availability.

Successful fertilization results in rapid cellular division and differentiation within the embryonic urchin that develops into the echinopluteus larvae (Fig. 4A) within the first 24 hours. Echinopluteus larvae are planktonic grazers that feed primarily on unicellular microalgae. The length of the planktonic larval stage varies greatly with species, population, temperature, and latitude and generally lasts from 2 to 5 weeks. When the planktonic echinopluteus develops a rudiment (a tissue that will become the juvenile urchin) it begins to search for an appropriate settlement surface where it undergoes metamorphosis. The appropriate substratum is usually determined by chemical cues and varies with species. Once a suitable substrate is located, the advanced larvae with a rudiment (Fig. 4B) will metamorphose, usually within an hour, into a small urchin (about 400 to 500 µm in diameter) (Fig. 4C). Growth rates vary with species, temperature, and food availability. Wild populations of *L. variegatus* will reach adult sizes of 1.5 to 3 inches (40 to 80 mm) within one to three years and *T. ventricosus* will reach adult sizes of 3 to 6 inches (80 to 150 mm). Both species appear to be able to reach reproductive age within one year if enough appropriate food is available.

The basic premise of sea urchin aquaculture is to grow a sea urchin that has large gonads of appropriate quality for the roe market. Though this seems relatively straightforward, it is a very complex and challenging process. Sea urchin gonads vary in size based on season, reproductive status, food availability, food quality, and other factors. Physical factors including temperature, salinity, oxygen, and light regime also affect gonad development. These and other unknown factors may affect characteristics of commercial gonad quality, including color, taste, and texture, all of which affect gonad desirability and market price. Unfortunately, the gonads cannot be assessed without opening the urchin (killing the animal). Sea urchin aquaculture is challenging but the rewards are potentially high with quality roe being sold at 40 to 100 dollars per pound with high export potential.

Sea urchin aquaculture is in its early stages worldwide and there is currently no commercial production involving closed cycle culture on land from larvae to adult with any species. Many sea urchins harvested in historical fisheries reside in cold water regions and their slow growth rates make the economic viability of closed cycle aquaculture challenging. Stock enhancement aquaculture (seeding small urchins into natural habitats) has been successfully employed and is ongoing in Japan, Chile, Canada and in some regions of the U.S. Consequently, reliable methods for captive spawning and larval culture are available but large deficiencies exist in the methods for the grow-out phase of production. Another form of aquaculture being practiced with sea urchins is gonad enhancement. In this approach, juveniles or small adults are harvested from wild stocks (or produced from culture), held in cages or other enclosures, and provided with large amounts of food to enhance gonad size and quality. For example, growout of juveniles in suspended cages has become common in China, but still requires the harvest of local kelp populations to feed these urchins. In the southern region of the U.S, no species have been cultured commercially at this time. Because of their rapid growth cycles, *L. variegatus* and *T. ventricosus* have strong potential as aquaculture species in this region. These species can be cultured in natural flow-through or synthetic sea water tanks, making on-shore culture a possibility.

Culture of *L. variegatus* has not been attempted on a commercial scale, but successful small-scale culture has been achieved. Gravid adult urchins are induced to spawn by injection of 1 cubic centimeter (mL) of 0.1 molar acetylcholine directly into the coelomic fluid through the soft tissue surrounding the feeding apparatus (Fig. 5A). After injection the urchins are placed oral side up (aboral side down) on top of a beaker to collect the gametes (eggs or sperm) that will be released out of the gonadapore (Fig. 5B). Since sea urchins lack secondary sexual characteristics, it is not possible to identify males and females prior to spawning; therefore, several individuals need to be injected to collect the appropriate ratio of male and female gametes.

A gravid female can release over 6 million eggs at a single spawning period. Gametes from each individual should be collected in separate beakers to prevent unwanted mixing or premature fertilization. Sperm can be collected directly from the surface of the urchin and stored on ice for a short period of time (30 minutes), until a female is spawned. Once the gametes are collected, the sperm is activated by diluting with seawater (approximately 1:1000; this also helps to reduce poly-spermy, or fertilization of the egg by multiple sperm resulting in non-viable embryos). Sperm is then added to the eggs to initiate fertilization.

Once fertilization has occurred (apparent by the formation of a fertilization membrane within 5 minutes) the zygotes are placed into gently aerated containers of seawater to allow development to the echinopluteus. At 24 hours the gut of the echinopluteus larvae has fully developed and they are fed a mixture of live unicellular algae at a minimum of 3,000 cells per cubic centimeter each day for early larvae and increased up to 6,000 cells per cubic centimeter for pre-metamorphic larvae. The micro-algae species that have been successfully used include: *Rhodomonas salina, Dunaliella tertiolecta, Phaeodactylum tricornutum, Isochrysis galbana,* and *Cricosphaera elongata*. A mixture of *D. tetriolecta, I. galbana* and *R. salina* can be used to obtain a more desirable nutritional profile. When echinopluteus larvae are ready to settle the rudiment will be clearly visible in the larvae. Larvae can settle on natural biofilms established in the primary culture containers or they can be transferred prior to settlement into secondary tanks containing diatom biofilms to enhance settlement and provide a live feed for new juveniles. Larvae are usually competent to settle in two to four weeks. If the larvae are in good health and biofilm is adequate, metamorphosis is usually successful.

Newly-metamorphosed urchins are approximately 0.4 to 0.5 mm in diameter and readily consume diatoms. Diatoms can be cultured on glass plates in aquaria

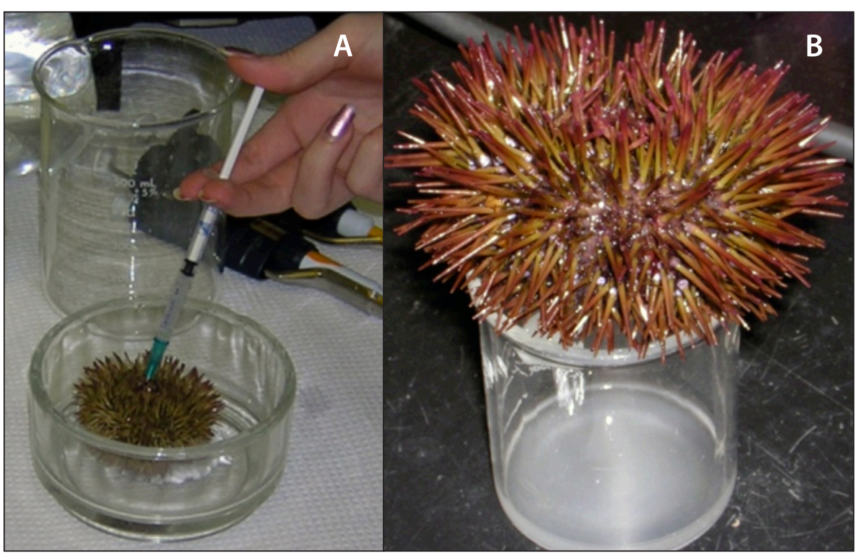

Figure 5. Injection and gamete collection from sea urchins. Sea urchins are injected with acetylcholine through the soft tissue surrounding the oral cavity (A). After injection (male shown) the sea urchin is placed oral side up over a beaker to collect the gametes (sperm in this instance) (B).

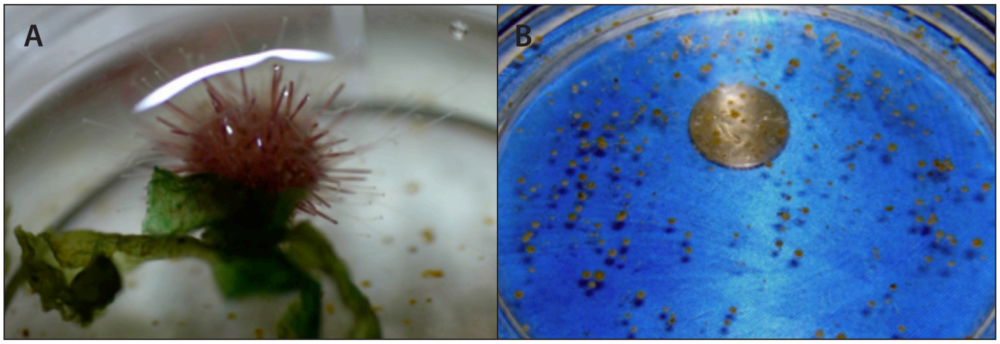

Figure 6. Juvenile *L. variegatus* eating on a ribbon of algal biofilm (A). Recently metamorphosed sea urchins in a standard petri dish (B).

to maximize surface area for settlement and feeding. A standard F2 media supplemented with 3 percent metasilicate is added to diatom tanks to enhance diatom growth. Once juveniles reach 1 to 3 mm in diameter (usually with one to two months) the diet is supplemented with a mixed taxa algal biofilm isolated from natural seagrasses (Fig. 6). Scrapings of epibionts from seagrass leaves are cultured in F2 media to establish the mixed taxa biofilm that is harvested and fed to the urchins. Once urchins reach 4 to 5 mm in diameter (ca. three months post metamorphosis) they can begin to feed on formulated feeds and grown to adult size in recirculating aquaculture systems. For *L. variegatus,* harvestable size can be obtained within one year.

There are no commercially-available feeds for the culture of tropical sea urchins on large scale. UAB and Texas A&M University, however, have developed a formulated semi-purified diet that has been shown in studies to support very good growth and gonad production in *L. variegatus.* This diet has yielded roe of very high quality as judged by professional chefs. Practical diets have not been tested and the cost of feed, feed conversion ratio, and other metrics of production need to be determined for commercial sea urchin production.

Though there are no specialized production tanks or systems for sea urchin aquaculture at the present time (several are in the testing phase), many of the fished sea urchin species are very adaptable and grow well in shallow aquaculture tanks or raceways at stocking densities up to three hundred urchins per square meter. Juvenile *L. variegatus* will readily consume formulated diets and grow to adult size in recirculating aquaculture systems (RAS) with high quality seawater at 68 to 79 °F (20 to 26 °C) and 30 to 35 mg/L salinity. *Lytechinus variegatus* have been cultured successfully in synthetic seawater using recirculating aquaculture systems (RAS). To date, RAS systems have included mechanical filters, biological filters, UV sterilization and aeration. Solid waste removal from these systems is different from those in typical finfish culture. When fed formulated diets, sea urchins produce very dense and round fecal pellets (negatively buoyant) that typically need to be siphoned out of the tanks once or twice per week as they are usually too dense for self-cleaning drains. This waste material can be discarded, but recent studies suggest that sea urchin feces pellets can be readily consumed by Pacific White Shrimp suggesting polyculture of urchins with other species is possible. We anticipate that mature sea urchins can be harvested for processing or potentially sold into live markets as a fresh product at premium prices. A significant advantage of on-shore commercial culture would be the year-round production of the roe as compared to seasonal availability in current fisheries.

Conclusions

The sea urchin fishery in the U.S. is greatly reduced due to overfishing and the relatively slow growth of sea urchins found in cool and cold-water regions. Continued strong demand and high prices for sea urchin roe has stimulated an interest in aquaculture. Sea urchin aquaculture is in its infancy, though some species of sea urchins associated with historical fisheries are currently being aquacultured in other parts of the world using stock-enhancement and gonad enhancement techniques. Two species of sea urchins found in the southern region of the U.S. have fast growth rates and will reach reproductive size in one year or less under culture conditions. The closed cycle culture of *Lytechinus variegatus* has been successful in small scale demonstration facilities and the roe has been judged as being of high quality for existing markets. More information is needed on aquaculture feeds and nutrition, culture optimization, and the economic analysis of sea urchin aquaculture before these species can be commercialized. Nevertheless, there appears to be strong potential and interest for the future aquaculture of these species.

We would like to thank Dr. Addison Lawrence and Texas A&M Agrilife for contributions in the development of sea urchin diets. We would also like to thank Dr. John Lawrence for his knowledge and contributions in understanding sea urchin biology and ecology.

Additional Readings

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