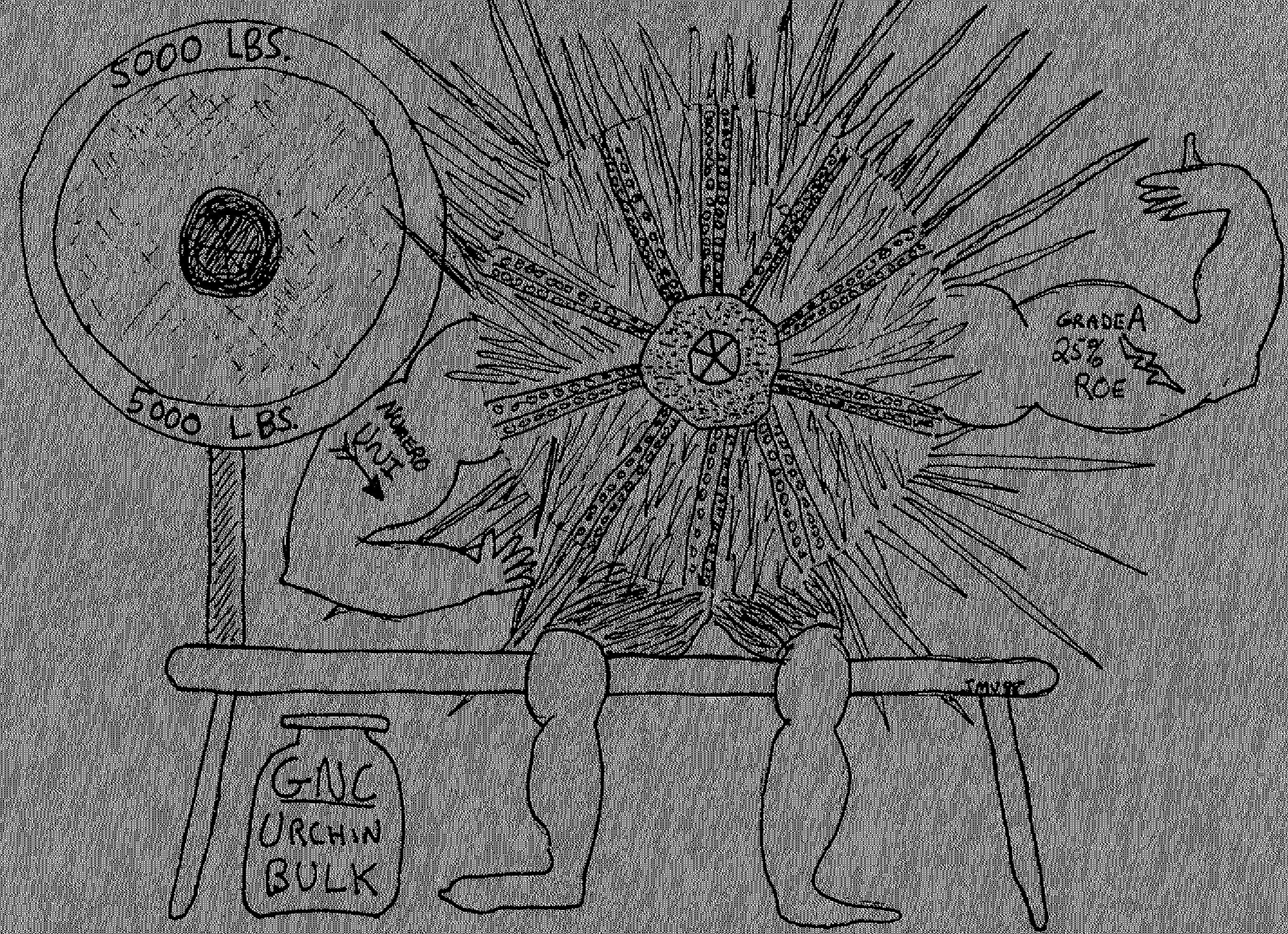
Feasibility of Urchin Aquaculture in a Cage System



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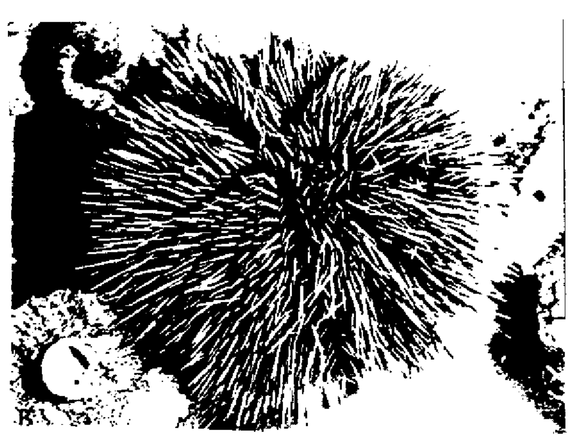
Abstract

The **F**easability of **U**rchin Aquaculture in a **C**age **S**ystem was a student research and design project that studied the bulking process of urchins in several proposed systems. Sea urchin roe has long been considered a delicacy in both Japan and France. Due to overfishing in their waters the Japanese are now forced to import urchins to meet the demands of the market. Because of the situation in Japan, harvesting urchins became a profitable fishery in the northeastern United States. In the 1980s this led to a local decline in the green sea urchin, *Strongylocentrotus droebachiensis*, population.

A prototype cage was created for the initial, short term bulking of the urchins. Twelve hundred pounds of urchins were bulked in the cage for a period of ten weeks. This resulted in an average percent roe content of 20.41% which represents an increase of 6.91% when compared to the roe content of 13.5% taken when they were first collected. The survivorship of the urchins was greater than 95%. These two statistics prove the feasability of urchins is a cage system. The knowledge gained from this prototype system was considered when designing a second, better system.

Using a modular type system as a model, an economic analysis was performed using hypothetical prices to study market feasibility and profit oppurtunities. Depending on the scenario, an investment in a bulking operation would yield 35-130%. This project indicated that urchin aquaculture could be performed on a large scale and prove to be profitable.



***Strongylocentrotus droebachiensis*,**
The Green Sea Urchin

Table of Contents

Why Urchin Aquaculture?

For hundreds of years sea urchin roe, or uni, has been considered a delicacy in Japan where it is eaten raw over rice or wrapped in seaweed. Japan is the largest consumer and importer of urchin roe in the world. In the past, Japanese waters readily yielded the majority of the country's demand for uni; but the populations of sea urchins found there have been steadily declining since 1987. As a result, Japan's share of the world catch has fallen rapidly from 73% in 1975 to just 17% in 1992 (Sonu, 1995). Thus, there is an increasing demand from Japan for high quality imports of urchin roe.

Since 1988, the United States has been the world's largest harvesting nation of sea urchins, and was the largest supplier to Japan in 1994 (Sonu, 1995). In the 1980's, the majority of this resource was obtained from the North Pacific off of California, but poor harvesting practices have since led to significantly decreased populations in these waters as well. Due to such uncontrolled over-fishing in Japan and California, there is an increasing pressure for urchin harvesting to meet the increasing Japanese demand. This has opened the doors to a highly profitable urchin industry in New England. Evidence for the high market value of urchins was displayed from 1975 to 1994 when imports increased more than three times in volume and 25 time in value (Sonu, 1995). These increased imports result from a strong demand, the declining harvests of Japan, and the strong yen.

However, the market can be volatile. Wholesale prices for fresh roe vary widely and depend on its quality, the time of year, and supply. The quality of the roe is of great importance, with the highest prices being paid for firm unbroken roe that is bright yellow or orange in color. The United States is able to maintain a powerful position in this market because of its harvesting season from the late fall through the early spring, which falls opposite of those of competing countries, who harvest in the summer.

When word of this profitable industry reached the East Coast of the United States, fishermen in Maine rapidly altered their attitudes concerning sea urchins. Green sea urchins, *Strongylocentrotus droebachiensis*, found along the Gulf of Maine were once despised by the local lobstermen because they scavenged lobster bait, but they have quickly become Maine's second most valuable marine harvest.

Maine profited from the export of urchin roe as far back as 1933, and was the only East Coast State with a commercial urchin fishery until the 1990's. In 1987, the first wave of Japanese urchin buyers came to Maine in search of new sources due to the shrinking supplies in Japan, California and other established fisheries. Within three years word of the high prices being paid for uni attracted many harvesters, again leading to a decline in populations. In 1994, dockside sales of sea urchins reached a total of $33 million. Harvesting procedures utilized were both diving and drag netting, either of which can have detrimental effects on urchin populations.

Drag netting is also extremely harmful to the benthic environment. In the 1980's the annual urchin harvest yield plummeted from a peak of 30 million pounds to 7 million before the state of Maine realized the necessity to institute size limits, licensing and other regulations.

In 1994, Maine began placing serious limitations on catching of sea urchins. Only those that are two inches in length, exclusive of spines, or larger can be collected; this is in addition to a closed season from May 15 to August 15, and prohibited night time harvesting. Because of this divers now must travel farther and dive deeper in order to find undepleted supplies of urchins which possess a high roe yield (NY Times, 1/2/96). Other states and countries which harvest sea urchins, such as California, Alaska, British Columbia and Nova Scotia, are required to monitor their catches, whereas Maine and New Hampshire are only required to attain licenses and abide by the regulations. This increasing human plague on marine resources calls for alternative methods to allow the industry to thrive. Thus, there is now a recognized need for aquaculture as a sustainable method to meet the expected world demand for high quality urchin roe.

General Urchin Biology and Behavior

Sea urchins, of the Phylum Echinodermata, Class Echinoidea, are conspicuous members of the macrobenthos of various marine environments (Lalli and Parsons, 1997). Native to the east coast of the United States is the green sea urchin *Strongylocentrotus droebachiensis,* however various other species are found on rocky shores, kelp beds and coral reefs. Urchins have a spherical calcareous test that is divided into five plates arranged in rows from the dorsal to ventral poles. Covering these plates are the spines that serve for the animal's orientation, locomotion, protection, and predation. The urchin's body can also be divided into aboral, or dorsal, and oral, or ventral, hemispheres. The oral hemisphere possesses the mouth which is directed downward toward the substratum. The anus is located atop the animal in its aboral hemisphere. Protruding from the shell are also many tube feet, or podia, that are used for attaching to substrates, and in feeding (Rupert and Barnes, 1994).

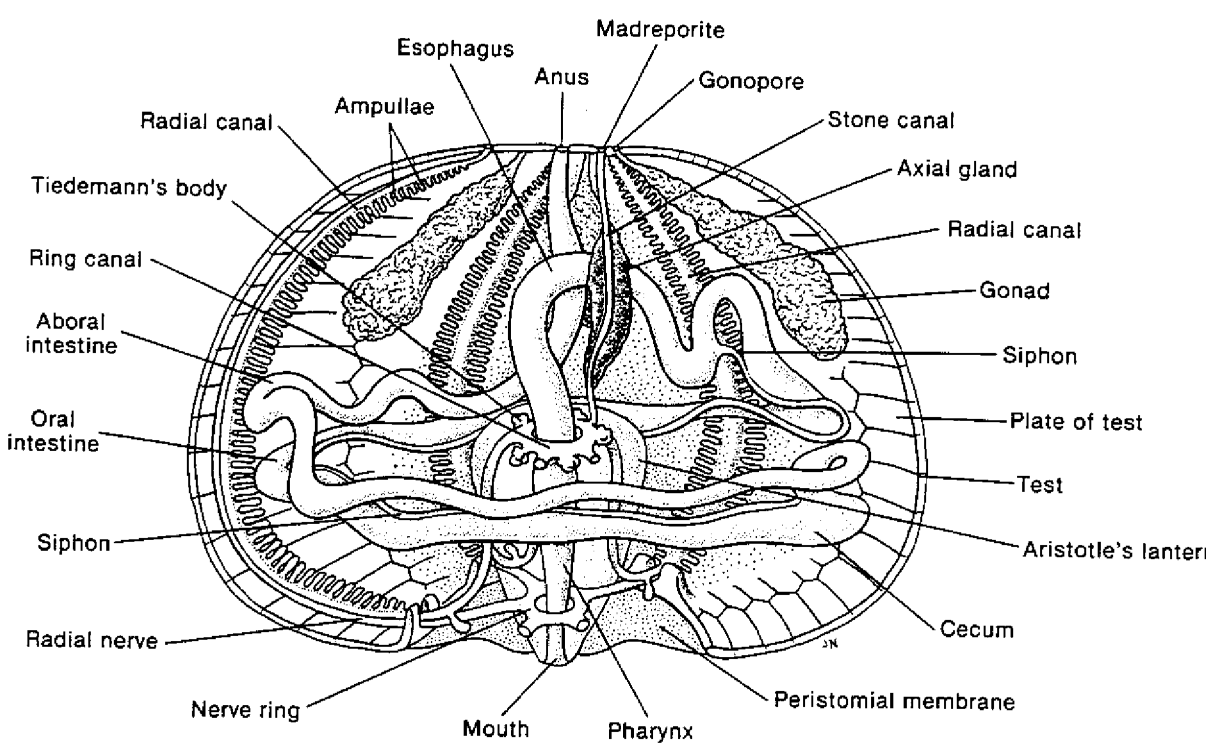


Figure 1: Anatomy of a Sea Urchin

The internal cavity is filled with 5 skeins of roe (Internet). This roe is what is deemed valuable in the market and enlarges to displace the rest of the internal organs during the bulking season (Figure 1). On the east coast of the United States this bulking season spans from late fall to early spring. It is a period characterized by rapid weight gain and food intake. This weight gain occurs in the gonads in preparation for reproduction in late winter or early spring.

It has long been believed that the green sea urchin is a herbivore, feeding solely on encrusting algae and kelp. However upon examination of the gut contents, remnants of sand dollars, sea stars, bryozoans, hydrozoans, sponges, tunicates, kelp covered with the bryozoan *Membranipora*, and mussels have been found, indicating that the green urchin is omnivorous (Nestler and Harris, 1994). This feeding strategy allows for the maximization of growth and reproduction in an urchin. Urchins feed using an apparatus composed of five calcareous plates and many teeth, referred to as Aristotle's Lantern (Figure 2). It is controlled by muscles that protrude and retract it. Most urchins graze upon hard substrate, scraping off encrusting algae. Feeding on drift algae and kelp as well, they require the use of their dorsal spines and tube feet to catch and maneuver it towards their mouths.

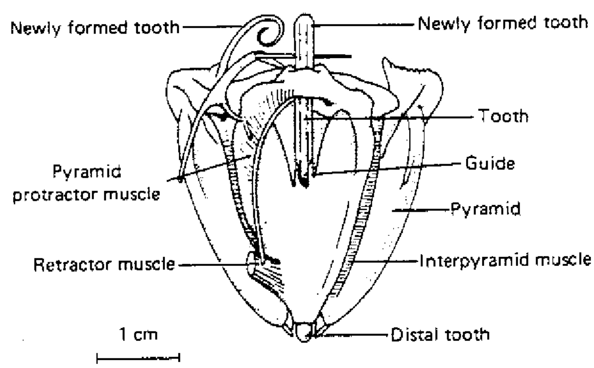


Figure 2: Aristotle's Lantern

Behaviorally urchins can be very particular creatures. They prefer areas of high current and will relocate themselves to take advantage of it. It has been observed that urchins will orient themselves in open coast, high wave action environments (Simoneau et al. 1994). Urchins will direct their movement according to their feeding activity. In the natural environment urchins are found in crevices between rocks, as well as other vertical surfaces, such as in kelp beds. Sea urchins behave antagonistically in these kelp beds by destroying them. This phenomenon has been clearly displayed in the ecology of the rocky shores of Nova Scotia. Before 1968, rich kelp beds thrived along the coast. However in the years to follow *Strongylocentrotus droebachiensis* became more abundant, creating barren grounds dominated by urchins where kelp once lived (Figure 3). These barren grounds extended along more than 400 km of coastline by 1980. As a natural feedback, the urchin populations were dissipated by disease in the 1980s, and kelp was allowed to reappear. The removal of natural predators has allowed the urchin populations to once again thrive (Lalli and Parsons, 1997).

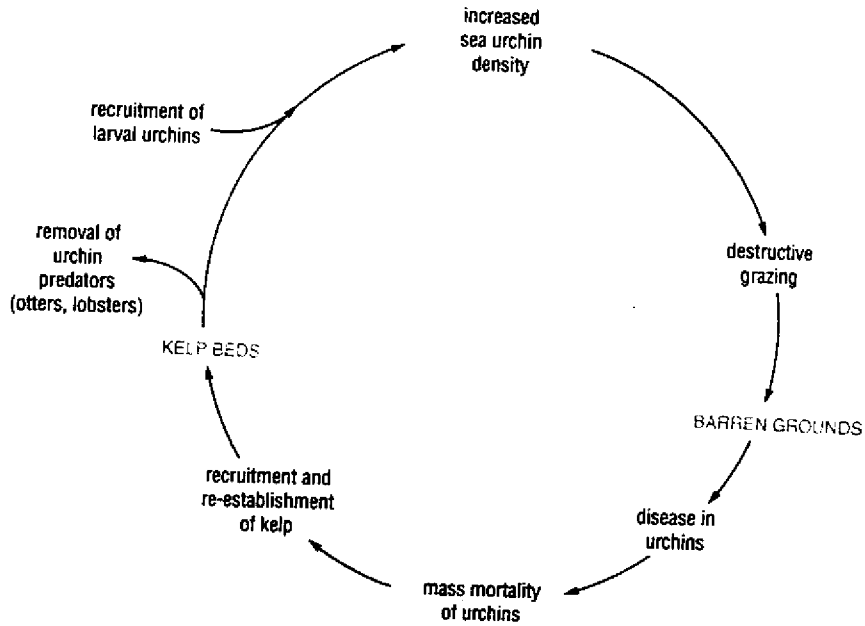


Figure 3: Kelp bed/Sea urchin Feedback Cycle

Project Objectives

The objective proposed for this project was to develop a biologically and technically sound containment system for holding and bulking large quantities of sea urchins. Before such a cage system could be designed the survivorship of sea urchins in a cage system needed to be determined and compared with the survivorship of those farmed on a ranch. Once sufficient information concerning the biology and bulking of urchins was obtained, a durable and economical cage system could be manufactured.

The goals of the project dealt with the bulking and survival of the urchins in a cage system. Maximizing the roe content was a top priority because it is the valuable part of the urchin. Keeping the urchins healthy and free of disease was also important in order to minimize losses. The cage needed to be manageable by the typical urchin rancher for both maintenance and harvesting. The cage materials had to be inexpensive and allow for easy assembly. An efficient system would maximize the number of urchins contained while minimizing the space required.

General Approach

A preexisting cage used for the initial prototype had been previously built for another aquaculture project. It had a 12' x 4'4" x 4'6" rectangular frame made of heavy duty PVC pipe covered with thick lobster wire, and had floats at either end which supported its weight. This cage was modified to meet the needs of bulking the urchins and was then hauled on a university logging truck to the University of New Hampshire's Coastal Marine Lab in New Castle, NH. With the help of the Coast Guard, located at the same site in New Castle, the cage was launched and secured to a dock on November third.

Fifteen hundred pounds of urchins were collected in late October near the Isle of Shoals. They were placed in the cage with our chosen food source for several weeks. During this time subsampling of the urchins occurred and growth data was collected. The cage was then beached and disassembled again, with the help of the Coast Guard. The urchins were removed and statistical measurements were taken on a portion of the population.

After reviewing the pros and cons of the original cage system, new designs were brainstormed. Three modular cage systems were constructed and placed at the Wentworth Marina in Newcastle. The feasibility of each of these cages was determined in order to make final conclusions about the necessary characteristics of an urchin holding and bulking raft system.

Design Criteria

1. Behavior Considerations:

In order to create a cage design beneficial for bulking, specific behaviors of the urchins had to be taken into consideration. Urchins orient towards and prefer a high amount of flow, which provides them with an ample supply of oxygen. This flow is also beneficial because it prevents the buildup of bacteria that often cause disease in a closed system. Urchins have the ability to climb and tend to hang vertically on a substrate rather than rest horizontally. Urchins excrete their waste through an opening located centrally on the dorsal side. The cage system was designed by taking into consideration these behavioral patterns and trying to simulate their positioning and feeding habits in nature.

2. Cage Considerations:

The cage needed to be designed so that the greatest surface area was exposed to the highest amount of flow possible, without creating a situation in which the urchins would form a flow blockade. It was necessary that there be enough space between the partitions to allow the urchins room to feed and maneuver. The urchins also had to be positioned extremely close to their feeding surface, approximately one-quarter of an inch. The materials chosen had to protect the urchins from predation and be light, to prevent excessive buoyancy needs. The final essential consideration was that the cage be equipped with easy access for feeding, such as a flip top.

3. Feeding Considerations:

When creating an artificial feeding system to be employed in the cage, not only the urchins feeding abilities were considered but also the time constraints of an urchin harvester. A material that the urchins were unable to eat through needed to be used, and in addition it needed to be placed close enough to the urchin so they were able to reach the food source with their mouths. When eating, urchins consume food through an opening on the ventral side using their mouths. They are also able to secure food passing by them using their tube feet and spines and pull it to their mouth. The feeding system also needed to be double sided in order to accommodate the feeding of urchins on each side of the feeding slot.

To maximize efficiency, the feeding system needed to be easy to deploy and withdraw from the cage. Preparation and application of the artificial food source needed to be possible in large amounts and able to be made ahead of feeding time.

Initial Cage Design

The goal of the prototype bulking system was to simulate a small-scale system employed at the UNH Coastal Lab. This small-scale system consisted of vertical slots of lobster wire that were oriented perpendicular to the flow of water. The urchins would attach themselves to the vertical surfaces, where they would have access to an artificial diet. This diet was coated onto window screens that could be slipped between each vertical slot. This method of bulking was tested by the UNH Coastal Marine Lab (Christa Williams). The results showed a five percent average increase in the percent roe content when using this approach (Harris 1998, unpublished data).

The large scale bulking system was constructed by modifying a pre-existing cage to minimize the cost of the prototype unit. The frame extended 12', with a width of 4'6" and a height of 4'4", giving a total working volume of 237 cubic feet. The structured frame was constructed entirely of 2" PVC piping, utilizing T-joints and elbow joints. Special water resistant glue was used to secure the piping to the joints, providing a permanent seal to the structure. Twelve-gage lobster wire had already been installed on each wall of the frame, enclosing the 237 cubic feet of space, creating a protected environment.

Two 300-pound floats had also been attached to the short-side ends of the unit, providing the buoyancy forces necessary to float the empty cage.

A few minor adjustments were necessary to meet the design criteria of the initial holding and bulking system. In order to load the urchins into the cage, the permanent top to the cage had to be remounted. Cutting the top off and reattaching one end using plastic tie wraps simulated a hinged door, providing a feasible entry into the system. The wire face that spanned the long side of the cage had to be temporarily removed to assist in the partition installation process.

The surface area required to meet the chosen urchin capacity was calculated to be 60 square feet. To fulfill this need the existing cage was divided into two sections. Each section was then divided into nine slots, each varying in width from four to six inches. The variation in width was used to determine the minimal working space necessary to successfully bulk urchins.

The slots were fabricated from 16-gage lobster wire. The dimensions for each partition were 44" x 54", with a 2" 90 degree bend located along the bottom and sides of the partition (Figure 4a). In addition, two 3" x 3" holes were removed from the bottom corners of the partitions to provide enough room for the 2" diameter PVC frame. A bending break, pedal shear, dikes, and wire clippers were used to mass-produce the 36 partitions necessary to form the slots. Tie

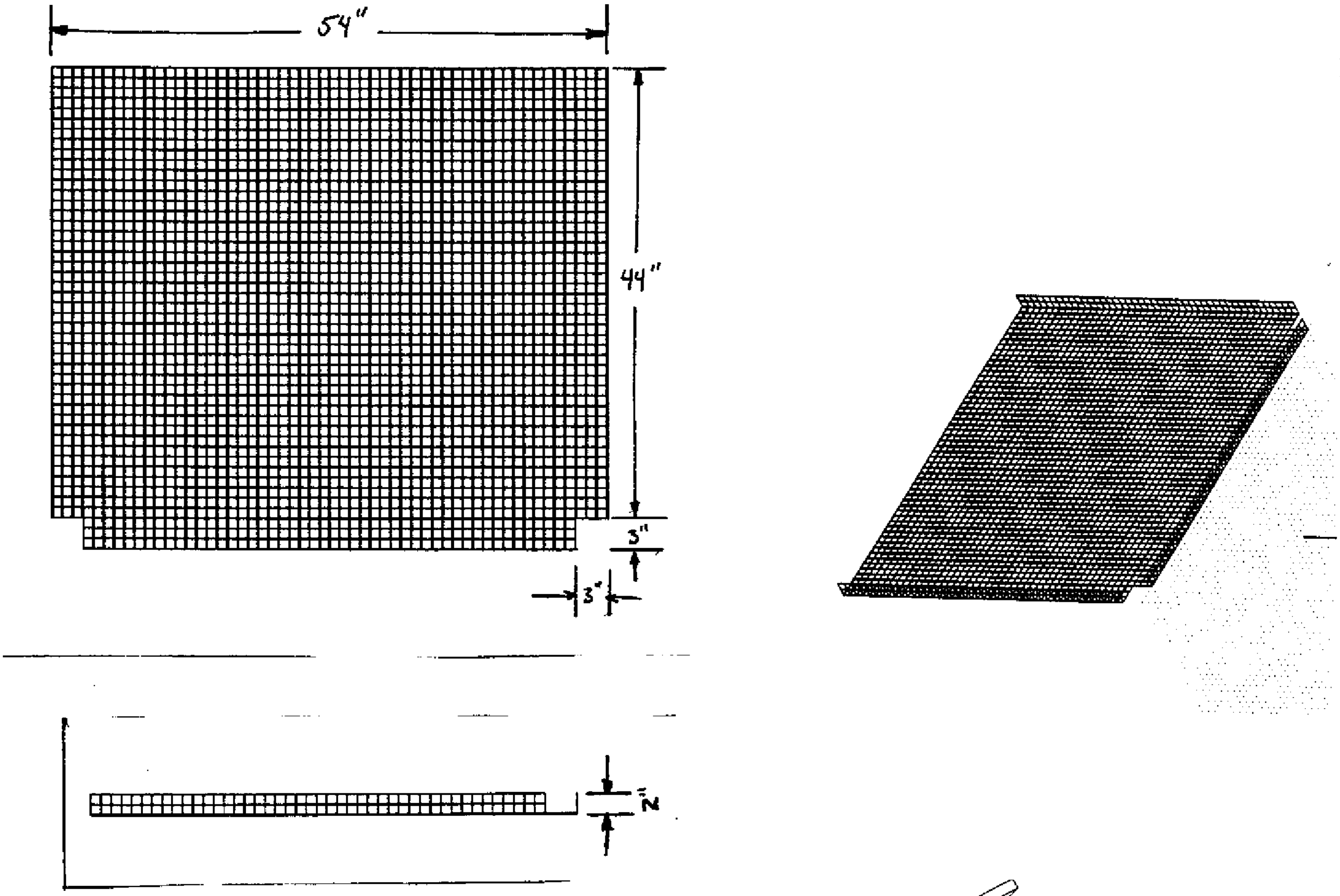


Figure 4a: Partition dimensions

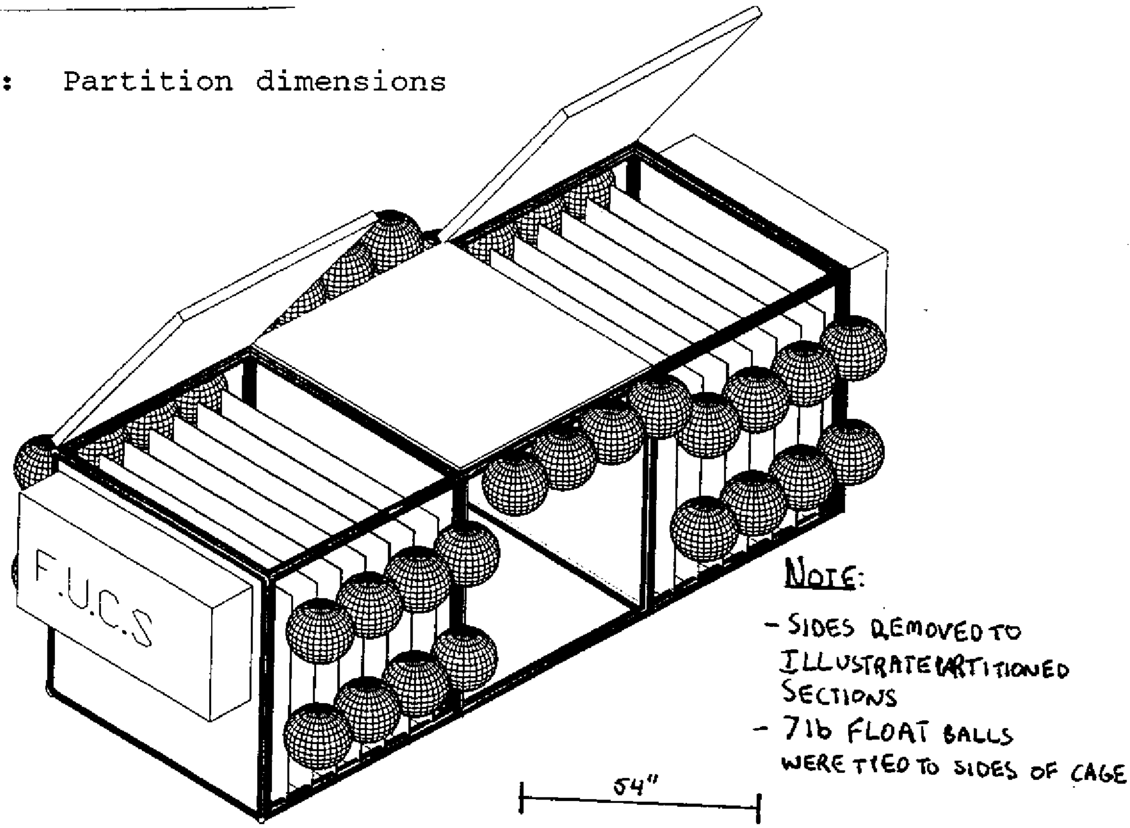


Figure 4b: Mechanical Drawing of the Prototype Cage

wraps were chosen to secure the ends of the partitions to the cage. The tensile strength, ease of application, cost, and corrosion resistance associated with the plastic tie wraps were the deciding factors.

The installation of the partitions was relatively simple. With the long side of the cage temporarily removed each partition was manually inserted and secured to the opposite side and bottom of the cage with tie wraps. After each section was filled, the remaining side of the cage was secured to the partitions and reattached to the frame of the cage.

Once the holding environment was completed, the cage was weighed to determine the buoyancy needed to float the system. The weight of the cage was determined at the Ocean Engineering building using a load cell where its weight was estimated to be approximately 800 pounds. Knowing the fact that urchins weighed one-fifth the amount in water of what they do in air, an additional 400 pounds had to be added to the cage when filled to its maximum urchin capacity. These two factors, combined, yielded a total working weight of 1200 pounds.

In order to meet this standard, an additional estimated 600 pounds of floatation had to be added to safely operate the system. The materials of the cage provided an estimated buoyancy force of 170 pounds, decreasing the added floatation requirement to 430 pounds. To compensate for the difference, sixty 7-pound floatation balls were attached around the cage

(Figure 4b). Four docking ropes were tied to the skeleton of the cage, completing the prototype bulking system.

Site Chosen and Why

For the duration of the experiment, the cage was docked at the United States Coast Guard Station. This area was chosen for many reasons; The foremost being that no rental fees were charged to the project for use of the Coast Guard's docks and boat house. A nearby drive-up beach, made the site ideal for transportation, launching and break-down of the cage (Figure 5).

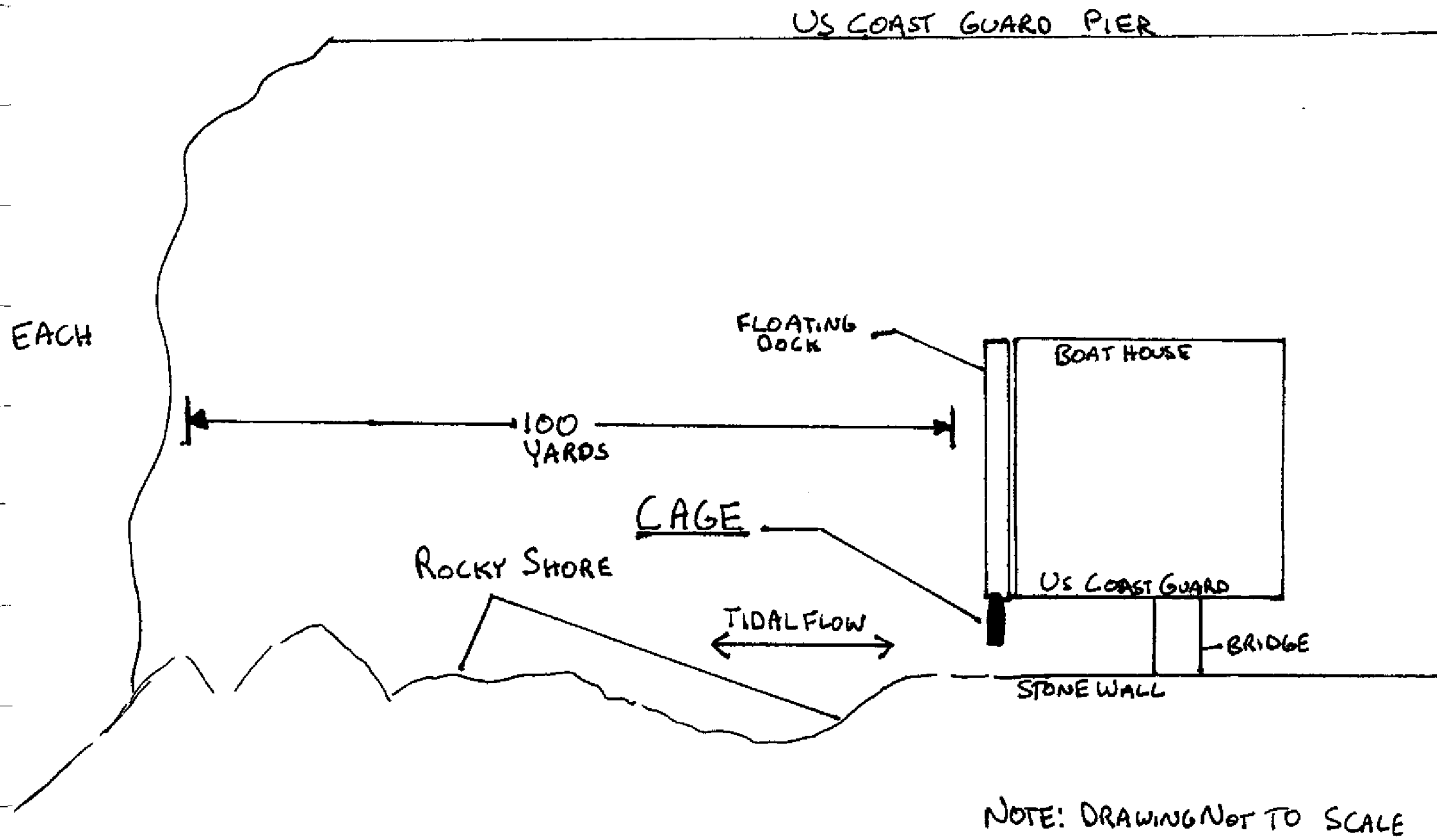


Figure 5: Location of cage site

The Coast Guard also aided the team with the in water transporting of the cage from the beach to the boat house dock. Their extra man power and boat proved crucial to the cages successful launch.

The dock to which the cage was fastened, floated in 5-6 feet of water at extreme low tide. This was enough depth to ensure that the cage, and the urchins, would always be submerged. The current through the channel was a steady 2-3 knots. Combined with a naturally occurring eddy, this current provided more than ample flow for the urchins.

The location of the UNH Coastal Marine Lab in proximity to the Coast Guard dock, the site of the cage, allowed for easy transportation of food and use of lab facilities for roe sampling. Because all SCUBA trips departed and arrived at this dock, the time for transportation of the urchins to the cage was significantly decreased.

Urchin Collection and Sites

The sea urchins were collected from the Isle of Shoals, located approximately 6 miles east of Portsmouth, New Hampshire. The three dive sites were located off the East Coast of both Star and White Islands (Figure 6). These locations were chosen because of their relatively calm waters, shallow depth (40 ft), and most importantly, abundance of urchins.

The urchins were collected using a rake and bag system similar to that used to collect tree leaves in the fall. The collecting equipment consists of a hand held garden rake and

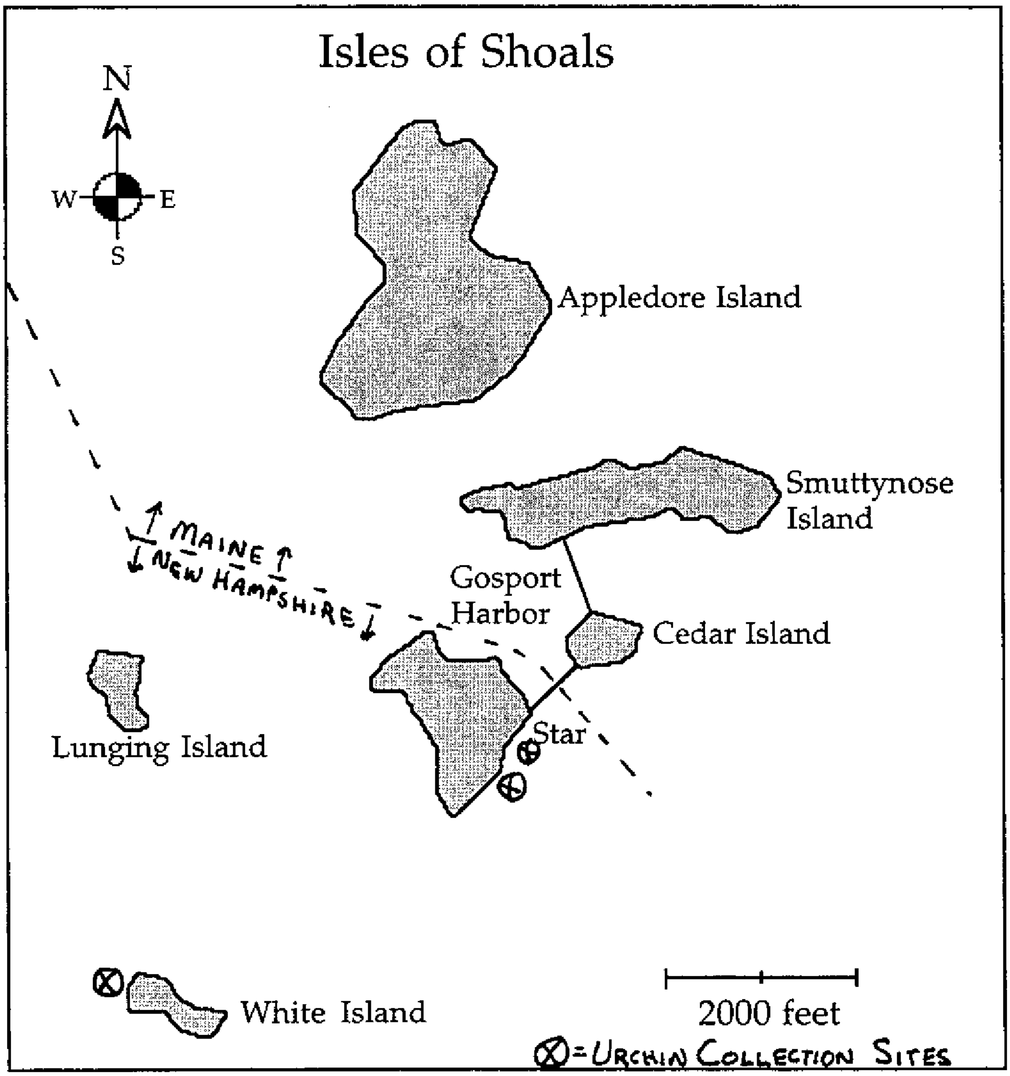


Figure 6: Map of the Isles of Shoals

numerous mesh holding bags. The garden rake provides the wedging ability necessary to pry the urchins from their substrates while preventing damage. The mesh bag provides a means of containment which allows for circulation, preventing suffocation of the urchins.

Three dives were conducted at each site with a crew of two commercial divers. The average collecting time for each dive was forty-five minutes, yielding an average of 85 pounds of urchins for each dive per diver. After the three dives were completed, the bags were hauled back to the UNH Coastal Marine Lab. The illegally sized urchins, those less than two inches in diameter, were sorted out, decreasing the total amount of urchins by 300 lbs. This yielded a three trip total of 1200 lbs of legal urchins.

The three trips provided the project team with first hand knowledge of urchin ecology in their natural environment. The urchins were scattered in tightly packed groups across the ocean floor. They were often discovered in cracks and crevasses along the rocky bottom, which seemed to provide a natural barrier for protection. The urchins seemed to migrate towards the vertical sides of the boulders, a characteristic that was weighted heavily during the design process of the holding/bulking cage system.

Technical Aspect of Artificial Food

As in any aquaculture scenario, an artificial method of feeding is most often desirable. Researchers at the UNH

Coastal Marine Lab have been using a feeding method for urchins which has been very successful. Water is boiled, then mixed with a soy based nutritional powder and pectin. Then small pieces (6" x 18") of window screens, which are used as a substrate, are dipped in the mixture and hung to dry. The screens are then inserted into the laboratory holding system, providing enough food to last for roughly three days.

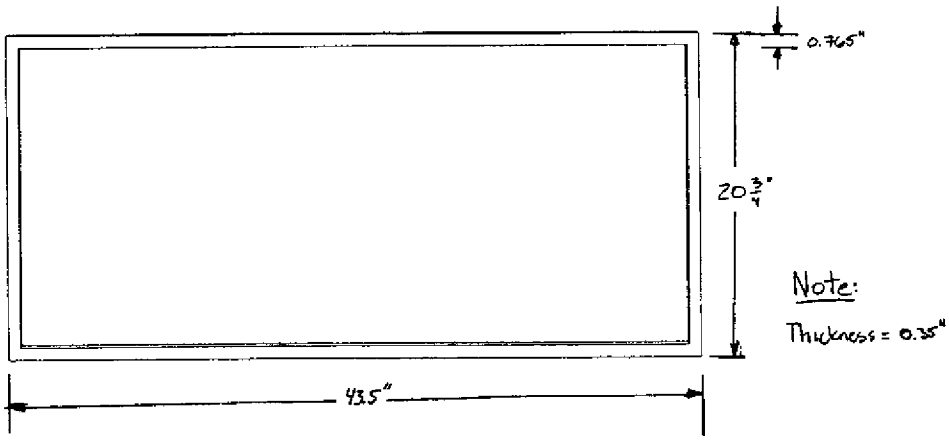


Figure 7: Screens used in feeding

It was theorized that this method could be expanded to work in the cage system. The window screens would be 20.75" x 43.5" and be framed with commercial aluminum framing (Figure 7). The screening was attached to the frames using two different adhesives. The first used was "Marine GOOP", but it was both expensive and time consuming to apply. The final adhesive utilized was hot glue. This worked well and was much more cost-effective than the previous method.

Because the food recipe had to be expanded to accommodate the increased number of sea urchins, a three burner, 150,000 Btu, gas stove was acquired to boil the water. Originally, it was fitted to be run on natural gas, but was reconfigured to be fueled by a standard "grill-size" propane tank. The artificial food cooked quickly on this stove.

There were however, many difficulties with the application of the food to the screens. The dipping method that was previously utilized did not work well with the framed screens. This was due to surface tension problems induced by the stiffness of the frame. Another major problem was the cooling of the mixture due to the increased surface area of the screen. The pectin would start to harden before the application was completed.

Overall, the screen-type artificial feeding method was unsuccessful and was never applied to the cage system. To ensure rapid bulking, another feeding method was utilized.

Feeding Method Utilized

Over a period of three months, the urchins were fed using drift algae collected at Odiorne Point in Rye NH. Standard fish boxes and netted bags were used to collect and store the algae. The main types collected were *Fucus*, *Ascophyllum*, and *Laminaria*. Each fish box or bag holds about

100 lbs of algae. The urchins were fed every two weeks during which they consumed an average of 400 lbs of drift algae. Between feedings, the algae was stored both in and out of the water. The bags that were stored outside became frozen and dried up, causing the algae to lose its nutritional value. However, the algae that was stored in the water remained fresh for longer periods of time, allowing quick access to the algae during feeding sessions.

During each feeding session, the urchins were scraped off the sides of the partitions with a plastic oar. This allowed them to fall to the bottom of the cage, so the algae could be packed into the partitions to maximize consistent feeding. Within a day, the urchins had climbed back up to the top of the partitions. Without this scraping method, only the top 6" of urchins would receive the drift algae, thus consistent bulking would not be successful.

Subsampling Methods

Throughout the bulking portion of the experiment subsamples of urchins were selected at random and the percent roe content of these urchins was calculated. This was calculated by first weighing the entire urchin, weighing only its gonads and then dividing the weight of the gonads by the entire weight of the urchin. Ten to fifteen urchins were measured during each subsampling and the values were averaged to estimate the percent roe of our population.

Breakdown of Cage and Final Counts

At the conclusion of the bulking period, the sea urchins were removed from the system to enumerate the mortality rate of the urchins in each section. To gain access to the urchins, the cage needed to be completely removed from the water and disassembled. Instead of lifting the system onto the dock, we chose to take advantage of the tidal changes to facilitate the process.

During the peak of high tide the Coast Guard towed the cage to the nearby beach, located about 100 yards from the dock. Using a towline, the cage was yanked up the beach as far as it could go and anchored to the shoreline. The ebbing tide provided full access to the cage on dry land. At this point the sides of the cage were cut away from the frame, providing quick and easy access to each section of urchins.

For each section of the cage, a sub-sample of fifteen randomly selected urchins was taken to measure roe content, to ascertain the success of the bulking system. In addition, the numbers of dead and living urchins were counted in each slot to obtain a mortality rate for the different sized sections. The statistical results of the final roe content were recorded (Appendix 1).

Further Development: Phase 2

Design Criteria:

Much was learned from the prototype cage system. From this was spawned a new set of design criteria. The first aspect was that the cage had to be modular. To avoid the previous beaching method and to allow for lifting the cage, it was decided that the modules would weigh no more than 100 pounds each. This would allow one or two workers to easily lift the cage out of the water at the time of harvest. A series of these modules could be rafted together to compose the aquaculture system.

The second criteria was concerned with the duration of time between feedings. It was theorized that in a large scale operation it would not be desirable to feed the urchins in a particular module more than once a week. Therefore the designed module should hold enough food to last for at least one week.

To ensure consistent bulking, all feeding methods were positioned facing toward the mouths of the urchins. However, due to urchin physiology, the food source had to be kept within 1/4" inch of the mouth. If not done, the urchin would be unable to reach its food. All cage modules had to adhere to this criteria

Three types of urchin diets were chosen to evaluate the most feasible one. The cages had to be designed to utilize these three types of diets. The first two being drift algae and old leaf produce from local grocery stores. The third diet that the modules had to accommodate was a pellet form of the urchin powder that was previously considered for the prototype cage.

Many criteria from the first prototype system were used in designing these later modules. Among these was allowing high flow to reach the urchins, thus minimizing disease and encouraging bulking. Also, the modules should maximize the amount of urchins while minimizing both cost and space needed.

Three Prototype Modules:

Using these criteria, three prototype designs were built. All were capable of holding 50 lbs of urchins and contained their own flotation devices.

The first module was a smaller version of the prototype cage system (Figure 8). It was built almost entirely from lobster wire scavenged from the previous system. It contained three isolated chambers for holding urchins. Each chamber was filled with a different food source (pellets, algae, produce). The top of the cage could open and close allowing quick and easy feeding access. The middle food trough was lined with aluminum window screening so that the pellet diet would not fall through the 1"x 1" square holes in the lobster wire. One end contained drift algae and the other contained spinach. Note: This module does not need to be taken from the water during feeding.

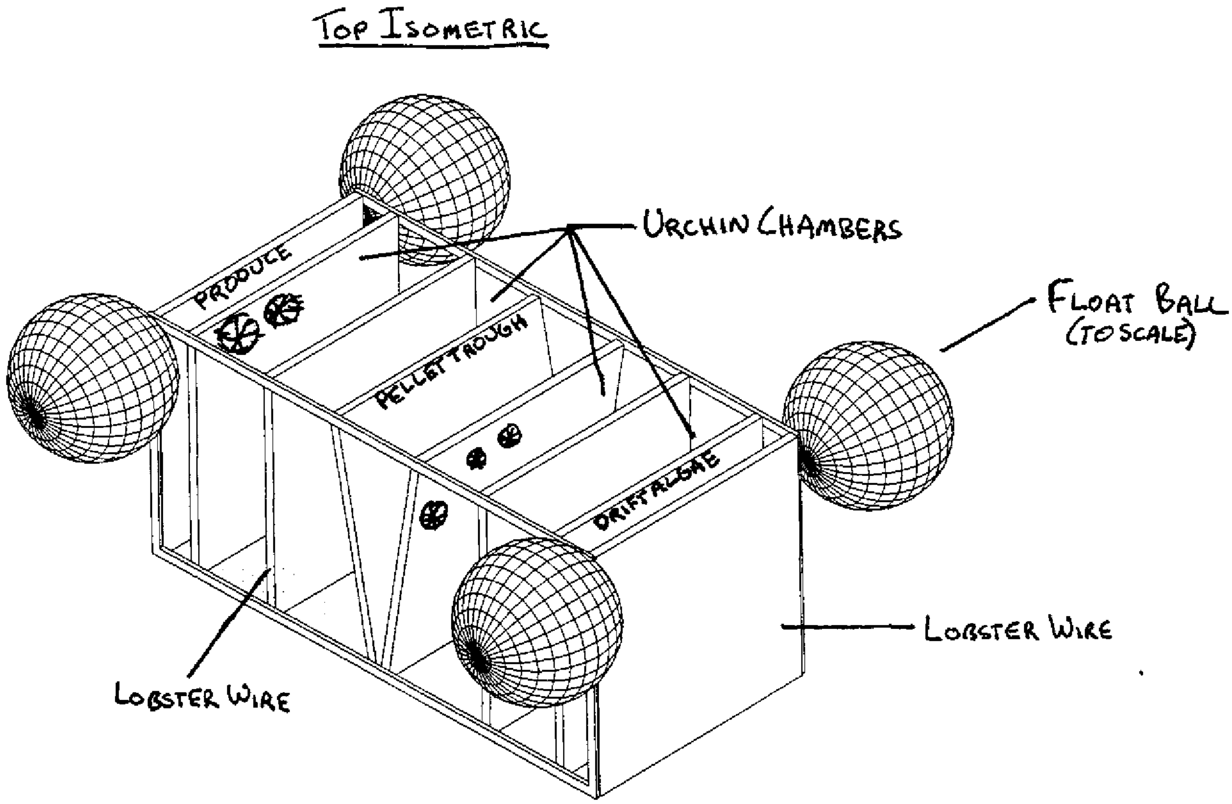


Figure 8: Mechanical Drawing of Modular Slot

The second module design relied heavily on the observation that urchins can hang in an "up-side-down" manner (Figure 9). This allowed the food to be constantly pushed down by the force of gravity toward urchins' mouths. With this design, the urchins were placed on the surface and the cage is placed in the water. Once the urchins had attached themselves with their tube feet to the lobster wire, the cage was flipped over. The urchins remained upside-down. All feeding compartments are on the top of the module, allowing for quick and easy feeding.

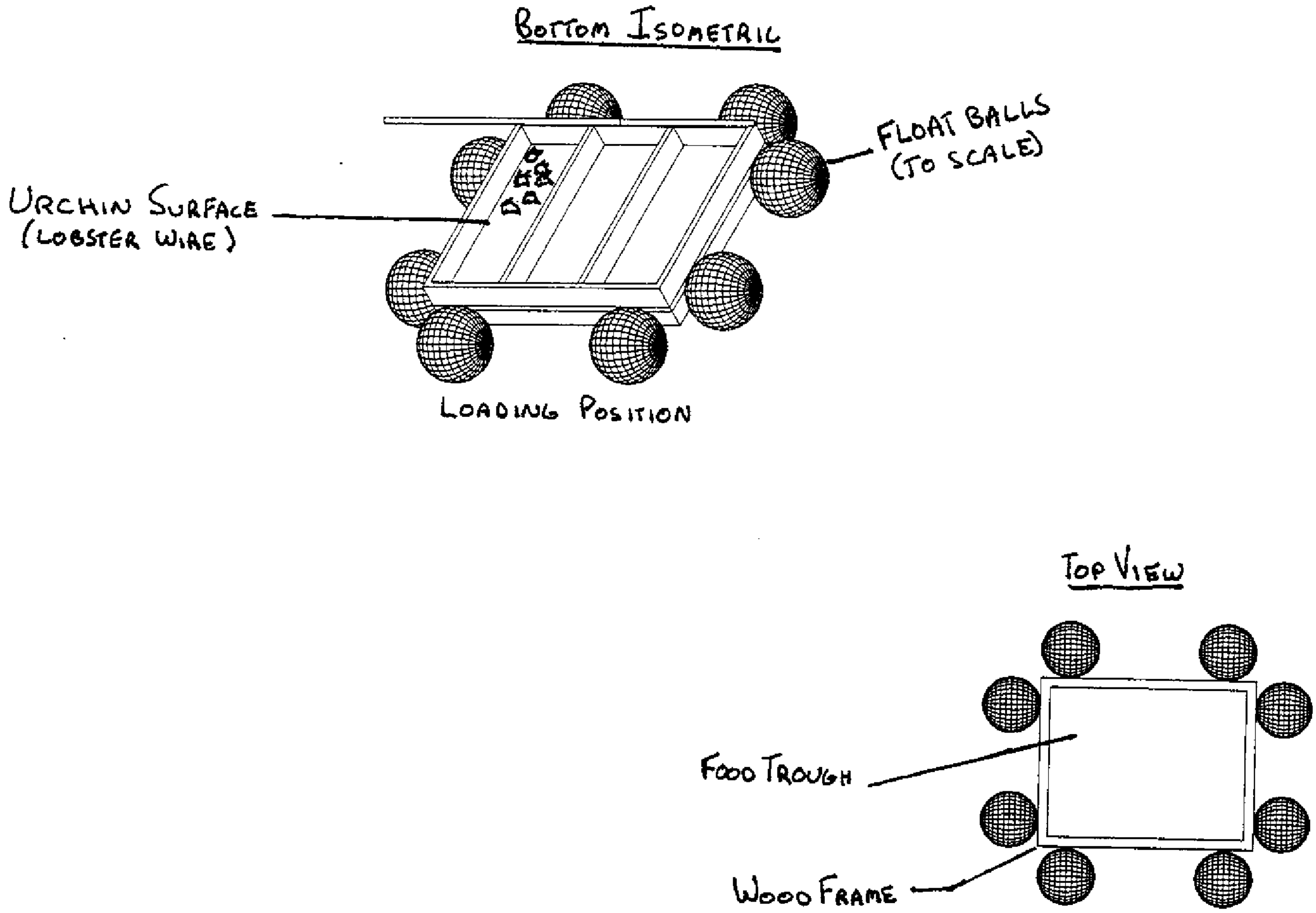


Figure 9: Mechanical Drawing of Inverted Feeding

The third module designed utilized the cylindrical shape that the lobster wire is stored and sold in (Figure 10). The urchins were contained in the cylinder and the food source was placed between the outside of the urchin chamber a plastic sliding cylinder. The food was then compressed by wrapping bungee cords around the outside of the plastic sliding cylinder. This constantly pushes food toward the mouths of the urchins. The end caps are composed of a wood frame and 2"x 2" lobster wire. The lobster wire spacing is critical, because it allows legal urchins to remain in the cage, while supplying insufficient surface area for the urchins' tube feet to hold onto the end cap. This ensures that no urchins will block the flow of water through the cylinder.

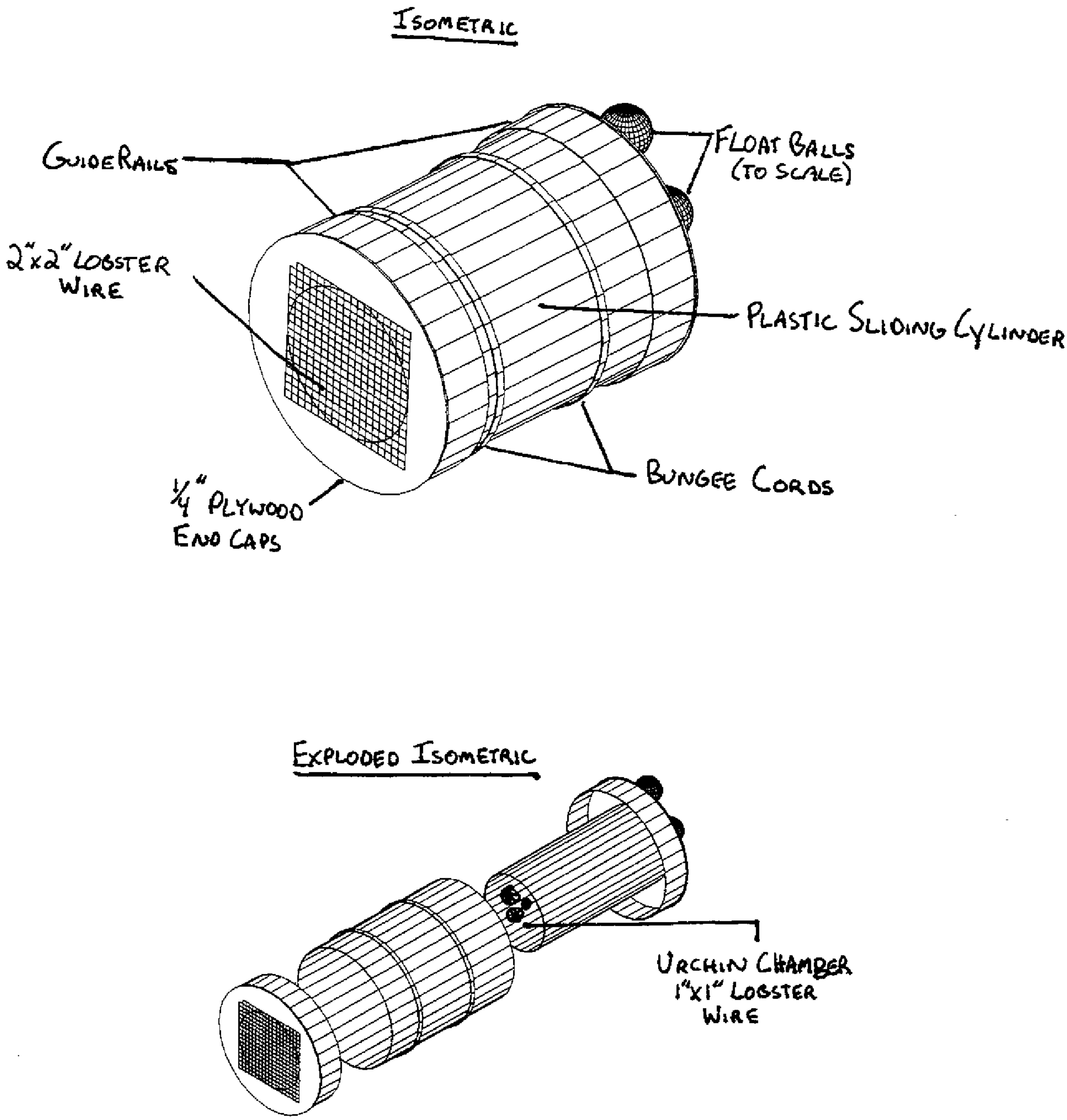


Figure 10: Mechanical Drawing of the Cylindrical Cage

The testing procedure of Phase 2

All three modules were tested at the Wentworth Marina, New Castle, NH. Due to the sporadic times of spawning, roe counts could not be considered as a means of experimentation. Instead, observation of food consumption rates and disease was performed.

DISCUSSION

Feeding considerations learned

Throughout the trials and tribulations of this project, it was determined that the method of feeding which utilized the artificial diet was ineffective on a large scale. Enlarging the system that is currently employed at The Coastal Marine Lab proved to be more labor intensive than originally anticipated. Problems arose with the applications of this feeding method. In order to feed urchins in adjacent sections, the screens needed to be coated on both sides. Due to the liquid nature of the artificial food mixture, it would not adhere properly to the screening. Utilizing a trough to apply the artificial food to the screens also proved ineffective causing rapid heat loss because the food began to solidify before application was complete. The hot temperature of the food mixture also caused the hot glue, which held together the framed screens, to unadhere. The insertion of the screens into the prototype cage was also unsuccessful, they were not easily inserted and removed from the designated food slots.

The large scale artificial food preparation method employed was not only difficult, but also labor intensive and ineffective due lack of an appropriate substrate and application method. An alternative method considered was the utilization of the urchins' natural diet, drift algae. This method proved to be extremely advantageous due to its abundance, ease of collection, minimal time commitment, and occurrence as a natural resource. The state of Maine requires the acquisition of a permit for drift algae collection, whereas New Hampshire does not. However, due to the depth of the prototype cage, the urchins had to be manipulated for the algae to reach those farther down into the cage. Due to the difficulty of monitoring the quantity of drift algae consumed, this method was unable to ensure consistent bulking.

Urchin Considerations and Specifications

Over the course of the project, many aspects of urchin behavior were observed. Urchins tend to be particular creatures and do many things to make themselves happy. It was observed that they will orient themselves more toward the water flow than to where their food source is located. They remained on the top half of the cage, between the surface to two feet below the water line even though the cage was four feet deep. A problem arose as the urchins oriented themselves toward the flow. They created a wall by stacking on top of each other and essentially blocking the flow to those behind them. With the flow inhibited, the urchins were more susceptible to an urchin balding disease, characterized by a loss of spines. In the open system however, this turned out to be less of a problem, but in captivity the disease usually spreads throughout the tank and can be fatal.

After exploring many cage designs it was discovered that the urchins would hang and feed vertically and upside down. This aided in creation of a modular system that could be managed by only one or two people. If they fall, the urchins are able to reorient themselves and return to their original position if desired. After being out of water for approximately 30 minutes they let go of the wire, which allows for easier harvesting.

Large Scale Production

In order for aquaculture practices to be deemed successful in terms of economic considerations, it must be performed on a large scale. Conveniently the sea urchin harvesting season is also the off season for lobstering in the Gulf of Maine, therefore fishermen would be able to focus their efforts on the maintenance of the caged systems. The most convenient way to approach a large scale production of this manner would be to rent out an easily accessible location at which the cages could be kept. A boat marina where the cages are sheltered from the harsh winter weather and where there is plenty of room to maneuver them would be an ideal location. Rental of marina space is reasonably inexpensive during this time due to the fact that most boats are taken out of the water for the winter season. These factors provide for a low cost, large area solution to the problem, allowing for a prospectively high economic yield.

Not only must the space for storage purposes be considered, but also the scale to be worked on. An urchin harvester must initially decide the quantity of urchins he/she is willing to work with. The cages must be positioned so that the greatest surface area faces the direction of maximal current. Urchins in the cages must be oriented to take advantage of this current but not allowed to create a blockade, inhibiting the current from reaching the other urchins. Their positioning must also enhance their ability to utilize the food provided. Depending on the size and capacity of the cages, one should be aware that extra floatation may be required to support the cage on the dock.

Attention must also be given to the method used to harvest from the cage at the end of the bulking season. The cage must either be small enough to hand lift from the water, or be on a pulley system that would allow for an ease of lifting. In order to achieve a large scale production with a high marginal return, many criteria must be considered and well thought through.

Economic Analysis

Depending on how they are used, the systems discussed in this paper can be economically feasible. To prove this, studies of three alternate utilizations for a bulking system were performed from purely hypothetical situations. (Appendix 2) From analyzing the results, it became clear that urchin bulking in a cage system can be economically profitable.

The first scenario explored was that of a venture capitalist who may not be willing to perform any of the labor him or herself. The investor would start by purchasing 12,000 pounds of urchins from a crew of commercial fishermen in the beginning of November. If the investor requested anorexic urchins (under 10% roe content), the price was estimated to be as low as $0.50/pound at this time. The one time cost of the system to bulk the urchins was estimated to be $6000. An investor could hire a full time caretaker to feed and watch over the bulking cages in a rented marina space. Over a two month process, the operation would bring the 12,000 pounds of urchins from near starvation to a desirable 20% roe content. If during the peek market (@ Dec 20), the investor could receive $2.30/pound for the urchins, he/she would receive around a 40% yield on the investment. However, in the following years, the investor can double his/her money. This is because the one-time cost of the system has already been absorbed.

The second scenario is similar to the first, however in this one, the investor is willing to perform the caretaking him or herself. He/she is also willing to store the cage system during the off season, haul the urchins, and collect any food necessary to minimize cost. Using the same buying and selling scenario as the first investor, this investor would receive a 55% yield the first year. In the years to follow, his/her investment would return 130%.

The final scenario was for a third party to own and operate a bulking company. This third party would own and operate the cages, oversee the rental of the marina and provide transportation. Aquaculturists would hire this operation to bulk the urchins before selling to an urchin dealer. Also, by having a supply of urchins in terrible weather, the urchin rancher would receive a much higher price than usual for his/her harvest. A percentage of the profits would be paid to the bulking company for services rendered.

This final scenario is thought to be a few years ahead of its time. Not until there are many more urchin aquaculture sites in a given area (example: Coast of Maine), would this scenario be profitable.

Market Comments

The urchin market is extremely volatile. It is dependent on aspects such as culture, economy and weather. For instance, a week of beautiful weather before Christmas enables many more divers to harvest. This floods the market with sea urchins, which in turn significantly drives down the price. It is believed however by this project that an aquaculture operation with a bulking system could survive a market such as this one. It is thought that having large amounts (>10,000 lbs) of high quality sea urchins available within a moments notice, could be used as influential leverage to secure a higher fixed price with a local urchin buyer. This of course depends multitudes on the skills of the business people involved.

It should be known that this project has not studied the sea urchin market and in order to have a profitable sea urchin operation, more research is strongly recommended and most likely required.

Concluding thoughts

The outcome of this research project demonstrated the economic feasibility and environmental need for an urchin aquaculture industry. Through biological measurements and field testing, a modular cage design with a contained feeding system proved to be a successful and profitable solution.

As a whole, urchin aquaculture is an undertaking worth studying for several reasons. The market for roe is large and it is receiving a high price per pound. The declining wild urchin population has resulted in the disappearance of urchins as a commercial fishery; aquaculture can fill this gap. Urchins are hardy creatures able to withstand temperature fluctuations, desiccation and manhandling while maintaining a high survival rate. The largest market for urchins is in Japan, and urchins are in highest demand around Christmas time. This means that the greatest amount of attention would need to be given during late fall which is when most other profitable fisheries are at a lull. Lastly, the system we are suggesting is not intended to be complex. Materials for constructing the cage and for feeding the urchins are readily available, inexpensive and easy to work with.

There are some uncertainties to keep in mind. The urchins that are raised in the cage cannot be obtained from the wild because this would deplete the populations. Teaming up with an urchin hatchery that can supply millions of young urchins is the answer. Although urchins can be contained in a cage system it has not been determined if it is better to bulk them this way or on the sea floor in a ranch.

Despite these questions, urchin aquaculture should be considered one of the most profitable up and coming ventures in fisheries.

APPENDIX I

SUBJECT:	Proposed Ocean Project for OE 797 - Ocean Projects Course
ADVISORS:	Professor Larry Harriss, Zoology Professor Jeff Savage, Mechanical and Ocean Engineering George Kinser, Potential Venture Capitalist
PROJECT TITLE:	Testing the Economic Feasibility of Controlled Fattening of Sea Urchins During October and November in Preparation for the Christmas Season Market in Japan for Speciality Urchins, and Again for April, 1998
DATE:	September 3, 1997

Background for Project

Sea urchins which were considered a scourge on both the Atlantic and Pacific coast of the United States 15 years ago have since been developed into a highly profitable fishery because "ripe" sea urchins are a delicacy in the Japanese and French markets. They are approaching the value of Beluga caviar in terms of the weight of the edible material and its cost per pound.

In the early 1980s, Professor Larry Harriss put together a student ocean project which had the purpose of developing a system for harvesting urchins off the bottom of the Gulf of Maine in mass quantities during the months of November, December, January and February. That is the time when lobstermen had little to do and could supplement their incomes by harvesting urchins and selling them to the Japanese. At that time, urchins were selling for approximately 10¢ apiece or perhaps $1.00 per pound, so a ton of sea urchins was worth $2,000. This project which was carried out by students under the tutelage of Dr. Harriss turned out to be highly successful and paved the way for the partnership of lobstermen with divers to harvest urchins during the off season and making as much as $15,000 in that period/boat.

However, other fishermen entered the field and used draggers as well as diving to harvest urchins and harvested them year round. As a result, recent years have seen a serious decline in productive barrens (large flats of sea urchins) and the quantity being produced annually is dropping prodigiously. At one time, sea urchins were the third most profitable crop in the Gulf of Maine behind lobsters and farmed Atlantic salmon. However, that is no longer the case, and there is need for an aquaculture approach to urchins if they are to survive as a profitable product in this area.

Some serious biological experimentation has been done on sea urchins and a method of holding them and feeding them has been developed to a fairly satisfactory level. However, it is not certain that holding urchins in things like rafts or tanks will be as effective in growing them as it would be to leave them on the bottom in protected areas and feed them in place. This would be possible if sea ranches could be set aside along the coast for raising urchins. There are some of these ranches already, but the land leases are hard to come by in the face of opposition by lobstermen, yachtsmen, and other people who want to use the same space along the coastline.

Moreover, urchins are most valuable when they are very fresh and can be shipped live by airfreight to Japan. This means they must be harvested on the day they are sold and this is very difficult to do in bad weather such as exists in late November and December in the Northeast. Therefore, if it was possible to have urchins be taken in October and put someplace where they could be held and still grow and fatten up for the ensuing 2-3 months, the possibility of achieving the highest possible price for them during the special and very profitable December market, would be much enhanced.

Purpose and Scope

The purpose of this project will be to:

1. Determine whether or not urchins grown in captivity, on some kind of a raft or in cages on the surface, can be fed and grow at the same rate as urchins which are left on the bottom in a sea ranch, such as the one that exists in Newcastle and is owned by Mr. Jay Gingras who will participate in this project. At least two biology students will be needed to conduct this experiment, but must start almost immediately this fall in order to be set-up properly for the December measurements.

2. Build a makeshift set-up for growing the urchins this fall in captivity, assuring that they have proper fluid circulation and proper set-up for feeding, such as already has been developed onshore at the New Hampshire Fishermen's Cooperative. Jury-rigged cage systems or holding pens must be built in September and early October with materials that already exist and follow the designs of those that exist for the somewhat successful holding systems developed last year at the New Hampshire Fishermen's Cooperative.

   However, the jury-rigged system will only be used through this December for the measurement of the fast growth of the urchins. After that, a second system must be developed which will be able to hold at least one ton of urchins, in which the urchins will be placed from the jury-rigged pen for growth through the months of January, February, March and April to determine if they can be held in this fashion through the winter for the purposes of selling them in a second market which develops in early and mid-summer in Japan for other holiday reasons. The challenge of building these second pen systems will be to design and construct one which carries out the functions of holding the urchins and growing them, but will be durable and inexpensive and economically as well as technically feasible. Developing such a technically and economically sound surface holding system for growing sea urchins will be a challenging engineering problem, requiring both good analysis and clever ingenuity and inventiveness.

Expected Budget

We are going to request a budget of approximately $2,000 for this project from the Ocean Projects Course, but we expect it to cost more and there will be other money provided by potential venture capitalists if it is needed to complete this work.

Number of Students Required

This project seems to require at least two biology students who are interested in aquaculture and two mechanical engineering students who are interested in design of a unique ocean system which would be duplicated many hundreds of times if it turned out to be a successful raft or floating cage design for raising urchins. The goal would be to develop a system which could be used by urchin ranchers up and down the coasts of Maine and New Hampshire and perhaps into Massachusetts and handling hundreds of tons of urchins annually.

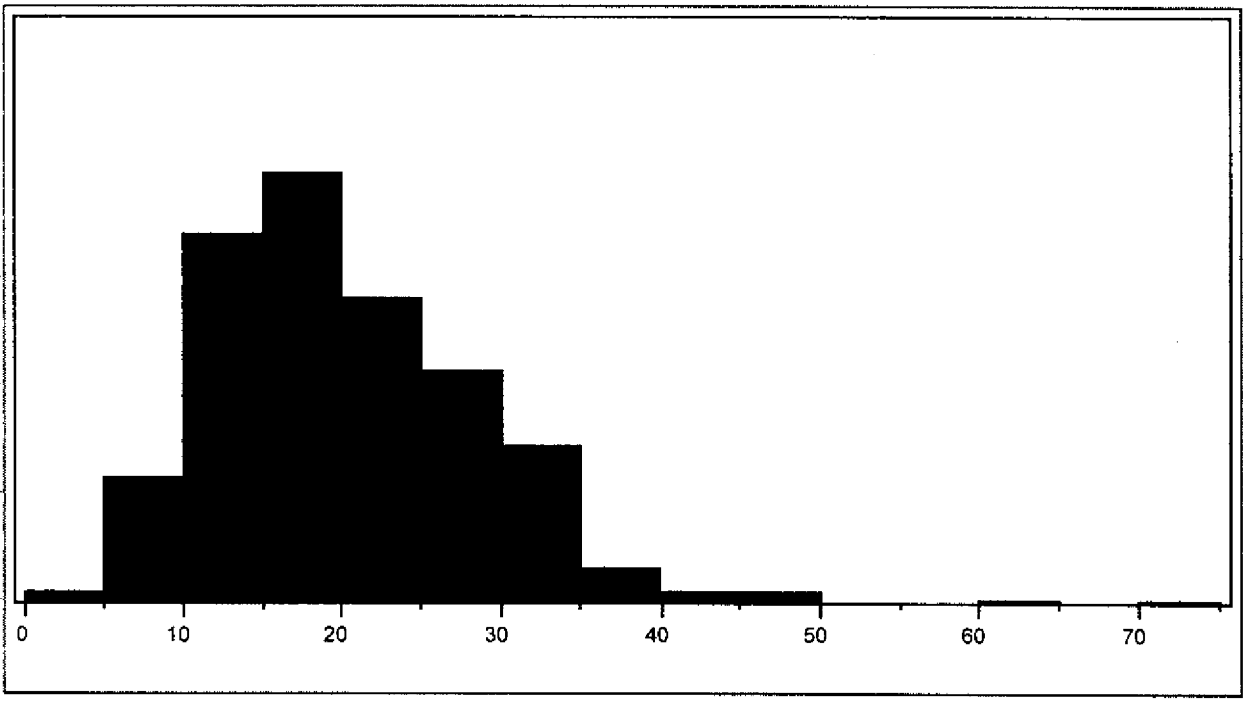
APPENDIX II

For A Buying Price of $.50/lb			
Cost Estimate		4/6/98	
	Cost/Unit	Qty	Total
Cage Cost	$1,000	6	$6,000
Capacity (LB urchins)	2000	6	12000
			$0
Marina Cost per ft (30 ft wide)	$50	25	$1,250
6 months Nov. 1- May 1			
Off Season Storage in Garage	$660	2	$1,320
May 1 - Nov. 1			
Urchin Buying Price	**$0.50**	**12000**	**$6,000**
1 Full Time Caretaker/ Feeder	**$40.00**	**100**	**$4,000**
Feeding -Drift Algae Method			
Algae Collectors Part time ($/hr)	$6	72	$432
Feeding- Old Produce			
State Permit	$25	1	$25
Hauling Cages To and From Storage	$400	1	$400
Labor	$100	1	$100
Hauling to Market Fee	$600	1	$600
Urchin Selling Price	$1.80	12000	$21,600
Convenience Charge	$0.50	12000	$6,000
Gross			**$27,600**
Cost with Drift Algae Option (First Year)			$20,102
Net Profit First Year			$7,498
% Yield for First Year			37.30%
Following Years Expected % Yield			95.72%
Cost with Produce Option (First Year)			$19,695
Net Profit First Year			$7,905
% Yield for First Year			40.14%
Following Years Expected % Yield			101.53%

For A Buying Price of $1.00/lb			
Cost Estimate		4/6/98	
	Cost/Unit	Qty	Total
Cage Cost	$1,000	6	$6,000
Capacity (LB urchins)	2000	6	12000
			$0
Marina Cost per ft (30 ft wide)	$50	25	$1,250
6 months Nov. 1- May 1			
Off Season Storage in Garage	$660	2	$1,320
May 1 - Nov. 1			
Urchin Buying Price	**$1.00**	**12000**	**$12,000**
1 Full Time Caretaker/ Feeder	**$40.00**	**100**	**$4,000**
Feeding -Drift Algae Method			
Algae Collectors Part time ($/hr)	$6	72	$432
Feeding- Old Produce			
State Permit	$25	1	$25
Hauling Cages To and From Storage	$400	1	$400
Labor	$100	1	$100
Hauling to Market Fee	$600	1	$600
Urchin Selling Price	$1.80	12000	$21,600
Convenience Charge	$0.50	12000	$6,000
Gross			**$27,600**
Cost with Drift Algae Option (First Year)			$26,102
Net Profit First Year			$1,498
% Yield for First Year			5.74%
Following Years Expected % Yield			37.30%
Cost with Produce Option (First Year)			$25,695
Net Profit First Year			$1,905
% Yield for First Year			7.41%
Following Years Expected % Yield			40.14%

APPENDIX III

Roe %



Moments

Mean	20.4114
Std Dev	8.9296
Std Error Mean	0.5434
Upper 95% Mean	21.4814
Lower 95% Mean	19.3415
N	270.0000
Sum Weights	270.0000

Section A	# per slot	# living	# dead
A-1	298	281	2
A-2	736	709	22
A-3	487	469	3
A-4	674	644	15
A-5	812	779	14
A-6	452	431	6
A-7	369	347	7
A-8	229	210	4
A-9	90	78	2

Section B	# per slot	# living	# dead
B-1	404	385	4
B-2	444	427	2
B-3	515	497	3
B-4	474	443	16
B-5	360	339	6
B-6	534	517	2
B-7	715	696	4
B-8	411	392	4
B-9	181	165	1

Section A				
	Urchin Mass(g)	Roe Mass(g)	% Roe Content	Color observed
A-1 1	67.52	10.84	16.05	
2	50.61	19.04	37.62	
3	91.92	28.09	30.56	
4	88.57	26.54	29.96	
5	45.77	10.74	23.47	
6	61.22	23.49	38.37	
7	47.56	4.07	8.56	
8	76.3	17.74	23.25	
9	64.49	9.83	15.24	
10	41.55	6.78	16.32	
11	55.56	9.04	16.27	
12	68.84	14.85	21.57	
13	71.25	12.76	17.91	
14	67.28	17.12	25.45	
15	47.74	6.95	14.56	
A-1 mean	63.08	14.53	22.34	
A-2 1	66.82	15.07	22.55	
2	71.02	24.69	34.76	
3	73.02	16.85	23.08	
4	62.98	9.65	15.32	
5	68.16	20.1	29.49	
6	105.67	16.4	15.52	
7	68.68	12.35	17.98	
8	69.05	11.4	16.51	
9	73.55	11.67	15.87	
10	57.15	13.65	23.88	
11	72.3	14.15	19.57	
12	68.12	16.87	24.77	
13	63.81	17.71	27.75	
14	35.61	4.11	11.54	
15	60.32	11.4	18.90	
A-2 mean	67.75	14.40	21.17	

	Urchin Mass	Roe Mass	% Roe Content	Color observed
A-3 1	48.33	5.75	11.90	
2	74.31	7.81	10.51	

3	59.67	22.48	37.67	
4	79.4	3.27	4.12	
5	68.13	7.15	10.49	
6	50.21	15.5	30.87	
7	51.59	10.35	20.06	
8	53.2	10.8	20.30	
9	90.7	18.29	20.17	
10	50.71	10.75	21.20	
11	58.86	4.55	7.73	
12	50.91	6.11	12.00	
13	57.35	8.31	14.49	
14	83.48	12.15	14.55	
15	43.86	3.57	8.14	
A-3 mean	61.38	9.79	16.28	
A-4 1	107.32	20.38	18.99	
2	87.44	19.76	22.60	
3	89.51	21.33	23.83	
4	87.74	27.25	31.06	
5	86.56	17.93	20.71	
6	86.33	14.13	16.37	
7	76.24	23.18	30.40	
8	58.98	12.47	21.14	
9	55.52	15.43	27.79	
10	117.16	37.65	32.14	
11	62.29	16.25	26.09	
12	78.94	15.11	19.14	
13	57.81	14.95	25.86	
14	55.68	10.98	19.72	
15	81.15	11.92	14.69	
A-4 mean	79.24	18.58	23.37	

	Urchin Mass	**Roe Mass**	**% Roe Content**	**Color observed**
A-5 1	59.48	8.07	13.57	
2	99.47	33.56	33.74	
3	77.52	13.39	17.27	
4	87.1	15.41	17.69	
5	80.43	21.22	26.38	
6	61.42	15.85	25.81	

7	66.32	15.75	23.75	
8	87.71	12.36	14.09	
9	101.82	23.35	22.93	
10	72.8	5.48	7.53	
11	114.88	15	13.06	
12	84.36	15.2	18.02	
13	75.74	12.32	16.27	
14	85.28	10.36	12.15	
15	95.73	12.91	13.49	
A-5 mean	83.34	15.35	18.38	
A-6 1	119.68	28.18	23.55	
2	53.66	4.29	7.99	
3	109.94	8.85	8.05	
4	82.72	12.88	15.57	
5	90.57	23	25.39	
6	61.92	10.35	16.72	
7	100.07	14.39	14.38	
8	90.93	29.35	32.28	
9	102.34	9.57	9.35	
10	102.4	26.53	25.91	
11	127.12	15.81	12.44	
12	68.81	6.73	9.78	
13	77.62	21.37	27.53	
14	104.35	13.05	12.51	
15	76.57	9.46	12.35	
A-6 mean	91.25	15.59	16.92	

	Urchin Mass	**Roe Mass**	**% Roe Content**	**Color observed**
A-7 1	113.75	21.81	19.17	
2	117.73	28.49	24.20	
3	62.84	17.17	27.32	
4	76.43	10.88	14.24	
5	84.7	6.53	7.71	
6	67	8.47	12.64	
7	81.81	23	28.11	
8	62.89	11.75	18.68	
9	60.08	6.54	10.89	
10	68.22	11.72	17.18	

11	95.57	26.34	27.56	
12	86.91	7.23	8.32	
13	68.07	10.4	15.28	
14	69.9	12.69	18.15	
15	114.05	31.77	27.86	
A-7 mean	82.00	15.65	18.49	
A-8 1	88.6	24.19	27.30	
2	158.77	52.53	33.09	
3	63.19	7.19	11.38	
4	77.7	25.45	32.75	
5	77.54	14.38	18.55	
6	62.23	4.33	6.96	
7	49.33	6.47	13.12	
8	70.7	6.86	9.70	
9	89.08	9.13	10.25	
10	78.23	5.82	7.44	
11	76.14	23.2	30.47	
12	52	9.25	17.79	
13	74.08	20.73	27.98	
14	67.2	16.42	24.43	
15	75.19	18.34	24.39	
A-8 mean	77.33	16.29	19.71	

	Urchin Mass	Roe Mass	% Roe Content	Color observed
A-9 1	89.89	25.52	28.39	
2	76.2	21.95	28.81	
3	72.95	19.85	27.21	
4	53.6	15.9	29.66	
5	56.93	14.92	26.21	
6	59.59	10.95	18.38	
7	57.19	11.55	20.20	
8	76.51	8.62	11.27	
9	51.52	8.7	16.89	
10	64.19	10.03	15.63	
11	116.91	29.69	25.40	
12	78.25	11.63	14.86	
13	97.72	10.32	10.56	
14	73.6	10.2	13.86	

15	61.75	9.33	15.11	
A-9 mean	72.45	14.61	20.16	

Section B				
	Urchin Mass (g)	Roe Mass (g)	% Roe Content	Color observed
B-1 1	91	30	32.97	4
2	93	35	37.63	4
3	88	16	18.18	2
4	116	31	26.72	4
5	101	15	14.85	2
6	91	14	15.38	1
7	101	19	18.81	3
8	81	20	24.69	4
9	76	21	27.63	3
10	100	8	8.00	1
11	179	43	24.02	3
12	52	9	17.31	4
13	59	18	30.51	3
14	94	13	13.83	1
15	110	17	15.45	2
B-1 mean	95.47	20.60	21.73	
B-2 1	112	35	31.25	4
2	151	33	21.85	3
3	71	11	15.49	1
4	105	23	21.90	4
5	44	10	22.73	2
6	82	15	18.29	2
7	72	10	13.89	2
8	64	14	21.88	3
9	89	27	30.34	5
10	81	22	27.16	4
11	100	18	18.00	1
12	65	21	32.31	5
13	69	11	15.94	1
14	98	16	16.33	4
15	76	10	13.16	2
B-2 mean	85.27	18.40	21.37	

	Urchin Mass (g)	Roe Mass (g)	% Roe Content	Color observed

B-3	78	14	17.95	2
2	116	16	13.79	1
3	80	21	26.25	4
4	98	15	15.31	1
5	115	19	16.52	2
6	118	20	16.95	2
7	105	23	21.90	2
8	112	24	21.43	3
9	106	15	14.15	2
10	98	13	13.27	1
11	63	17	26.98	2
12	68	11	16.18	2
13	71	8	11.27	1
14	80	15	18.75	2
15	192	39	20.31	1
B-3 mean	100.00	18.00	18.07	
B-4	95	19	20	1
2	78	28	35.90	2
3	88	19	21.59	4
4	93	12	12.90	5
5	57	14	24.56	1
6	81	9	11.11	1
7	70	10	14.29	2
8	186	11	5.91	2
9	74	34	45.95	3
10	77	14	18.18	1
11	81	13	16.05	2
12	138	13	9.42	2
13	70	31	44.29	4
14	93	15	16.13	3
15	119	20	16.81	2
B-4 mean	93.33	17.47	20.87	

	Urchin Mass (g)	Roe Mass (g)	% Roe Content	Color observed
B-5	119	13	10.92	3
2	123	22	17.89	2

3	146	19	13.01	5
4	179	39	21.79	5
5	71	50	70.42	5
6	84	53	63.10	5
7	89	13	14.61	3
8	98	23	23.47	2
9	89	17	19.10	2
10	94	16	17.02	2
11	100	23	23.00	5
12	52	16	30.77	1
13	136	20	14.71	3
14	69	10	14.49	1
15	88	13	14.77	1
B-5 mean	102.47	23.13	24.60	
B-6	92	25	27.17	4
2	138	31	22.46	3
3	89	22	24.72	1
4	63	11	17.46	2
5	68	9	13.24	1
6	120	21	17.50	4
7	50	15	30.00	5
8	106	28	26.42	5
9	103	28	27.18	4
10	68	21	30.88	4
11	115	27	23.48	1
12	114	16	14.04	1
13	84	19	22.62	3
14	93	18	19.35	1
15	76	26	34.21	5
B-6 mean	91.93	21.13	23.38	

	Urchin Mass (g)	Roe Mass (g)	% Roe Content	Color observed
B-7	111	26	23.42	5
2	122	18	14.75	3
3	99	27	27.27	5
4	100	30	30.00	5

5	55	16	29.09	4
6	86	19	22.09	4
7	103	21	20.39	4
8	60	9	15.00	2
9	104	17	16.35	4
10	79	11	13.92	1
11	132	11	8.33	1
12	113	19	16.81	1
13	83	23	27.71	2
14	73	21	28.77	5
15	112	15	13.39	5
B-7 mean	95.47	18.87	20.49	
B-8	123	16	13.01	2
2	97	31	31.96	5
3	92	10	10.87	1
4	102	24	23.53	3
5	76	27	35.53	3
6	80	19	23.75	2
7	94	10	10.64	1
8	70	17	24.29	5
9	78	10	12.82	4
10	123	12	9.76	4
11	90	16	17.78	1
12	80	14	17.50	2
13	126	19	15.08	5
14	79	22	27.85	1
15	50	17	34.00	5
B-8 mean	90.67	18.00	20.56	

	Urchin Mass (g)	**Roe Mass (g)**	**% Roe Content**	**Color observed**
B-9	63	19	30.16	2
2	70	7	10.00	1
3	67	12	17.91	2
4	48	9	18.75	5

5	60	14	23.33	5
6	75	11	14.67	4
7	54	7	12.96	1
8	40	18	45.00	5
9	78	5	6.41	1
10	56	7	12.50	2
11	108	17	15.74	4
12	151	5	3.31	1
13	100	34	34.00	5
14	100	40	40.00	5
15	100	8	8.00	2
B-9 mean	78.00	14.20	19.52	

References

Department of Marine Resources describes Sea Urchin research needs. 1993 Commercial Fisheries News: 43.

Lalli, Carol, and Timothy Parsons. 1997 Biological Oceanography: An Introduction. Great Britain Butterworth-Heinemann 187.

Munk, Nina. "Choppy Waters." 1993 Forbes : 108-110.

Nestler, E.C. and Harris, L.G. 1994. "The Importance of omnivory in *Strogylocentrotus droebachiensis* (Muller) in the Gulf of Maine". In David, B. (ed) Proc. 8th Int. Echinoderm Conference, Dijon. (In Press)

Revkin, Andrew C. 1996 "Despised Sea Urchin Enriches Maine Coast." New York Times: C33.

Rupert, E. and Barnes, R., Invertebrate Zoology. New York Saunders-College Publishing: 952-960.

Sea Urchin Harvesters Association-California. Online. Netscape Navigator. www.seaurchin.org. April 16, 1998.

Simoneau, A., Call, K., Beach, C., and Vogel, L.,1993 Variations in Growth Due to Wave Exposure and Diet in the Green Sea Urchin *Strongylocentrotus droebachiensis*.Sea Grant Ocean Projects Course Report. University of New Hampshire, Durham: 26.

United States Department of Commerce. 1995 The Japenese Sea Urchin Market.Washington: NOAA.