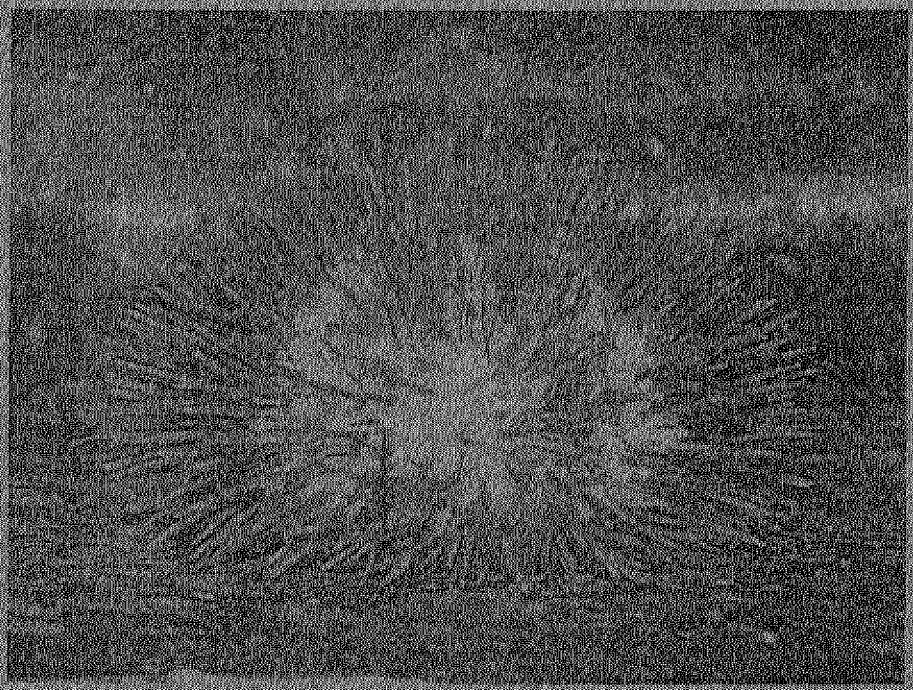
URCHINS

2001-2002 UNH Ocean Technology 797 Project



Aimed at optimizing the juvenile grow out of the green sea urchin, *Strongylocentrotus droebachiensis*, using a suspended cage system.

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Abstract

The commercial harvesting of the green sea urchin, Stronglyocentrotus droebachiensis, has become a major fishing industry in the Gulf of Maine. Due to the continued harvesting of Gulf of Maine urchins and poor natural recruitment, a successful stock enhancement plan must be employed in order to maintain an urchin fishery. The purpose of this investigation was to develop a commercial-scale suspended underwater caging system for the cultivation of juvenile green sea urchins. The engineering component of this project was to design a cage that would be stable for a wide range of currents and underwater turbulence associated with the environment in which it will be placed, while maximizing vertical surfaces for urchin dispersion. The biological component sought to understand urchin behavior in the cage system, while optimizing growth through examining past bottlenecks. Biological experimentation supported a positive correlation between current speed and urchin growth, and initial density trials indicated that at some threshold density urchin growth would decline. The engineering results conducted on the preliminary design proved that a suspended cage system is not only feasible, but also quite effective in reaching all of the established goals for stability and endurance. The overall system behavior presented in the analyses is positive evidence that implementation of the final commercial design is the next step in urchin aquaculture.

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1. Introduction

The commercial harvesting of the green sea urchin, *Stronglyocentrotus droebachiensis*, has become a major fishing industry of North and South American as well as Japanese temperate coasts (Andrew et al., 2002). *S. droebachiensis* is an abundant and ecologically important member of shallow subtidal benthic communities in the northern Atlantic as well as Pacific oceans. In the Gulf of Maine (GoM), the large scale harvesting of urchins began in the late 1980s, and rapidly increased to reach its peak as the GoM's second largest fishery. Before declining to its present place as the fourth largest fishery, the harvest peaked in 1993, when 39.3 million pounds was taken from the GoM for a financial yield of 23.5 million dollars (Maine Department of Resource). Due to severe over-harvesting and the failure to implement fisheries regulations in foresight, the number of green sea urchins inhabiting the GoM has decreased considerably. Subsequently, the annual harvest has also declined. The urchin fisheries estimated yield for the 2000-2001 season was only 12 million pounds, and the predicted harvest for the 2001-2002 season is expected to show a 29% decrease in yield.

Due to the continued harvesting of GoM urchins and poor natural recruitment, a successful stock enhancement plan must be employed in order to maintain an urchin fishery. Harris et al. (2001) documented the consistent minimal *S. droebachiensis* recruitment that plagues the GoM. Therefore, a successful hatchery system is needed in order to enhance the region's urchin stock. The research efforts reported here represent one study aimed at the long-term goal of maintaining a viable green sea urchin fishery in the GoM.

There are many concerns facing the development of a successful *S. droebachiensis* system of growing out hatchery reared juveniles for out planting. A field-deployed system needs to consider the ambient physical, biological and structural parameters, which will influence the growth and survival of the animals. Among the most important reported variables to be considered are: ambient water current (Williams and Harris, 1998) and temperature (Garrido and Barber, 2001), quality and quantity of diet (Wahle and Peckham, 1999; Meidel and Scheibling, 1998; Lemire and Himmelman, 1996), predation, crowding (Wahle and Peckham, 1999), genetic predispositions (Harris,

personal communication), as well as the internal environment of the hatchery system. Previous experimentation has revealed that a suspended cage system may be ideal for the juvenile grow out of urchins to a size adequate for stocking the GoM (Kraft and Gordon, 2001).

Previous aquaculture experiments have also revealed presently unexplained growth variation (Madigan et al., 2001), which may prove to be a significant bottleneck to successful urchin aquaculture. In addition, the labor and facilities costs of the current Japanese system would make it difficult establish a similar hatchery system in the United States. Hagen (1996) and Saito (1992) documented the Japanese system for commercial scale cultivation of larval and juvenile urchins in detail. This shore-based system grows juveniles to 20 mm, in large facilities, before out-planting them to be harvested by fisherman. The GoM requires a more cost effective way to raise juvenile urchins to a size large enough for out planting.

The purpose of this project was to design and test a field-suspended cage system for growing juvenile green sea urchins. The project was not only comprised of a biological component, which sought to examine the most interesting influences on *S. droebachiensis* growth within the cage system, but also an engineering component, which focused on the design of the cage system that would house the animals. The design element built off of previous experimentation (Kraft and Gordon, 2001) considering physical stresses and predation in the external design of the cage and its placement in the water, as well as surface area and substrate in constructing the internal cage environment. It was decided that a suspended cage design would maximize water exchange and algal film growth, while reducing predator entrance. Such a cage system would also reduce labor and facilities cost. Therefore, it also became important to design a cage, which would ultimately allow for commercial up scaling. With the proper model scaling and analysis, it is assumed that the small cages will provide a good background knowledge to eventually develop a full-scale design.

In general this study endeavored to promote the development of a sustainable *S. droebachiensis* fishery. This research more specifically aimed at one engineering goal and two biological goals.

Engineering goal:

- To design and implement a suspended cage system that would survive ambient stresses and promote within cage urchin growth and survival.

Biological goals, aimed in general at investigating variation while maximizing growth:

- To provide support for laboratory (Williams and Harris, 1998) and previous field studies (Kraft and Gordon, 2001), which examined the influence of water current on urchin growth. H_1: Growth will increase with increasing current speed to some maximum. With further increase in current speed, growth will decline.
- To examine the effects of within-cage density on urchin survival and growth. H_3: At some threshold density growth and survival will decline.

2. Conceptual Design

2.1 Initial Design for Biological Field Research

2.1.1 Physical Parameters

The most important determinant for the size of the cage was the availability of urchins. Keeping in mind the total number of urchins, the dimensions of the cage were selected to be 18" by 22" by 36". The rectangular shape would be the easiest to construct as well as make variations after behavioral analyses were conducted. This size would allow for multiple cages with enough urchins to conduct all of the biological experiments proposed in the introduction.

The external frame was made of PVC piping and was enclosed by a ¼" wire mesh. Internally, the cage was divided into six compartments by Plexiglas. Nylon rope was used to connect the cage to both the buoys and the mooring system. This rope was chosen because it would maintain its integrity in salt water and not significantly deform or stretch under the tensions it would be subjected to. Consult Figures 1 and 2 for a visual representation of these dimensions and structure.

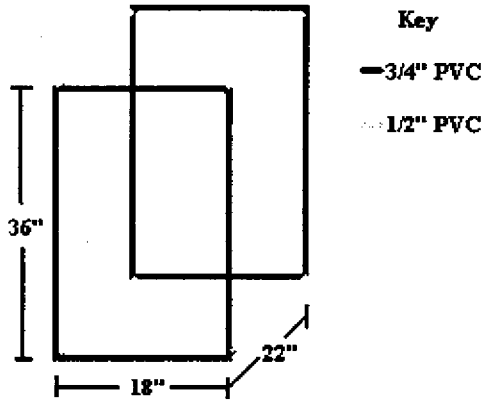

Figure 1. External Structure and Dimensions

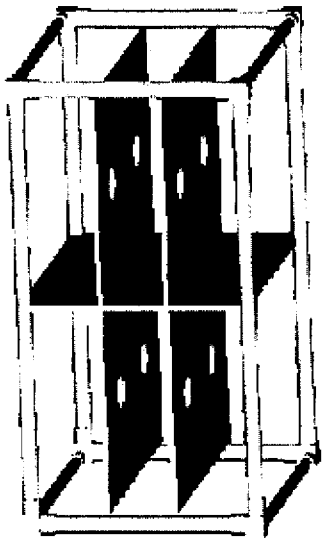

Figure 2. Cage Without Mesh

2.1.2 Environmental Parameters

The cages were placed at the mouth of the Piscataqua River near the UNH Coastal Marine Laboratory in Newcastle, New Hampshire (Figure 3). The water level ranges from 10 to about 20 feet deep, depending on tide and season. Currents are small in this protected area, although still significant enough to provide the necessary data for cage performance. For the calculations in this study, a steady current of 1 knot will be used. This is considered a worst case scenario current, since the location in the harbor is protected from the volatility of the open ocean.

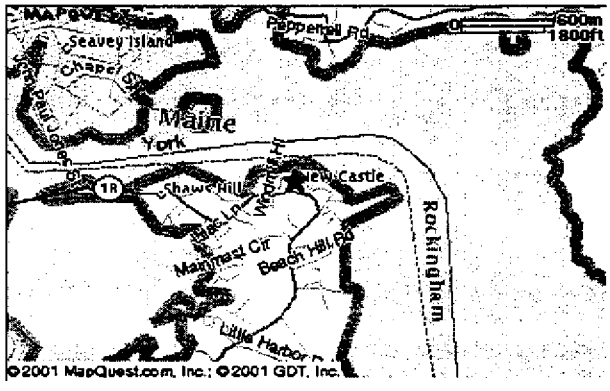

Figure 3. Location of Cage Testing

2.1.3 Design Variables

The first variable is the orientation of the Plexiglas inside of the cage. The significance of the Plexiglas biologically is its ability to collect a biofilm of bacteria, algae and sessile invertebrates for the urchins to feed on while acting as a substrate for them to attach to and grow. Figure 4 is an illustration of the design developed for internal structure.

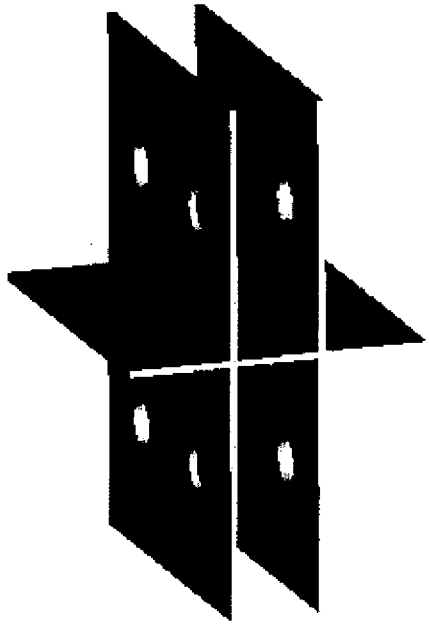

Figure 4. Plexiglass Arrangement

It has been found in laboratory research that the urchins prefer the substrate to be oriented parallel to the water flow. This is beneficial in terms of hydrodynamics because it nearly eliminates the drag due to the Plexiglas. Also, there will be holes of 2 inch diameter drilled into the Plexiglas in order for the urchins to move freely throughout the cage. Although detrimental to the fluid flow in terms of added turbulence, this is necessary for the biological aspect of the experiment which deals with the behavior of the urchins in the contained environment.

The second major variable was the method of mooring the cage to the sea floor. When discussing the mooring of the cage, the only imperative is that the weight is greater than the buoyant forces due to the cage and anchoring but still manageable to lift for proper cage maintenance and observation. The most effective approach is to connect the

trap to a single weight with the utilization of a swiveling joint (Figure 5). The swiveling joint will allow the cage to rotate on the vertical axis in order to orient itself with the fluid flow.

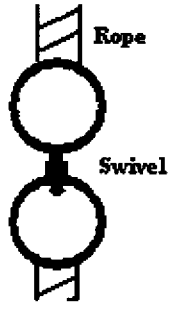

Figure 5. Swivel

The third and final variable is the method of buoying the system. The options were either a surface buoy or subsurface buoy with a small marker buoy attached loosely to establish its location.

The surface buoy would largely eliminate the effects of current but would require rope, which is very flexible for the changing water depths. If this were not available, it is possible that a control system could be developed which monitored the water level and adjusted the rope length accordingly. Another variation on the subsurface buoy would be a variable ballast buoy, which could be operated from the surface of the water. Ultimately these arrangements were ruled out for the current task because of the complexity and time constraints.

A subsurface buoy would provide a constant tension in the rope and thus it would be easier to examine and model the behavior. It also has benefits in respect to movement of the line and wear on the parts (Yuta, 2000). Unfortunately, the current acting on the cage will also be acting on the buoy, increasing the overall system drag. The entire system is displayed below in Figure 6.

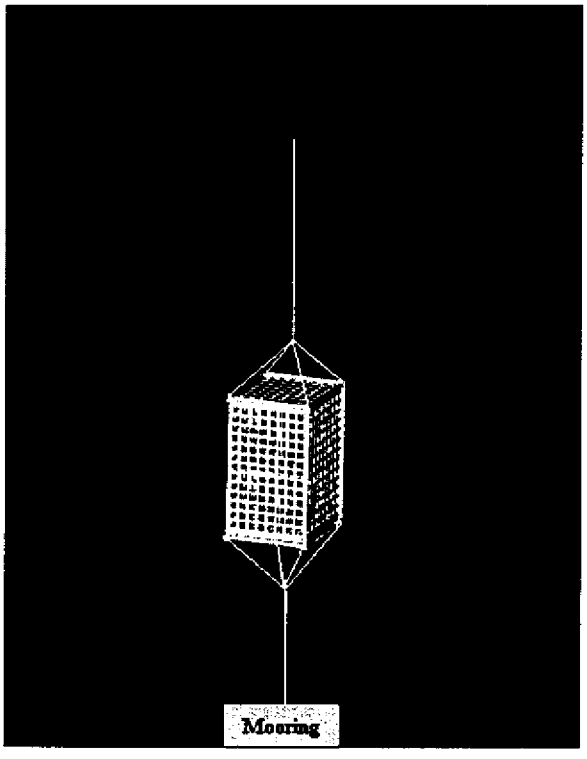

Figure 6. System with Buoy, Cage, and Mooring

2.2 Variations on Initial Design

After monitoring and working with the cages for a period of time, several design modifications were made. These modifications were both for engineering/ease of use purposes as well as biological purposes.

2.2.1 Engineering Modifications

The first modification involved eliminating some of the rope being used. The ropes connected to the subsurface buoy and surface marker buoy were getting tangled and proved to be a bit of a hassle to manipulate. Instead of connecting the subsurface buoy to a rope, four smaller buoys were connected to the top corners of the cage. This change would make little difference in terms of cage behavior but prove to be a significant help in terms of cage operation.

The other major modification involved the mooring system conflicting with the frequent monitoring of urchin development. It became apparent that lifting the entire system out of the water was difficult physically for the group members as well as

detrimental to the integrity of the cage itself. In order to fix this issue, a pulley system was implemented. The cages were all placed within range of a pier where rope could be tied off for research purposes. Instead of directly connecting the cage to the mooring, the rope from the bottom of the cage was fed through a carabineer and back out of the water. By pulling on the rope from the surface, the cage could be brought down to the desired height above the bottom.

2.2.2 Biological Modifications

A small adjustment was made shortly into the study because of lack of urchin availability. The original cages were too big to run all of the desired experiments concurrently. It was determined that if each dimension was cut in half, the 1/8 volume cage would be perfect for the studies on effects of varying currents. The Plexiglas was not included in this design because it was determined that manually feeding the urchins was suitable for this type of experiment.

Near the end of the experimenting, a new model had been proposed, which utilized a series of wire mesh shelves enclosed in an external frame. This design will be addressed in greater detail later in the report, but it is important to note that shelves were created with this new cage in mind. These shelves were tested individually to determine if the future cage would be as effective for urchin development as the original.

3. Biological Methods

3.1 Initial Growth and Survival Investigation

The initial observational experiment tested the growth rates and survival of green sea urchins under two environments, as well as provided observational data on urchin behavior in a grow-out cage system. The cages used in this experiment are described in Section 2.1.1. The cages provided 14,254 $in.^3$ of volume, 3,672 $in.^2$ of wire mesh surface area, and 1,980 additional $in.^2$ of Plexiglas surface area for the urchins to distribute on. Doors were cut into the wire mesh to enable extraction of the urchins for measurement.

The cage systems were deployed without urchins two weeks prior to experiments, in order to allow fowling of the cages by native flora and fauna. Cage 1 was deployed near the floating dock adjacent to the Coast Guard boathouse. Cage two was suspended off of the pier near the entrance. One hundred urchins (sizes 10-20mm) were added to

each cage on 12/6/01. Measurements of the tests of all urchins were taken prior to the experiment and three weeks later on 12/30/01.

3.2 Current v. Growth Experiment

A subsequent investigation sought to examine the relationship between urchin growth and the current speed in which the cage system was placed. The four cages used in the experiment were the 1/8 the volume scaled-down models of the initial cages (1,782 $in.^3$), with 918 $in.^2$ of ¼"wire mesh surface area. The cages each held 30 urchins, size class 20-30 mm. Cages were hung at 50 yd intervals from the University Pier, in an attempt to get variable current data. This experiment was monitored starting 1/11/02 through 2/23/02. Cages were retrieved bi-weekly and the tests of all urchins were measured.

3.3 Density v. Growth

Nine cages (8"x13"x14") were constructed out of ½" rubber-coated wire mesh. Each cage was 1,456 $in.^3$ in volume and provided 796 $in.^2$ of wire mesh surface area. Industrial strength Velcro® was used to seal the door of the cages. The cages were strung in groups of three, with each cage having a different density. Densities of 10, 20, and 40 urchins were used. The order of the densities along the string was changed between the three groups to eliminate depth dependent variables. Urchins were supplemented with *Laminaria* at a density of 1.5g *Laminaria* per urchin. Urchins were measured after two weeks to determine growth rate variability caused by density.

3.4 Gut Content Analysis

The final biological component consisted of a preliminary analysis of urchin gut content, with the prediction that smaller urchins, relative to larger individuals of the same age, may be impeded from growing by nutritional competition, which is taking place in the gut. Six lab-reared urchins of the same age, three greater than 30 mm in diameter and three less than 5 mm, and 18 urchins from the initial field experiment, eight larger than 30 mm and ten smaller than 15 mm, were dissected and their gut content analyzed for parasite presence. Each of the urchins within the two subsets had been held under similar conditions. The urchins were cracked open using a sterile dissecting knife. The intestines of one urchin were placed on a sterile Petri® dish and analyzed under a compound scope (40X) for the presence of ciliates.

4. Engineering Results and Analysis

There are many different methods to analyzing this system both theoretically and experimentally. However, the mathematics involved in analytical analysis become quite complex and nonlinear when wave and current interaction are introduced. A proven method to the overall analysis of this suspended cage system is the finite element method. If an accurate finite element design of the overall system can be produced including all materials and their respective mechanical/physical properties, a simulation of the system response can be made with varying currents and wave action. Figure 7 shows the finite element model of the proposed system as modeled on MENTAT, with the defined properties shown in Table 1. Although this version is a bit simpler than the actual design, it will still provide a good general model.

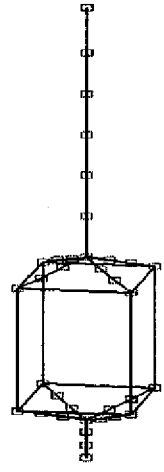

Figure 7. FEA Model

	ρ (lbf*s^2/in^4)	Di (in)	Do (in)	L1 (in)	L2 (in)	L3 (in)	ν (in^2/s)
PVC	1.23E-04	1.25	1.5	36	22	18	
Sea H2O	9.62E-05						2742
Nylon Rope	7.72E-05		0.438	60	12	8 x	15.3
Foam Buoy	2.25E-06		6	16			
Plexiglas	1.32E-04						

Table 1. Material Properties

Following the generation of the finite design, the analysis can be conducted with the help of a program called Aqua-FE. This program has been specifically designed for analysis of suspended cages and has been proven to accurately model the nonlinear behavior.

The first test conducted was to check the accuracy of the overall design. In order to do this, the system was tested under static conditions, i.e. no waves or current. If the tension in the rope at the mooring is equal to the buoyant force minus the weight of the system, it must be statically correct.

Loading condition	Force (N)
No wave, no current	39.42
No wave, no current Analytical prediction	39.71499563
Current 0.5m/s	51.36
Current 0.5m/s, wave height 0.3m, length 36 m, period 6s	61.2 (Max)

Table 2. Loading Conditions

Table 2 above displays the force calculations which prove that the modeling is accurate. It also displays the finite element analysis results of the rope tension above the mooring after the addition of current and waves. As one would expect, the maximum force in the rope occurs when there is both current and wave activity present.

Also important to the analysis is the overall stability of the system. Using AquaFE the displacement of any desired location on the design can be measured. Figure 8 shows the steady state displacement of the cage under 1 knot current and no wave activity.

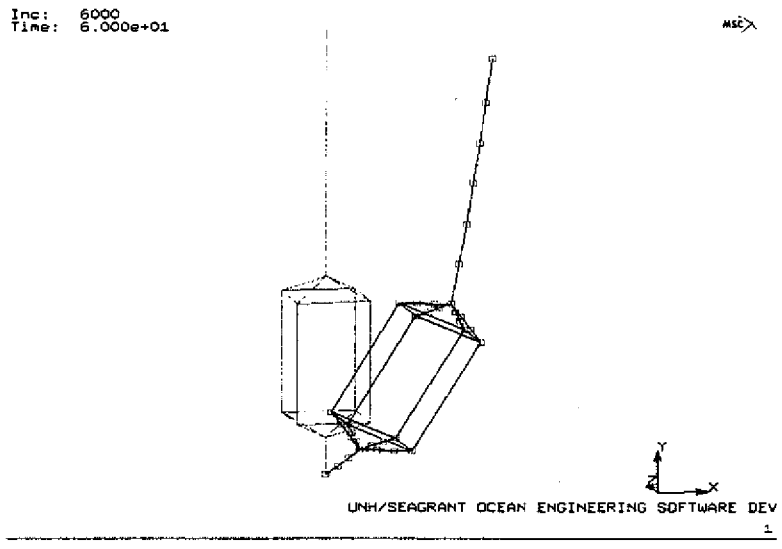

Figure 8. Displacement of Cage

It was determined that the cage movement and the buoy movement would be the most important responses to measure after waves were introduced to the system. This response is important to the urchins because they cannot survive if the movement is too rough. Figure 9 shows the displacements of the cage (B) and buoy (A) as a function of time under the current and wave parameters defined in Table 2. Later in the study current values were measured at several different cage locations. The maximum current measured was actually 0.1 meters/sec, which is five times less than the values tested for. This supports the original worst case assumption.

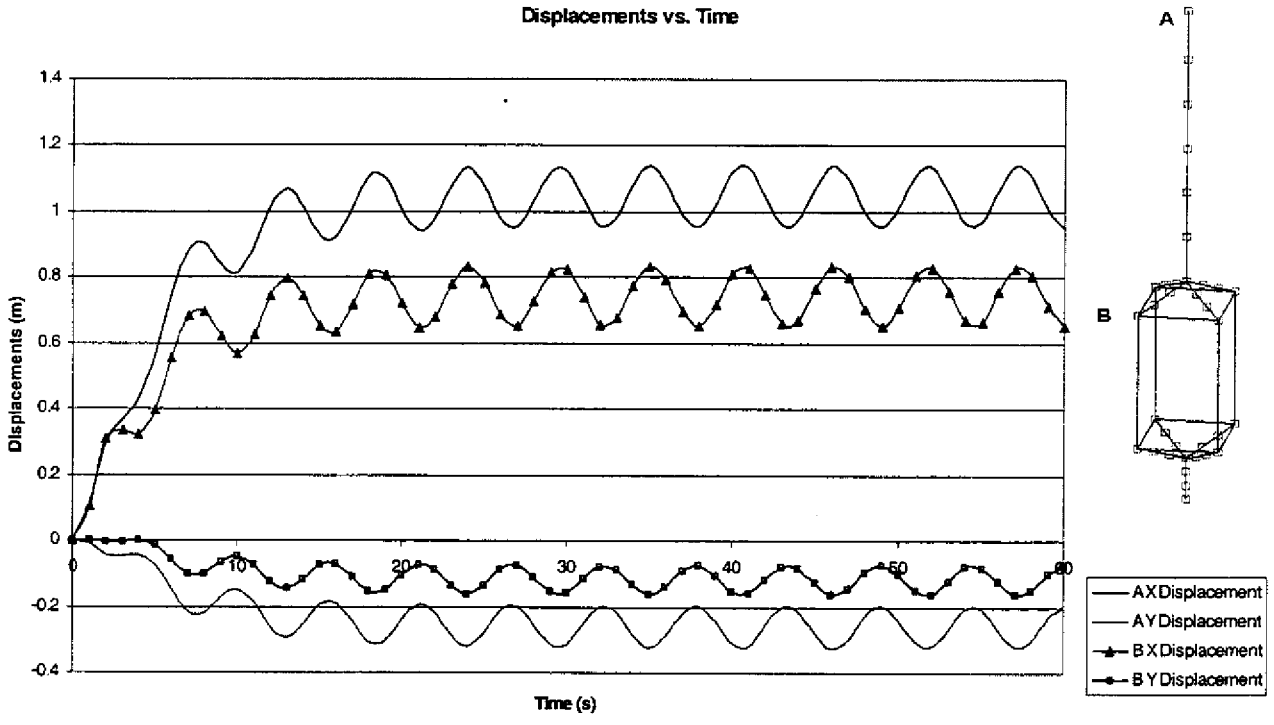

Figure 9. Displacements v. Time

As one would expect, the buoy moves a bit more than the cage but both display a sinusoidal motion. The period of oscillation for the system is a function of wave period, so one would expect the motion to be quicker with decreasing period. It is important to note that in an area such as the harbor where the cage is placed, wave activity is much smaller than the conditions tested for.

5. Biological Results

5.1 Initial Growth and Survival Investigation

Between 12/6/01 and 12/30/01, urchins in Cage 1(floating dock) grew an average of 0.78 mm, while urchins in Cage 2 (pier) grew an average of 2.68 mm (Figure 10). The average percent size increase of Cages 1 and 2 were 6.23% and 19.53% respectively.

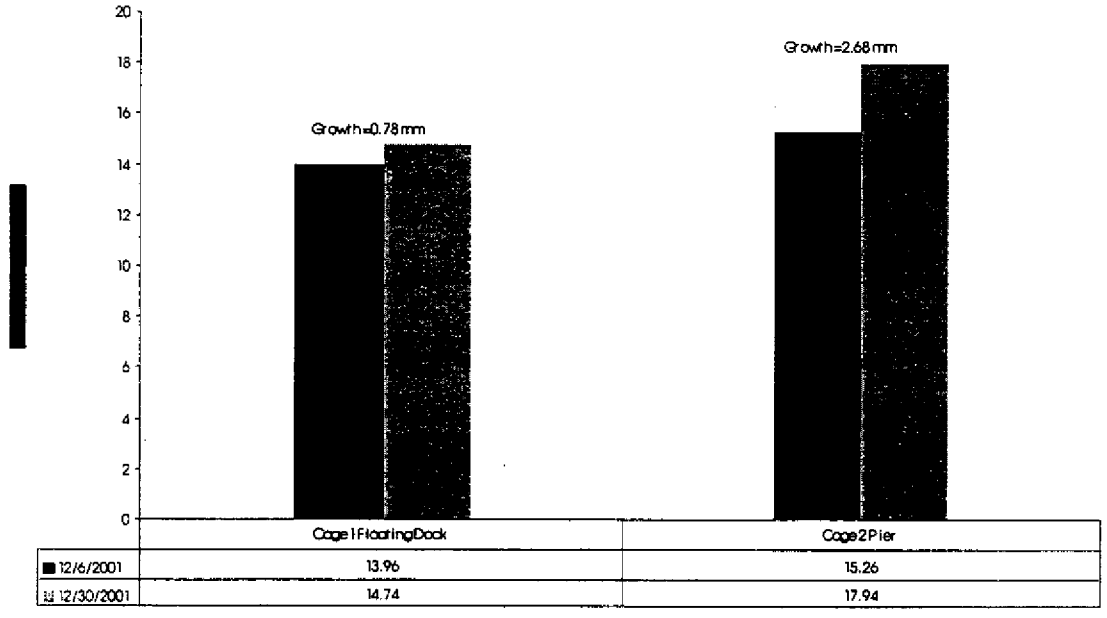

Figure 10. Initial Growth Expermental Results

Urchins in both cage systems were seen distributed primarily along the vertical surfaces of the wire mesh. Very few were seen on either the vertical or horizontal Plexiglass® panels in the middle of the cages. Additionally, very little clumping of urchins was observed. Instead, individuals spread out, utilizing all of the surface area. Lastly, it was observed that the algal bio-film (the urchins food source) that developed on Cage 2 was much more extensive than that on Cage 1.

5.2 Current v. Growth Experiment

This experiment was monitored starting 1/11/02 through 2/23/02. The average current velocities for cages 1-4 were $0.10ms^{-1}$, $0.036ms^{-1}$, $0.043ms^{-1}$, and $0.01ms^{-1}$, respectively. The average growth increases for each cage were 1.27mm, 0.67mm, 0.47mm, and 0mm, respectively (Figure 11).

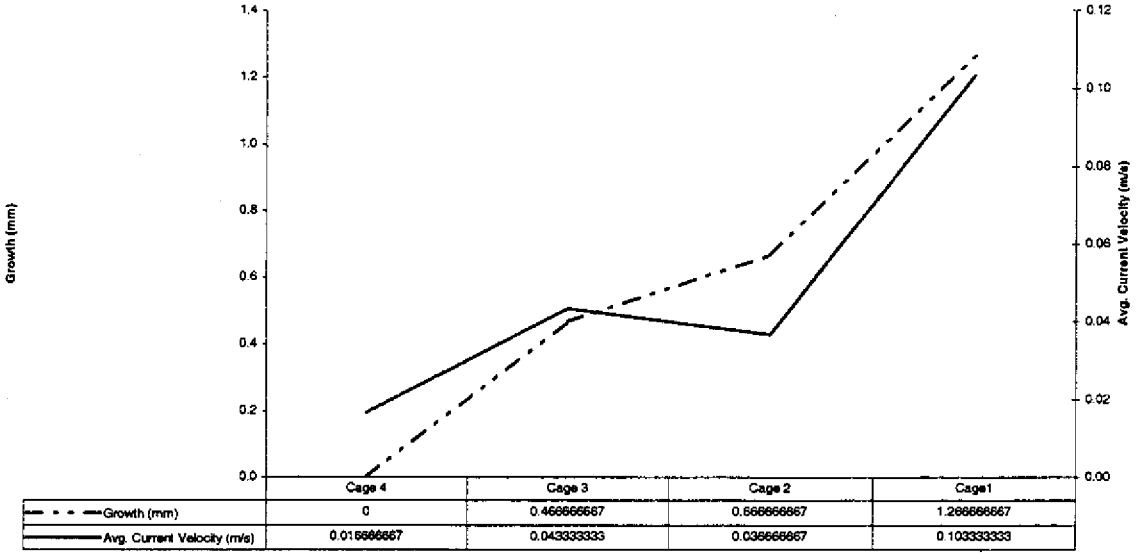

Figure 11. Growth v. Current Speed Results

5.3 Density v. Growth Experiment

A third field-conducted experiment was carried out starting 3/29/02 through 4/13/02 examining the affect of within-cage density on urchin growth. Average growth for cages with ten urchins ranged from 0.56 mm to 1.2 mm, with a mean of 0.79 mm (Table 3). Cages with twenty urchins had average growth increases ranging from 0.49mm to 2.15mm, with a mean of 1.51mm. Mean growth of urchins at forty per cage was 0.34mm, with the cage averages ranging from 0.18mm to 0.5mm. The distribution of sizes was seen to be different between the two higher densities (Figure 12 and 13).

Number of Urchins per Cage	Avg. Growth per Cage (mm)	Mean Per Density (mm)
10A	0.6	
10B	0.56	0.79
10C	1.2	
20A	2.15	
20B	1.9	1.51
20C	0.49	
40A	0.5	
40B	0.35	0.34
40C	0.18	

Table 3. Urchin Growth v. Density

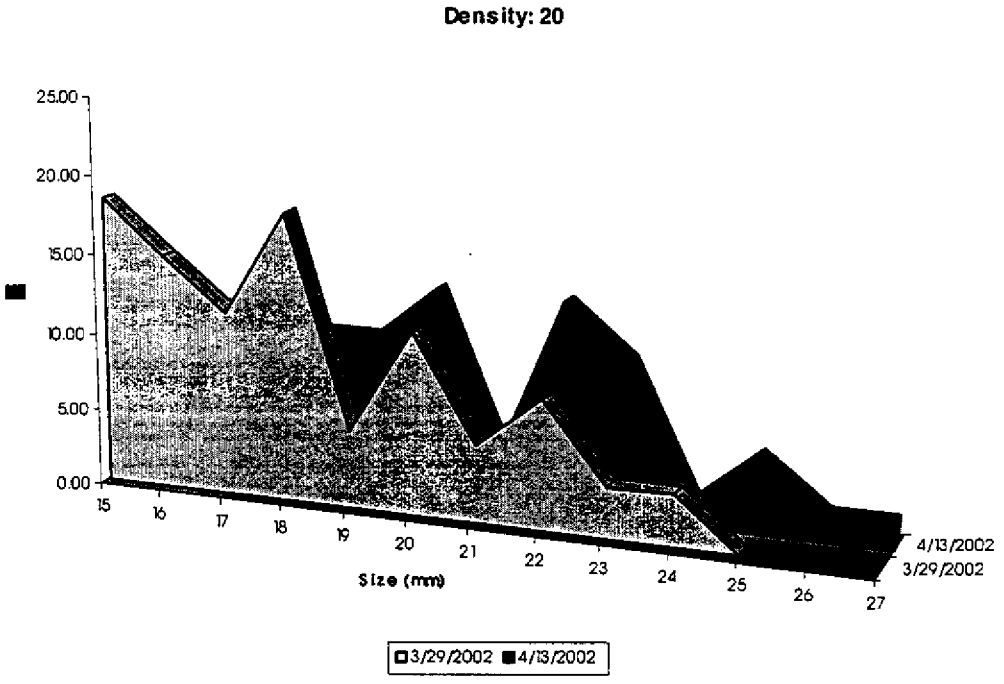

Figure 12. Density 20 Histogram

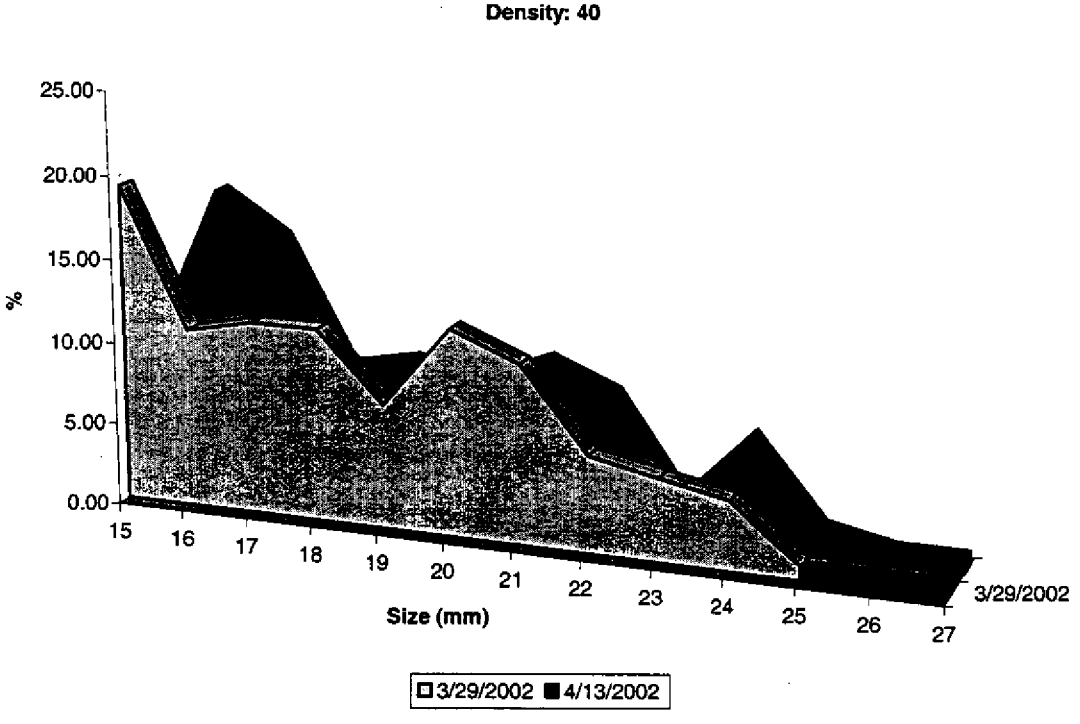

Figure 13. Density 40 Histogram

5.4 Gut Content Analysis

Of the three urchins measuring less than 4mm in the preliminary gut inspection, all three contained a large ciliate. The three urchins measuring greater than 30mm were all free of these gut parasites.

Ten urchins of size class 12-15mm were dissected and analyzed for gut parasites. Of these ten small urchins, three had no gut parasites present, four had fewer than ten parasites present, and three had greater than ten parasites present. Ten larger urchins between 21 and 25mm were also dissected and the intestines analyzed for parasites. Of these larger urchins, four had no gut parasites present, four had fewer than ten present, and three had greater than ten parasites present.

6. Biological Discussion

The initial growth experiment was designed to observe the growth, survival and behavior of caged green sea urchins. Because *S. droebachiensis* are grazers on microflora and microfauna, which settle to substrate, a current should enhance the rate of recruitment of microbiota to the cage system, providing the urchins with more food for growth while also aiding in respiration.

Cage system one was deployed near the floating dock adjacent to the Coast Guard dock, a location where the current is extremely variable due to direct boat traffic and wooden piling current obstruction, which leads to an unpredictable eddy field. These eddies reduce the amount of beneficial laminar flow over the cage system, reducing recruitment of microbiota carried by the current and could also be detrimental to urchin growth via shear force. Cage system two was placed off of the pier close to the entrance an area with low current speed, steady laminar flow, unbroken by pylons. Increased laminar water flow over the cage system enabled more recruitment, which was evident by the large amounts of algae and other organisms settled on Cage 2 in comparison to Cage 1. Mean growth of urchins in Cage 2 was over three times the mean growth of Cage 1, providing evidence that an environment providing steady laminar flow does enhance growth of urchins by providing opportunity for more food recruitment.

Also important in the initial experiment was the observation of the underwater behavior of the urchins in the cage system. When in a lab environment or in many field

locations, urchins tend to gather in clusters on vertical surfaces and crevices. A tight bunching of urchins may increase intraspecific competition and could be a significant contributor to the size differentials between urchins of the same age class, with urchins at the bottom of clumping aggregations receiving less nutrition and therefore taking longer to develop. Underwater observation of urchins in the experimental cage system showed the urchins being relatively spread out, and not clustered in the corners. At no time did the urchins in either cage form clumping aggregations. The results are a positive indicator to the cage design providing optimal surface area for the urchins, a higher density (greater than 100 urchins) in the cage is obviously possible and necessary to determine the behavior of urchins in an intensive commercial system.

The subsequent current verses growth experiment was conducted to find the optimal current in which to culture the green sea urchin. The cage size employed was modified in order to conserve urchin numbers, but also retain the relative relationship between density and cage volume.

The data supported previous studies, demonstrating a strong positive relationship between current speed and urchin growth. Unfortunately, the data did not show a threshold current speed strong enough to be detrimental to the growth of the urchins (Figure 11). Average currents provided in the data were gathered by random sampling, which could be an explanation to why Cage 2, which had a lower mean current than Cage 3, had a higher growth increase than Cage 3. The outcome could have been due to human error in measuring the urchins or the current. Another possible explanation to the occurrence is that Cage 3 was located behind an abutment of the pier, which caused eddies in the flow of the water. These eddies could have caused a similar effect on growth as in Cage 1 of the initial experiment.

The experiment testing the effect of density on urchin growth demonstrated a considerable decrease in urchin growth in the most densely packed cages (Table 3). It is interesting to note that the lowest density cages monitored showed a decrease in average growth when compared to the intermediate density cages. Thus, leading one to ask the question: If the food ration of each urchin is the same between cages of different density, what advantage may be given to urchins held under higher density? In fact, the observed difference may be an artifact of the large range in urchin size measurement or the length

of experimental monitoring. In any event, it is probable that there remains a strong relationship between urchin density and growth rate of individuals. At some threshold density, competition for space probably deters growth due to forced clumping, which reduces water flow needed for respiration. Evidence of this is found in Figures 12 and 13. At the highest density (Figure 13) it can be seen that some animals grew to a size equivalent to the maximum seen in the intermediate density cage (Figure 12). Crowding and behavioral interactions probably resulted in fewer animals having optimal growth rates in the highest density cage.

The gut content analysis was conducted in hopes of developing hypotheses for future testing, with full understanding that it would only be a preliminary investigation. Dissection and use of compound microscopy revealed both parasites (several ciliate species differentiated visually) and bacteria living within the urchin stomach. The examination of lab-reared urchin's gut content did point to a trend of parasitic presence within smaller individuals (less than 5 mm) compared to larger urchins (greater than 30 mm) of the same age. However, larger sample sizes of animals dissected are further studies are needed to strengthen the claim that parasite presence influenced urchin growth.

The examination of field-tested individuals did not demonstrate a similar trend with respect to size. Interestingly several different species of ciliates were found in both sizes of field-tested urchins. Future experimental direction should focus on the specific identification of the parasites and bacterial flora residing in the *S. droebachiensis* intestinal tract.

In conclusion, the research presented here contributes considerably to the further understanding of urchin growth variation, and maximization, which is needed in order to implement a successful *S. droebachiensis* aquaculture system to stock the GoM fishery. In addition, the research has spawned several new directions, which should also be pursued.

The investigation provided further support for the strong positive relationship between current speed and urchin growth, although a threshold speed was not found above which growth decreased most probably due to physical stress. Future laboratory or field experiments should focus on manipulating current speed in order to determine

whether such a threshold exists. This will have strong implications as to the type of environment commercial urchin aquaculture should take place in. In addition, the results provided initial support for the hypothesis (H_3) that density influences the within cage growth of urchins. Further experimentation should increase the within cage density to 80 urchins, and monitor growth for longer periods.

As stated earlier, some interesting hypotheses may be developed and tested stemming from the preliminary gut content analysis. Initial research should focus on species identification and physiology in order to determine the possibility of nutritional competition. Genetic predispositions, allowing certain individuals to possess a natural antibiotic to gut parasites, could result in those individuals growing to a larger size in the same amount of time as smaller individuals who compete with parasites for nutrient absorption. Alternatively, antibiotics could be developed, which would relieve said urchins of gut parasites, and their subsequent growth compared to those off of the antibiotics. Comparisons of gut bacteria may result in different cultures leading to different nutritional dynamics, and this possibility should also be investigated in order to more fully understand the variation in growth within distinct populations.

7. Commercial Design

As stated in the introduction, the ultimate goal of this study is a commercially effective grow out design. The reason for going into such detail with the original model is to provide a solid basis of understanding for this up-scaled design. With an understanding of the hydrodynamics of the first model along with the biological goals of the project, the final design could be created.

A commercial design for this project would be subjected to deeper and much more volatile waters. For this reason, a wooden frame replaced the original PVC structure. Pressure treated wood will not affect the urchin growth and will provide the needed stability in the rough waters in the Gulf of Maine. It also eliminates the need for sub surface buoys because the wood provides its own buoyancy in water. The external frame dimensions are 10' by 10' by 6', providing a total buoyancy of 489 lbs. Calculations for this effect are shown in Appendix A. With this magnitude of buoyancy,

a safe size mooring would be at least 1000 lbs. Figure 14 is a model of the external frame.

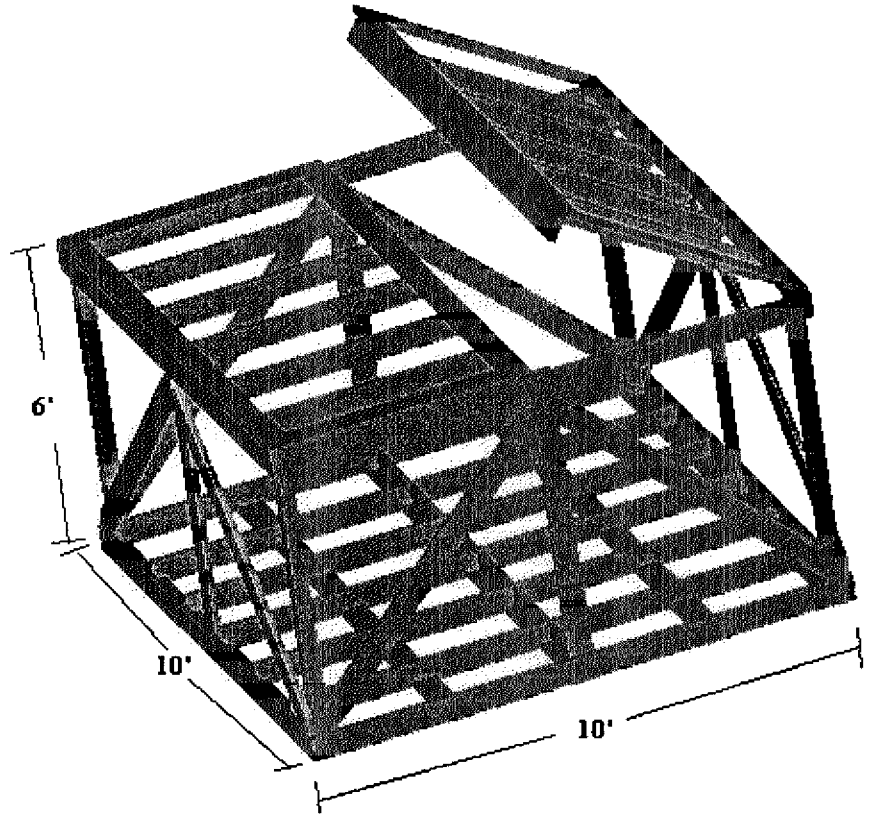

Figure 14. Wood Frame for Commercial Design

When viewing the frame it is possible to see the 12 divisions within the frame for each individual shelve. The shelves will slide into their respective slots and be secured in place when the top is closed. The shelves will be placed in an upright position due to the tendency of urchins to attach themselves to vertical surfaces. In this manner, more urchins can be placed per volume of each cage. This particular figure shows the top with one side open in order to visualize how the shelves will be removed from the system to be monitored. When the cage comes to the surface, it will be a simple process of unlatching the locks that will hold the top sections down in order to remove the shelves. The hinges for the shelves are shown in Figure 15. This can be accomplished from within a boat or done by a diver monitoring the system underwater.

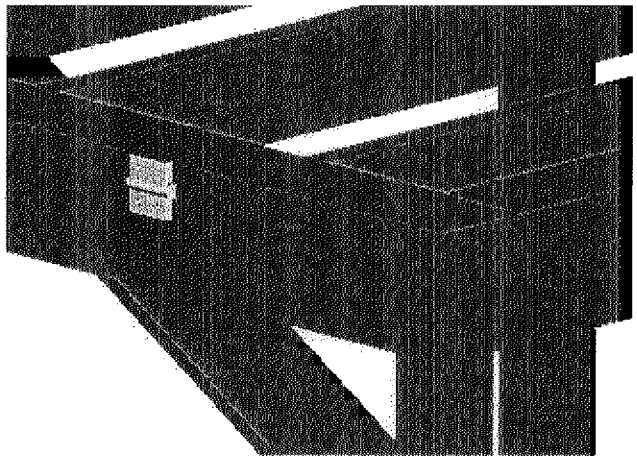

Figure 15. Hinge for Top of Cage

The shelves will be constructed of the same wire mesh that was used in the original model. The mesh is strong enough to hold its form when shaped correctly, eliminating the need for PVC or some other material aside from the wooden shell. The corners and edges can be fastened together with small cable ties. Each shelve has the external dimensions shown in Figure 16. Note that the dimensions of the actual mesh gauge are not drawn to scale, but serve as a representation of the material.

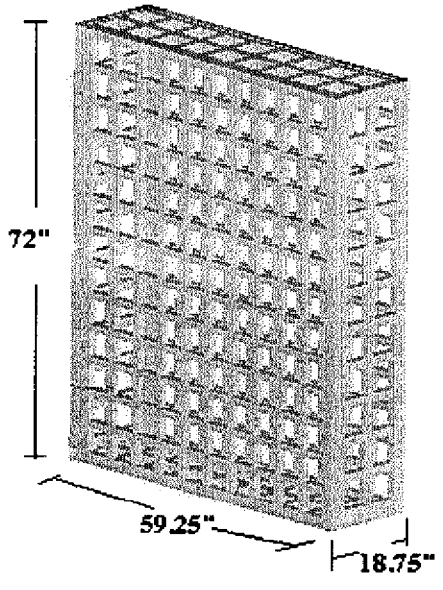

Figure 16. Wire Mesh Shelf

Assembly of the entire system only requires the insertion of the 12 shelves into the external frame. As stated before, the top doors are hinged so the shelves can be slid into their slots and locked into place by closing the doors. Figure 17 demonstrates the appearance of the system with the left door closed and the right door open.

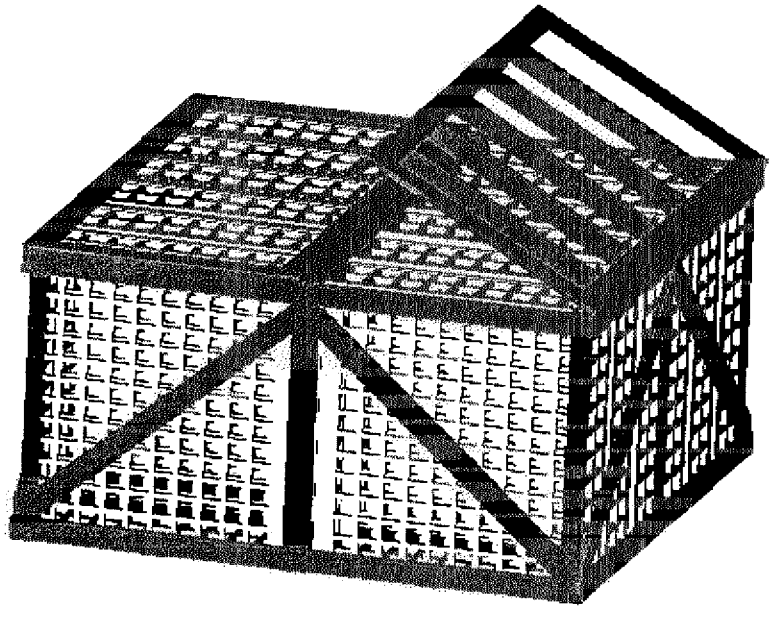

Figure 17. Entire Cage System

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Appendix A

Final Design Calculations for Water Buoyancy of External Frame

Wood Frame Primary Dimensions

$l_1 := 10ft$ $\quad area_1 := 3.5in \cdot 3.5in$

$l_2 := 6ft$ $\quad area_2 := 1.5in \cdot 5.5in$

$l_3 := 6ft$

Total Volume of Wood Frame

$vol\_4x4 := area_1 \cdot l_2 \cdot 4$

$vol\_2x6 := \left(26 \cdot area_2 \cdot l_1\right) + \left(4 \cdot area_2 \cdot l_2\right) + \left(8 \cdot area_2 \cdot \sqrt{61in^2}\right)$

$total\_volume := vol\_4x4 + vol\_2x6$

$total\_volume = 3.216 \times 10^4 in^3$

Mass of Wood and Mass of Water Displaced

$\rho_{H2O} := .998 \frac{gm}{cm^3}$ $\quad \rho_{wood} := .577 \frac{gm}{cm^3}$

$mass\_water := total\_volume \cdot \rho_{H2O}$ $\quad mass\_wood := total\_volume \cdot \rho_{wood}$

$mass\_water = 525.945kg$ $\quad mass\_wood = 304.079kg$

Buoyancy of Wood Frame

$buoyant\_force := g \cdot (mass\_water - mass\_wood)$

$buoyant\_force = 489.132lbf$