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Integrated Multi-Trophic Aquaculture

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Abstract

The purpose of this experiment was to test the effects of integrating multiple trophic levels into an aquaculture system as well as to compare the growth of organisms included in this system to those grown in monoculture. Ideally, this integration would benefit the system by reducing waste accumulation that has become so prevalent a problem in monoculture projects and it would provide additional commercially important species that should increase the economic potential of the system. The results were positive in that a system including *Tautogolabrus adspersus*, *Strongylocentrotus droebachiensis*, and *Ulva lactuca*, commonly known as Cunner, Green sea urchin, and Sea Lettuce, showed evidence of minimal waste accumulation and positive growth in the organisms.

Background Information

Integrated Multi-trophic Aquaculture

Aquaculture is a growing industry that is making a difference in sustaining and improving how wild fisheries, as well as land-based systems, are maintained. The world over, demands for seafood are growing as wild fish stocks become stagnant and even decline (FAO, 2006a). Much of this can be appeased through aquaculture, though the question remains: how can aquaculturists become more efficient in regards to both biofouling in their systems and the surrounding coastal waters as well as in maintenance costs? The industry is without a doubt growing, but problems still arise due to water quality sustenance and a reliance on fish meal-based diets derived from wild harvested fish (Barrington *et al.* 2009).

Land-based, recirculating aquaculture systems re-use water, so it is obvious that maintaining water quality has been an issue. In addition, field-based projects that utilize cages and net pens in coastal waters deal with similar problems, but instead, the impact of waste accumulation is targeted at the surrounding area – causing environmental degradation, which, in turn, inhibits the growth of the aquaculture project (Gowen and Bradbury, 1987; Chopin *et al.*, 2001).

Integration of different trophic levels to relieve some of this stress is an approach to this solution that has growing interest. By integrating a commercially important seaweed species that can facilitate growth by consuming the dissolved nitrogenous wastes of fish and other cultured species, economic potential of a system is raised while simultaneously lowering environmental impacts (Chopin, 2006).

If an additional commercially important species (i.e. mollusks, crustaceans, or echinoderms) is added to the system that will consume the solid fish wastes, the economic potential of the culture is further increased and environmental impact drops even more. The idea is to create a self-sustaining, simplified food chain so that each organism lives and grows off of the waste products of another (Chopin, 2006). Each organism is chosen carefully for a given role within the system - all genera produced in this one system can be harvested or out-planted and certain crops can be used as food for others.

Taking all of this into account, it goes without saying that each species in an integrated multi-trophic aquaculture (IMTA) system must be selected very carefully. To guarantee successful growth and profit, aquaculturists should follow a set of guidelines. First, local species that are well adapted to local conditions should be used in order to prevent the risk of an invasive species taking over the surround area and disrupting its ecological system (Barrington et al. 2009). Secondly, species should be chosen based on how well they complement species of different trophic levels. Integrated species should be able to feed off of the waste products of each other to improve water quality and provide efficient growth. Both particulate organic matter and dissolved inorganic matter should be taken into account. Thirdly, choose species that can grow to a significant biomass so that they can act as an effective biofilter. Fourthly, choose species that have a set or perceivable market value so that maximum economic input can be achieved. Lastly, use species that are acceptable with respects to regulations and policies in order for further exploration of new markets to occur (Barrington et al. 2009).

Cunner (*Tautogolabrus adspersus*)

Due to the high cost associated with constructing and maintaining recirculating aquaculture systems, most culturing has been focused on growing high-profit ornamentals, but recently there has been growing interest in culturing baitfish which can be used to supply the northeast's very successful recreational fishing industry (D. Berlinsky, pers. comm. 2010). The problem is that most of the aquaculture production for growing baitfish has been of species only fit for fishing in southeast and Mid-Atlantic waters, leaving baitfish production for use in the northeast untapped.

When deciding what fish species to use in this experiment, it was considered that striped bass and Bluefin Tuna are the most fished species in the northeast, so, naturally, a baitfish for these species would be ideal (L. Harris, pers. comm. 2010). We chose to use *Tautogolabrus adspersus* because it was readily available in the Gulf of Maine and could withstand the cold environment of the experiment of about 13 degrees Celsius (Bigelow, 2002).

Green Urchins (*Strongylocentrotus droebachiensis*)

Strongylocentrotus droebachiensis are very marketable organisms. Their gonads, which make up more than 20% of their total biomass, are considered a delicacy in Japan and many other countries around the world (Robinson, Castell and Kennedy, 2002; Robinson, 2004). Urchins are also used prevalently in schools as educational tools and in research as model organisms. They are even sold to U.S. Asian markets and sushi restaurants. The U.S. was the major supplier for high quality roe in the 1990s, but since then catch numbers have plummeted so obviously there is a demand that is not being met (Robinson, 2004).

It is estimated that Green Urchins can be sold for $10.00 per urchin for research use and $3.00 per pound with regards to sushi trade. Urchins used in educational settings hit about $5.00 per individual. The difference in price is due to the quality of the organism. For instance, an urchin that has been well grown with a known age, sex, and spawn time has a much higher market value (L. Harris, pers. comm. 2010).

Aside from their high market value, *Strongylocentrotus droebachiensis* are desirable for our experiment because there is peaked curiosity as to whether urchins will eat fish feces in an integrated aquaculture system or not (Chopin, 2006). If they do, profit from these systems could go up due to the cleanliness of the system and the addition of another marketable organism. In addition to the experimental feed of fish feces, urchins eat kelp species that can be grown in the same system, which, again, cuts costs and boosts profit (L. Harris, pers. comm. 2010).

Seaweed (*Ulva lactuca*)

Seaweeds are commonly sold for human consumption as wrapping around sushi rolls. They are also used as a fishmeal replacement in fish diets (Chopin and Sawhney, 2009). In IMTA systems, they are very useful as biological filters, absorbing and utilizing nitrogenous fish wastes to perform photosynthesis (Chopin, 2006). This is key in our experiment, because it will create a better living environment for our other organisms. Many different species of seaweeds can be used in an aquaculture system but *Porphyra yezoensis*, *Chondrus crispus* and certain kelps (*Saccharina latissima* and *Laminaria digitata*) are considered ideal because of their tough morphology and the fact that they don't really need to be taken care of too much (Carmona *et al*. 2006). We chose to use *Ulva lactuca* because of its availability to us and similarity to these marine plants.

Objectives

1) To integrate multiple trophic levels into an aquaculture system and observe the effects of this on waste accumulation.
2) To compare the growth of organisms in an IMTA system with fish and one without fish.
3) To measure the amount of waste produced by each organism in a 24-hour period.

Materials & Methods

Integrated Systems

Twelve 10-gallon aquaria and two 50-gallon aquaria were used to house two separate recirculating systems in this experiment. Two separate systems were used so we could compare the effect of fish and their waste accumulation on the system. Six separate aquaria were used in each system in order to observe the effects of the organisms on the system more efficiently (Figures 5 and 6).

Mesh cages were built to trap *Tautogolabrus adspersus* off the docks at UNH's Coastal Marine Lab. Sea urchins were provided by Larry Harris and taken from the Urchin hatchery in Portsmouth, NH. *Ulva lactuca* was taken from the side of the docks at the Coastal Marine Lab. Rocks and small self-made cage "houses" were put in the aquaria as refuges for the fish which would simulate the rocky environment that we took the organisms from (Bigelow). This would, hopefully, reduce some of the stress put on the fish from taking them out of their element.

Thirty green urchins were distributed among the three top aquaria in each system 10 urchins per aquarium. Two Cunner were also housed separately in two of the three urchin aquaria in System #1. Sea Lettuce was distributed evenly among the middle three aquaria in both systems (Figure 6). The *Ulva* was split up into three separate aquaria in each system in order to have more of an effect on filtering the water and improving water quality.

In order to aerate and tumble the sea lettuce, air tubes were created by puncturing holes in plastic tubing, which were then laid across the bottom of each of the six lettuce aquaria and secured under rocks (L. Green, pers. comm. 2010). Mesh cages were placed around the outflow valves of these aquaria in order to keep the *Ulva* from being sucked in and caught. Each row of sea lettuce aquaria had a light source directed from above in order to facilitate photosynthesis. These lights had special bulbs that were designed to not give off heat. This was essential in order to keep the sea lettuce at the desirable temperature (C. Neefus, pers. comm. 2010).

Fish food consisted of mussels, and kelp was used for urchin food (along with fish feces, a factor of the experiment). Theoretically, *Ulva lactuca* was supposed to use the dissolved nitrogenous wastes produced by *Tautogolabrus adspersus* and *Strongylocentrotus droebachiensis* and the light provided to perform photosynthesis. This was a major query of our experiment.

Growth

Water quality data was taken for one month. This included measurements of salinity, pH, water temperature, ammonia concentration, nitrite concentration, and nitrate concentration. Fish were fed 4.0 g of mussel daily, and urchin kelp feed was in constant supply. Lights used for the sea lettuce were turned on at 8 A.M and off at 5:30 P.M. every day by an automatic timer. At the start of the experiment, 15 urchins were randomly chosen and dissected to measure test diameter (mm) as well as jaw length (mm). The urchins' tests were measured with digital calipers after being euthanized by submersion in alcohol. After dissection, each Aristotle's lantern was cut out of each organism and then separated into the five individual jaws. These individual jaws were dried for 24 hours to facilitate soft tissue decay and then measured using digital calipers. This was done at the end of the experiment as well in order to compare growth.

Waste Accumulation

A separate waste accumulation experiment was conducted after the main experiment. Twelve urchins were moved into clamshell Tupperware containers and two fish into half-filled 5-gallon buckets with aeration. All of the organisms were allowed 24-hours of starvation in order to empty their digestive tracts, and then fed a daily portion. Urchins were fed 10.0 g of kelp, and fish 4.0 g of mussel. The amount of solid waste produced by urchins was filtered out and weighed. The amount of kelp remaining in each feeding container was also measured. This was also done for the fish buckets in addition to taking water quality measurements of ammonia, nitrites, and nitrates.

Results

Parallel Recirculation System Setup

At first we were only working with one system. Two Cunner were put in each aquarium, totaling 6 fish, but we found that this had to change because there was a clear hierarchy of dominance. Larger *Tautogolabrus adspersus* were attacking smaller fish for food, space, etc. so each fish received its own aquarium to preserve test subjects. Two fish were found dead on separate occasions and one injured so we disposed of the dead animals and the injured fish was taken out of the system and put in a separate aquarium to recover.

Before the formal experiment started, all of the aquaria were emptied and cleaned in order to provide an optimal, sanitary environment for the organisms. During this process, a 10-gallon and a 50-gallon aquarium were broken. This was a major set back because not only did we have to find new aquaria, but we had to get holes drilled in them for intake/outtake valves as well as buy a new bulkhead for the 50-gallon aquarium because the one it had was unrecoverable. This set the experiment back about 2 weeks.

Initially, the *Ulva* was kept in pens that we made out of mesh and power heads were put in the aquariums to increase water flow which tumble the seaweed and circulated nutrients. This proved counter-productive because the *Ulva* didn't have enough room to free-float and tumble (L. Green, pers. comm. 2011). Also, the *Ulva* was not being properly aerated in the pens which was inhibiting photosynthesis so we took all of the pens out and let the *Ulva* float freely (L. Green, pers. Comm. 2011). This led to a few problems, the main one being the powerheads doubling as blenders and were slicing the *Ulva* to pieces and another being *Ulva* getting caught in our out-flow valves, so we decided to remove the power heads and put meshing around the water flow valves in order to retain the *Ulva* in the proper tanks. To accommodate the aeration problem we added perforated air hoses along the bottom of the tanks which both added oxygen to the water as well as adequately tumbling the seaweed.

In the beginning, the lights were kept on all the time with the thought of maximizing photosynthetic activity, but this caused the *Ulva* to suffer photo-inhibition, which sent it into a reproductive state (C. Neefus, pers. Comm. 2011). This is a natural, seasonal timer incorporated in the *Ulva* because it is an annual but for our purposes we needed to keep in in the growth phase (Chopin et al. 2001). Once this happens, the *Ulva* is essentially useless to us as a biofilter, so we had to replace it with more gathered from the coast (C. Neefus, pers. Comm. 2011). After getting new sea lettuce, we talked to graduate student Lindsey Green and came up with a strategy to standardize the amount of light exposure and prevent more *Ulva* from switching over to reproduction. Timers were added that would turn on the lights at 8:00 A.M and turn them off at 5:30 P.M, lowering the amount of maintenance time we had to provide and eliminated any variability humans might cause as well as standardizing the exposure in both systems.

Organism Growth:

Tautogolabrus adspersus, the fin fish, showed an average increase in biomass of 5.3g after 30 days of feeding on crushed muscle tissue (Table 1). Fish #1, the smaller one, grew from 47g to 50.2g while Fish #2 increased biomass from 94.6g to 102g giving an average growth of 5.3g per fish over 30 days (Table 1). *Ulva lactuca* increased its wet biomass by 18.3g in System #1 and only 15.0g in System #2 over the experimental period using the nitrates, nitrites and ammonia produced by the fish and any nitrogenous wastes given off by the urchins (Table 1) (Barrington et al. 2009). *Strongylocentrotus droebachiensis's* growth rates were tracked comparing changes in test diameter and average jaw length. Initial results were taken before the 30 day feeding experiment began by randomly selecting 15 individuals and measuring test diameter with calipers and then extracting the jaws for measurement. The average test diameter from the initial batch was 21.01mm and the average jaw length of each urchin was 7.23mm (Figure 2). Following the experimental period the same procedure of selection was done and 15 urchins were randomly selected from each system to compare to the initial results. *Strongylocentrotus droebachiensis* from System #1 had an average test diameter of 23.74mm and an average jaw length of 7.91mm, increases of 2.73mm in test size and 0.78mm longer jaws after one month (Figure 2). This is compared to System #2, the control setup without any fish, where the average test diameter was 19.72mm and jaws were 6.61mm (Figure 2).

	Fish and *Ulva* growth		
	Initial Biomass (g)	Ending Biomass (g)	growth (g)
Fish #1	47	50.2	3.2
Fish #2	94.6	102	7.4
Ulva System #1	238	256.3	18.3
Ulva System #2	217	232	15

Table 1: Initial and ending biomasses of both Cunner and the *Ulva* from System #1 and System #2.

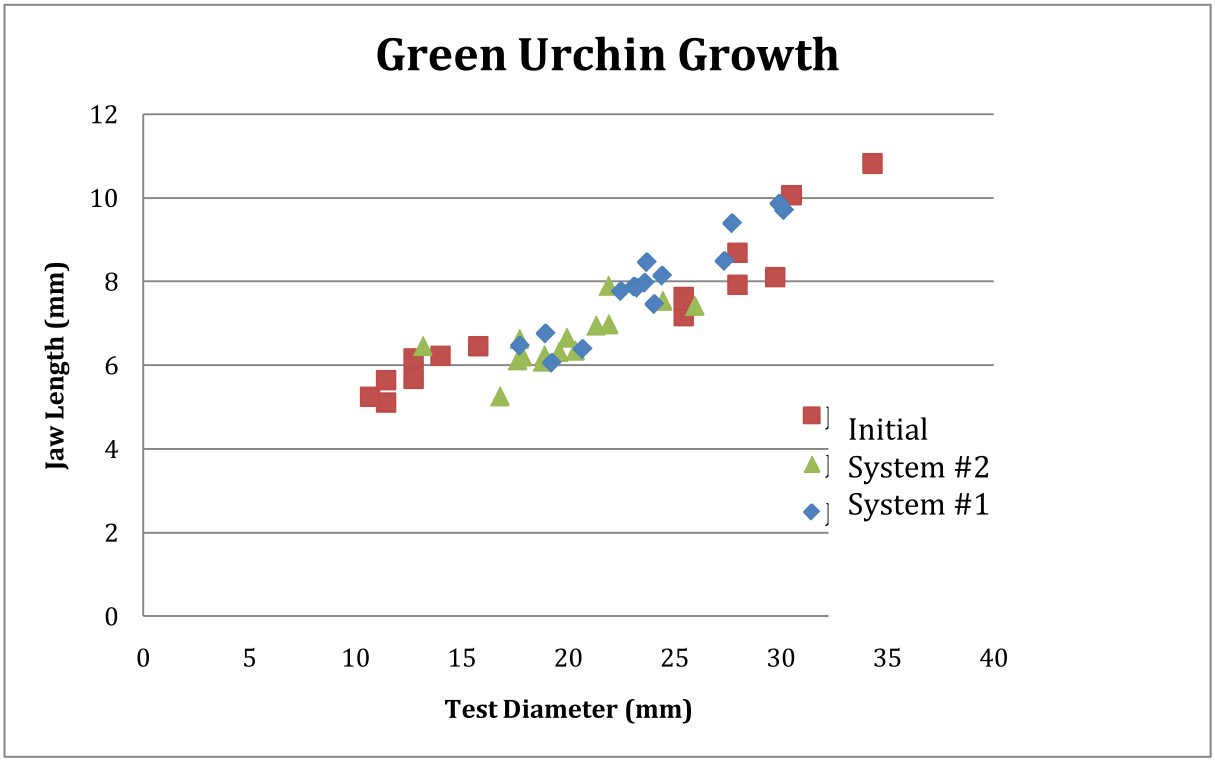

Figure 1: Green urchin sizes (Jaw length and test diameter) from both systems. Initial sizes indicate randomly selected urchins from before the experiment began.

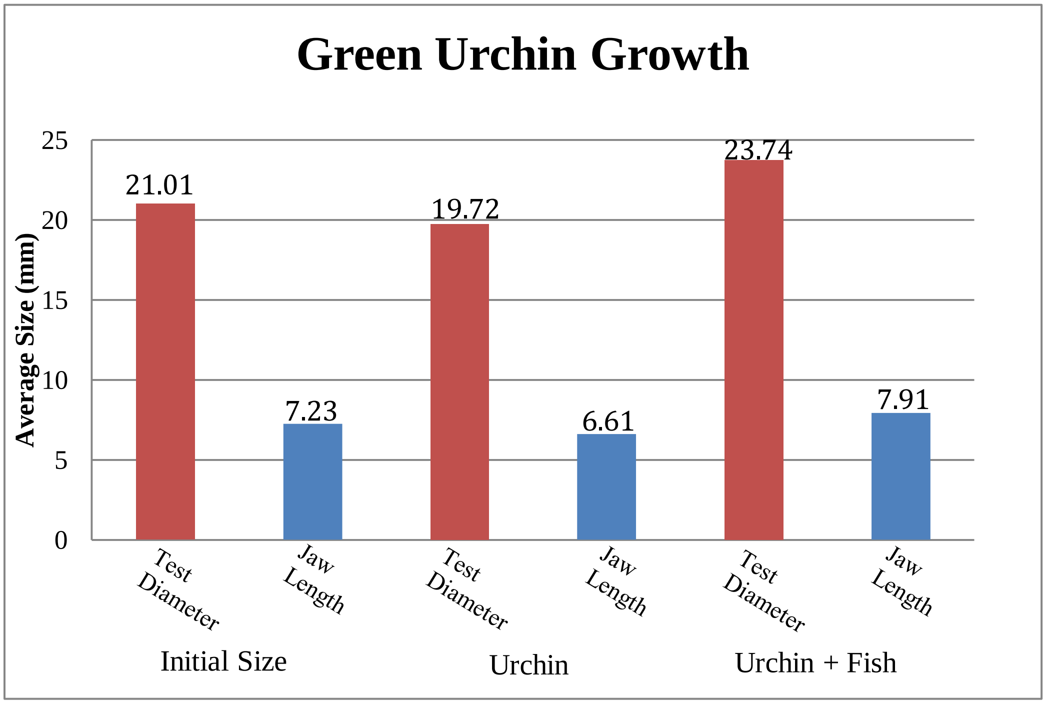

Figure 2: Average of 15 Green urchin sizes from before and after the experimental growth period.

Organism Waste Production:

Out of the three species found in both integrated aquaculture systems, two were heterotrophs and one was an autotroph. The heterotrophs, *Tautogolabrus adspersus* and *Strongylocentrotus droebachiensis*, produce both solid and nitrogenous wastes which are metabolized by the autotroph, *Ulva* (Barrington et al. 2009). After a 24 hour starvation period and a 24 hour feeding period 12 Green Urchins, *Strongylocentrotus droebachiensis*, averaged 0.325g of solid waste produced by each urchin; all were wet weights (Table 2). This waste was produced from 0.415g of kelp consumed per urchin in the 24 feeding period which leaves 0.09g being metabolized for energy and growth in each urchin every 24 hours (Table 2). Waste produced by *Tautogolabrus adspersus* was entirely dissolved nitrogenous waste, no solids observed. Both fish were kept in separate 2 gallons of pure sea water with an airstone and after the 48 hour waste production experiment increases of 0.20ppm ammonia, 0.25ppm nitrites, and 10ppm nitrates were observed on average (Table 2). This waste was produced after consuming *Mytilus edulis*, blue muscle, tissue. Cunner #1, the smaller, ingested all 3.0g of muscle tissue over the 24 hours while the larger Cunner only ate 2.8g. *Strongylocentrotus droebachiensis* is known to be an omnivore so in the recirculation systems any leftover *Mytilus edulis* tissue would have been consumed (L. Harris, pers. Comm. 2011).

Animal Waste Production

Urchin	Kelp added (g)	Mass Consumed (g)	Solid Waste Produced (g)
1	10	0.4	0.4
2	10	0.41	0.4
3	10	0.96	0.1
4	10	0.66	0.4
5	10	0.7	0.4
6	10	0.55	0.2
7	10	0.1	0.3
8	10	0.1	0.4
9	10	0.08	0.3
10	10	0.4	0.4
11	10	0.51	0.3
12	10	0.11	0.3
	Avg	0.415	0.325
Cunner	Muscle added (g)	Muscle consumed (g)	Nitrogenous Waste Produced
1	3	3	0.15ppm ammonia
			0.25ppm nitrites
			10ppm nitrates
2	3	2.8	0.25ppm ammonia
			0.25ppm nitrites
			10ppm nitrates
	avg	2.9	

Table 2: Amount of food consumed by Green urchins and Cunner in 24 hours following a 24 hour starvation period compared to the amount of solid and dissolved nitrogenous wastes produced by each individual; all are wet weights. The nitrogenous wastes accumulated in 2 gallons of pure sea water.

Water Quality with a Biofilter:

Throughout the past academic year we have experimented with different treatments and sources of water for our Parallel Recirculation Systems. It all began with using seawater collected from the New Hampshire coast at the Coastal Marine Lab but later we decided to limit the variables of water content, because of the extreme variability in seawater chemistry. We mixed our own water by combining Instant Ocean and De-ionized water to the proper salinity, 35ppt. Our method of maintaining healthy nutrient levels in each system was to employ a biofilter, the *Ulva lactuca* because it will remove the harmful nitrogenous wastes and grow as a result (Chopin et al. 2001).

System #1 was the experimental system integrating *Tautogolabrus adspersus* with *Strongylocentrotus droebachiensis* and *Ulva lactuca* the two animal species were in the top three tanks with the biofilter in the middle tanks and the mixing reservoir at the bottom (Figures 5 and 6). The average salinity of System #1 was 34.5ppt over the 30 day experiment, average Nitrite levels remained at 0ppm, Nitrates 3.125ppm, and ammonia 0.09ppm (Figure 3). The pH of System #1 was an average of 8.31 during the experimental period and temperature was maintained at a steady 13 degrees Celsius throughout all levels of both systems, each which had ~100 gallons of water circulating at all times (Figure 3). System #2, containing only *Strongylocentrotus droebachiensis* in the top levels and *Ulva lactuca* in the middle tanks, recorded an average salinity of 32.18ppt over the 30 day experimental trial (Figure 2). Nitrites were 0ppm, Nitrates were also 0ppm, and ammonia was 0ppm in the water column but the pH was slightly more elevated than System #1 with an average of 8.56 in System #2 (Figure 2). As you can see, without the *Ulva*, or another filtration method, the waste produced by *Tautogolabrus adspersus* and *Strongylocentrotus droebachiensis* as mentioned above would have quickly reached toxic levels.

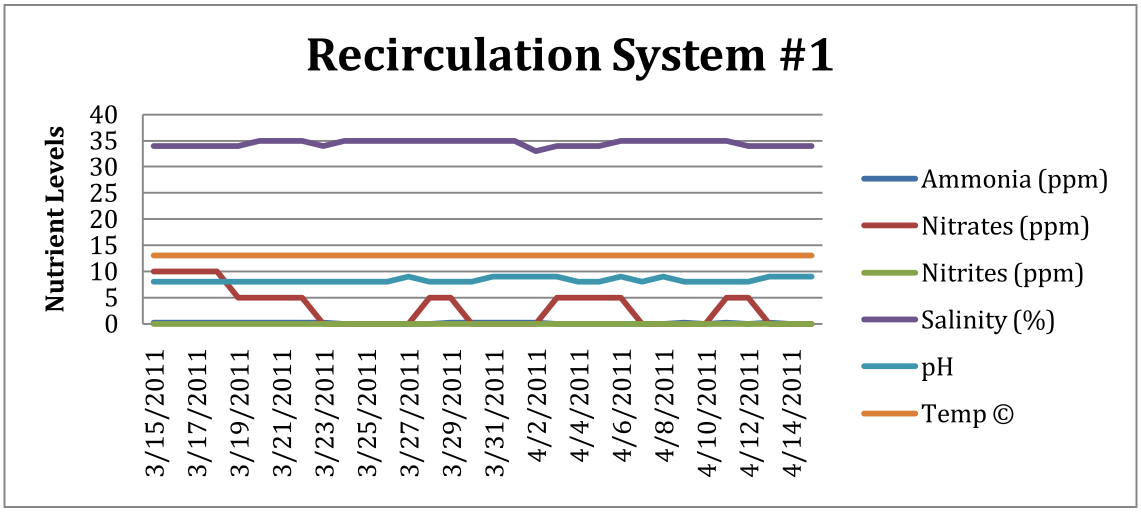

Figure 3: Track of water quality in the completely integrated system containing *Tautogolabrus adspersus*, *Strongylocentrotus droebachiensis*, and *Ulva lactuca* over the 30 day experimental period.

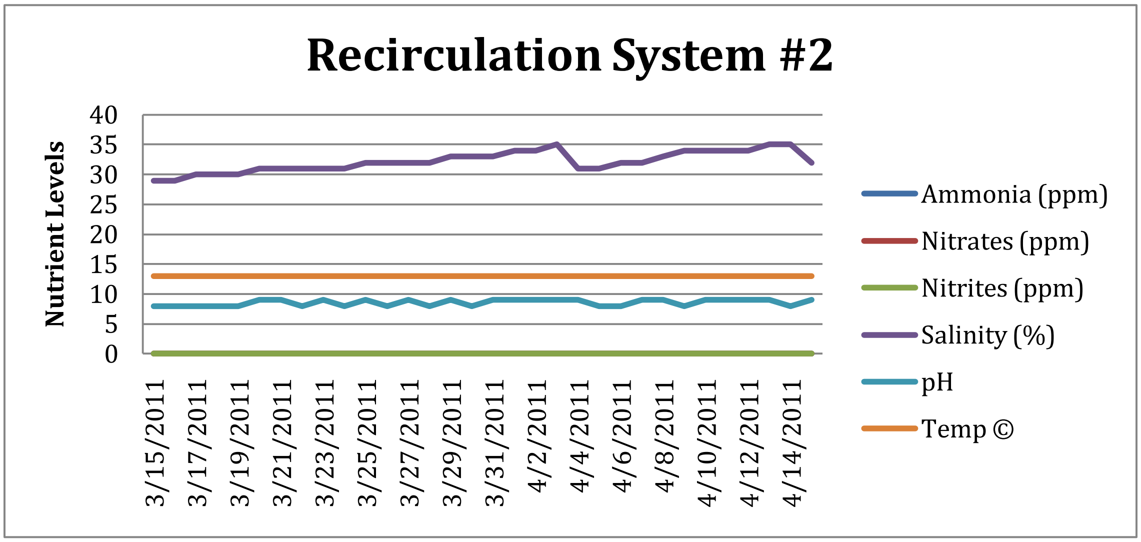

Figure 4: Track of water quality in the control system, *Strongylocentrotus droebachiensis* and *Ulva lactuca*, over the 30 day period.

Figure 6: Experimental setup #1 Cunner and Green Urchins in the top aquariums, *Ulva lactuca* in the middle aquariums, and a mixing reservoir in the bottom. Setup #2 is identical other than the absence of *Tautogolabrus adspersus* in the top aquariums.

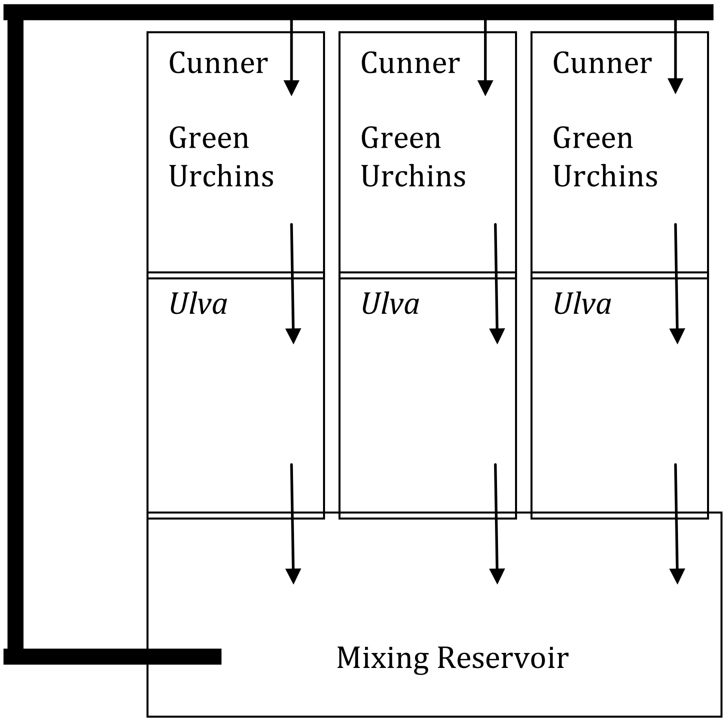

Figure 7: drawing of Experimental #1 to match Figure 6. Arrows indicate water flow (line width indicates flow volume).

Discussion & Conclusions

Water quality in both systems remained fairly constant, especially once we had the lighting, aeration and water circulation worked out. System #1, including fish, had higher levels of ammonia and nitrates dissolved in the water which indicates there is an excess of nitrogen in the system allowing for optimal seaweed growth (Barrington et al. 2009). This increased nitrogen level can be attributed to the presence of *Tautogolabrus adspersus* because System #2 had lower nitrogen levels and only contained *Strongylocentrotus droebachiensis* and *Ulva lactuca* (Figures 1, 2, and 7). Indicated by the presence of nitrogenous wastes dissolved in the water is the capacity for more *Ulva,* or another autototroph, to filter and metabolize the nitrogen compounds (Barrington et al. 2009). With more biofilters the water quality be further improved and the growth of more seaweed for feeding or other commercial use is made possible and either way, costs will be reduced and there will be more product for use.

All organisms in System #1 showed more growth at all trophic levels than System #2 (Figure 5, Table 2). This is exactly what we were looking for, experimental proof that with the presence of fish and urchins and *Ulva* together in an aquaculture system would yield more production. Not only that, we now can report that these organisms can share the same system and not compete with each other because of the different niches they occupy and actually feed off the others' wastes cleaning the system and promoting growth. Finding that *Strongylocentrotus droebachiensis* will actually consume fecal matter from the fish, leading to increased growth, is a great breakthrough in itself because they can now recycle more materials and experience greater increases in biomass which results in greater sales of gonads and use as sushi (L. Harris, pers. Comm. 2010). Using Cunner as the fin fish was a forced choice based on temperature salinity tolerance as well as availability. Prime fish candidates would be those in high demand on the market, especially those who live up in the water column rather than bottom dwellers because of the shared space with the urchins. We now know that urchins will consume fish fecal matter so that shouldn't be an issue of species and as long as the fish can tolerate matching salinity and water temperature as the *Strongylocentrotus droebachiensis* there is a great chance for a successful aquaculture program (D. Berlinsky, pers. Comm. 2010). Another barrier that a full tilt aquaculture program would have access to is timing pellet feeders rather than breaking up muscles and feeding the fish by hand, with a large operation you would time feeding times and standardize mass of food, forcing the fish to eat that food or die (Berlinsky). We didn't have that option with the Cunner because of availability, funding, and timeframe we had to cater to their every need to keep them happy and alive but in a further study those other options should be applied to get more accurate results for an aquafarm. *Ulva lactuca* growth was the most difficult part of the experiment because of the much altered environment we were growing it in. one batch totally failed in the fall because of lack of water circulation and photon inhibition and overexposure. This led to the use of timers for the lights, 9 hours/day, and the airstones to aerate and circulate the water without damaging the *Ulva*. The growth measurements did show increased growth in System #1 however due to more available nutrients (Table #2).

Waste production ranged from dissolved nitrogenous waste, produced by both *Tautogolabrus adspersus* and *Strongylocentrotus droebachiensis,* to solids produced by the *Strongylocentrotus droebachiensis,* the urchins consumed any solid waste produced by *Tautogolabrus adspersus*. Any solid waste produced by the fish was eaten by the urchins, resulting in the increased growth they experienced when in the presence of *Tautogolabrus adspersus* (Figure 5). Although no solid waste was observed from the fish waste production experiment, there have been observed fecal pellets produced by *Tautogolabrus adspersus* (Barrington et al. 2009). Production of the dissolved nitrogenous wastes makes sense because that is the most rapidly produced waste product, liquids, because animals are trying to maximize the use of the solid biomass for growth and energy (D. Berlinsky, pers. Comm. 2010). The accumulation of these wastes may seem high per fish in 2 gallons of water for only a 24 hour period but some of the consumed muscle mass probably hasn't been processed yet but as Figures 1 & 2 showed, even with both fish living in the 100 gallon system, the water quality remained similar to the system without fish due to *Ulva lactuca.* Solid wastes produced by the urchins were observed even over a 24 hour period (Table 1). Starvation of the urchins was necessary to make them apt to eat more of the kelp and allow them to empty their guts of any pre-consumed material. 0.415g being consumed from the available 10g is a very small portion consumed but that is by each urchin over only 24 hours. This 4.15% proportion of consumption is actually not alarming because invertebrates eat and grow slowly and can go for long periods of time without food if necessary, especially in colder water (Harris). Our urchins might not have been extremely stressed into eating after only 24 hours without food but that can be good because they are demanding less food to sustain them which could save money. Production of 0.325g of solid wet waste is a rather large portion of the 0.415g consumed but due to the slower metabolism, some of that waste could still be from previously consumed material (Table 1). Despite all of this waste production, this can be positive for your system if you have other detritovores present or have the ability to remove this waste and use it as fertilizer.

In future related experiments keeping track of regular feeding rates and volumes are imperative in order to relate to organism growth and possible costs of aquaculture. When gathering results on urchin growth make sure to get the initial and final biomass in addition to the test diameter and jaw length because that is what is going to interest most buyers either for gonads or sushi. Also, in our experiment, we should have measured the average test sizes once the urchins had been divided up between systems in order to get a percent increase in biomass to go with the body sizes. When tracking waste production in your system there will also be dissolved wastes produced by *Strongylocentrotus droebachiensis.* This can easily be done by taking water quality measurements to compare over time using YSI or chemical tests while at the same time monitoring individual consumption rates and solids produced.

The use of multiple organisms from different trophic levels is possible and extremely productive in aquaculture. Integrating these organisms into the same system is an extremely efficient use of space, one of the largest limiting factors for aquaculture (Barrington et al. 2009). It also leads to increased growth for each species used in our study due to the nutrient cycling done by autotrophs and heterotrophs which both cleans the system and keeps nutrient levels from reaching dangerous levels as well as leading to growth of other organisms (Table 1 and Figures 1 & 2). When forming an aquaculture system it would be extremely advantageous to utilize multiple species to minimize costs and maintenance while increasing production and eventually profit.

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