# Patterns of succession on available substrates in the mariculture system of Bajia Cuajiniquil and their implications for sustainability

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## Abstract

A persistent problem with marine aquaculture, one that may stand in its way of sustainably supplementing the world's demand for fish, is the biowaste – fish feed, excrements and carcasses – that accumulates on site. In the mariculture system of Cuajiniquil there may be a solution already in place; filter feeding invertebrates have colonized the cages and are living off the excess nutrients intrinsic to a mariculture farm. In this study I looked at how these filter feeders are arranged on the surface of the cages and whether or not they could colonize introduced frameworks. By surveying transects of each net on site and placing wood and metal frameworks into the bay, I was able to look for patterns in filter feeder species abundance, richness and diversity. The data from my study suggests that there are three major dictators of filter feeder colonization: protection, depth and substrate complexity.

## Resumen

Un problema persistente con la aquacultura marina, que puede presentarse en su forma completa de manera sostenible para la demanda mundial de pescado, son los residuos biológicos - la alimentación de los peces, excrementos y organismos muertos - que se acumulan en el sitio. En el sistema de maricultura de Cuajiniquil puede haber una solución, que ya en ese lugar, invertebrados que se alimentan por filtración han colonizado las jaulas y viven del exceso de nutrientes producto de una explotación de maricultura. En este estudio examine la forma en que estos organismos filtradores se organizan en los comederos de las jaulas, y si estos tratan o no de colonizar marcos introducido. Mediante el estudio de transectos en cada una de las redes en el sitio y con la colocación de marcos de madera y metal en la bahía, fui capaz de buscar los patrones de alimentación de filtradores en cuanto a la abundancia, riqueza y diversidad de especies. Los datos de mi estudio sugieren que hay tres grandes jugadores en la colonización de los filtradores: la protección, la profundidad y la complejidad del sustrato.

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Ocean fish stocks cannot support the current demand for seafood, and seafood consumption is only expected to increase in the coming years (Glenn & White 2007). Without innovative solutions, wild fisheries around the world are projected to collapse by the year 2048 (Worm 2006). Marine aquaculture – the farming of aquatic fish, mollusks, crustaceans and plants – currently accounts for about half of the sea food consumed in the world, and will most likely increase to fill the ever widening gap between wild supply and human demand (Pittenger et al. 2007). While highly promising, mariculture comes with several ecological, economical and social problems. Keeping large numbers of marine organisms in one place can drastically alter the site's ecosystem by impacting water quality, nutrient cycling, seedstock, disease transfer, phytoplankton abundance and genetic variability (Zedan 2004). Many of these stressors stem from the concentration of waste products at mariculture sites. Waste comes from the feed, feces and carcasses that are all contained by the nets with the farmed fish (Pittenger et al. 2007) and results in high concentrations of soluble inorganic nutrients like nitrogen and phosphorous (GESAMP 2001). In these conditions phytoplankton blooms can easily cause anoxic water, and waste-borne viral and bacterial infections can spread rapidly through both farmed and wild populations (Glenn & White 2007). The challenges of waste are thus important to address to move mariculture closer to sustainability.

Solving the waste problem means finding a way to extract, or filter waste particles out of the water effectively. Filter feeders then seem like the natural choice, as they are often considered optimal foragers, and feed by extracting particles from the water (Lehman 1976). Certain qualities to filter feeders may make them ideal candidates for this very purpose. Some species may orient to different particles, and can selectively feed only on those elements (Cavallo 2007). Bivalves, a large and efficient class of filter feeders, assimilate preferentially to the elements in the highest concentration in the water – whatever element is most common is the one they assimilate most efficiently (Reinfelder 1997). Most species are able to maximize the net rate of energy gained from their food (Lehman 1976). If they can be successfully harnessed, filter feeders could be the ideal biofilters in high nutrient, mariculture waters.

A clue to this kind of integration might be present in the mariculture pens of Bahia Thomas. Located near the fishing town of Cuajiniquil in the Guanacaste province of Costa Rica, the Bahia Thomas site farms Spotted Rose Snapper (*Lutjanus guttatus*) in three cages, or modules. The modules are made of nylon nets and hang down into the water in a cone shape, with the point of the cone at six to seven meters beneath the surface. When I observed these nets in May of 2009, the net on Module Three had been in place for about one year, and the net on Module One had been in place for a few days. Thousands of organisms had attached to the on year old, Module Three net, many of which were filter feeders. These individuals had nearly covered the net especially near the bottom of the module, which was blanketed entirely with La Paz Pearl Oysters (*Pinctada mazatlantica*).

Could these filter feeders, already present on the module nets, be a clue to waste filtration on a larger scale? A small-scale system like Bahia Thomas might provide a place for testing solutions to the challenges faced by mariculture. To look at biofiltration by naturally colonizing filter feeders, I posed two questions.

(1) What is the composition of filter feeder species living on the module nets? The established community on Module Three could indicate the number and type of filter feeders that can establish onto a net in a year. Those who colonize Module One in the ten days of observation will indicate early colonization patterns for a similar substrate type. Together, these indicate the naturally occurring filter feeders in the bay, and those that might most efficiently be extracting nutrients. By surveying the community on these nets with transects, I was able to construct a map of morpho-species and their abundance at different depths on the module nets.

(2) What filter feeders can colonize artificial structures in ten days? To address this second question, I introduced artificial structures into the bay near the modules. The organisms that establish on the artificial structures might indicate the first steps to recruitment on different substrates, and ways in which farmers can introduce substrate to recruit biofilters.

The comparison of Module Three's net community, Module One's colonization pattern and the larvae that colonize the artificial structures in ten days point to the differences in community development between the two substrate types. The species found on Modules Three were very different from the species found on the introduced structures, however they both seemed to follow distinct trends for species number and abundance. This information could be a starting point for designing management systems for Bahia Thomas, and mariculture on a larger scale – whether that means introducing more nets, allowing existing nets to establish filter feeding communities, or introducing structures into the bay to establish permanent ones.

## Materials and Methods

I conducted my study in Bahia Thomas, a bay near the town of Cuajiniquil in the Guanacaste province of Costa Rica (Figure 1). The mariculture system in Bahia Thomas consists of three cone shaped cages (modules) suspended in the water with buoys and rings of polyvinyl chloride (PVC) pipe. The tip of the cone hangs six to seven meters below the surface, and the top extends out from the water into three meter by three meter square openings. The nets are made of 2cmx2cm nylon mesh, and each pen holds between 150 and 300 Spotted Rose Snapper (*Lutjanus guttanus*) in different developmental stages.

### *Modules One and Three*

On 7 May 2009, when I began data collection, the net on Module One had been in use in the bay for four days, and the net on Module Three had been in the water for over a year. To survey the individuals on these nets I took transects of each net on both the inside and outside surfaces at 0-1m, 1-2m, 2-3m, 3-4m, 4-5m, and 5-6m. Each day I surveyed one depth level. First I attached a long measuring tape to the top of the net to serve as a depth guide. Starting on the outside surface of Module Three I used a carabineer to attach a 20cmx20cm transect box to the net at a random location. For each transect I made one free dive per morpho-species. For all morpho species I counted the number of individuals I observed in each box. In the case of sponges I also recorded the percent coverage within the transect. For Module One, I recorded the percent algae coverage, as well as any other species I observed. I repeated this process for five transects on each surface for each module at each depth. For example, on 11 May 2006 I surveyed five transects between 3-4m on Modules One and Three both inside and outside, for a total of 20 transects. In total, 120 transects were evaluated (Appendix A and B).

### *Artificial Structures*

I designed the artificial structures for this study after previous work done with artificial reef construction, in which structures were designed to provide a realistic substrate through which organisms could move fluidly (Perkol-Finkel & Benyahu 2005). On 6 May 2009, nine 1m x 1m x .5m frames were constructed out of Molina by Chango in Cuajiniquil. I wrapped each frame in a strip of wire mesh .25m wide, leaving large spaces to allow for fish and other organisms to move within the structures. On 7 May 2009, I deployed the frames in three sets (A, B and C) of three boxes (1, 2 and 3) that floated in a vertical line from the surface to the bottom (Figure 2). On 16 May 2009, after ten days in the water, I removed the frames one at a time and counted the number of individuals that had colonized them. To keep unit effort the same for each surface, I identified a consistent side of each frame that had the same surface area and features (Figure 3). Together with Kimmie Riskas, we used hand lenses to count morpho-species on each surface for 20 minutes. Each side consisted of .03m$^2$ of metal mesh and .0915m$^2$ of wood. In each corner there were three nails. Once the timer started, I counted the number of individuals per morpho-species using a hand lens on all four sides.

Later, for both the Modules and the artificial structures, I grouped morpho-species into phylum, and identified them to genus as species when possible (Table 1).

## Results

### *Module One*

In five days of observations, the algae coverage on Module One's net showed distinct trends for the inside and outside surfaces of the net (Figure 4). Inside the net, the average percent algae increased with time, from 22% coverage to 70%. Outside the net, the average algae coverage stayed relatively stable around 27%, with a high of 34% and low of 22%.

### *Module Three*

When the inside and outside surfaces were totaled, the net on Module Three demonstrated a high variability between phylum with depth (Table 2). Cnidaria and Chordata for example, stayed relatively constant at all depths of the net, while Echinodermata and Mollusca showed definite increases in abundance with increasing depth. Athropoda showed a decrease in abundance with depth, while Porifera and Annelida showed peaks at specific depths (three meters and 2.5 meters respectively). Overall number of species increased with depth, while number of individuals decreased (Figure 5). The Shannon Weiner Diversity index increased with depth, although not significantly so.

Inside the Module Three net there were significantly more individuals (Wilcoxin Sign Rank Test, t=.012) than outside, but the same number of species (t=.2103). Although not a statistically significant difference (Wilcoxin Sign Rank Test, t = .1242), the Shannon-Weiner diversity index value inside the net peaked at 5-6 meters, while outside it peaked at 3-4m (Figure 6). The large oysters, *Pinctada mazatlantica*, were only found between three and six meters deep on the inside of the Module Three net.

### *Artificial Structures*

The species abundance on the artificial frames differed greatly between the wood and metal substrates (Figure 7). Significantly more organisms colonized the wooden frame than the metal wiring (Wilcoxin Sign Rank Test, t = .0004), but like the inside and outside of the nets, the same species were found on both wood and metal.

Between the three sets of frames (A, B & C), there was no significant trend in number of species (Two-way ANOVA, p>.1242). Number of individuals and Shannon Weiner Diversity Index also showed no significant variation (p> .2103 and p>.1543 respectively).

### *The Relationship*

There was little overlap in the morpho-species that occurred on the Module Three nets and the frames – I found only three species on both (Table 1). Two of these overlapping species were in the phylum Arthropoda.

Combined, the nets and artificial structures showed a trend of increasing diversity with depth (Figure 8).

## Discussion

From the data I can suggest a few parameters that might benefit the culture and maintenance of filer feeders: protection, depth and substrate complexity.

### *Protection*

There is clearly something special about the inside of the Module Three net compared to the outside of it. That there is no significant difference in the species composition between the two sides indicates that larvae can travel through the net and establish on either surface. This, in conjunction with the significant difference in the number of individuals inside the net suggests that the inner surface is providing some sort of benefit to the larvae and organisms that live there. The larvae can travel between and settle in either place, but those that settle on the inside have a higher survival rate.

This same trend is reflected in the algae colonization on Module One (Figure 4). Algae colonized and grew over the inside of the net much faster than it did the outside, reflecting the same kind of benefit to organisms inside the net over those outside.

The inner surface of the net could provide several advantages. Organisms there are that much closer to the high nutrient water produced by the fish food and waste. They are also shielded from all fish species but the Spotted Rose Snapper, who eats the fish food provided by the farmers, and doesn't significantly graze on the nets. The outside surface has no such protection, and is grazed by fish like Cortez Angel fish, Porcupine fish and others. Some studies have suggested that larvae can select for protected substrates over open ones, in which case larvae here may be selecting the inside surface (Keough 1982). Inside the net the larvae that settle are protected, and thus the inside surface can support more individuals than the outside, where they are pruned away.

### *Depth*

The trend on both Module Three and the artificial structures is one of increasing diversity with depth, although the deepest of all the frames was only around eight meters (Figure 8). Larger filter feeders like the *Pinctada mazatlantica* also begin to dominate the inside surface around 3-4m deep, which corresponds to an increase in diversity at that depth. This result is not surprising, as diversity is known to increase with depth to around 2,000m before declining again (McKinney et al. 2007). The same factors that cause this open ocean diversity gradient (environmental stability and nutrients) are most likely the cause in Bahia Thomas as well. Below three meters, wave action and turbulence decreases significantly, and nutrients from the surface waters inevitably sink. These nutrients are what filter feeders require, and thus it makes sense that they're more abundant and diverse with increasing depth.

### *Substrate Complexity*

Diversity and abundance of filter feeders seems to be heavily dependant on substrate type and quality. The *Pinctada mazatlantica* that begins on the inside surface of the Module Three seems to be intrinsically linked with the diversity and abundance of other filter feeders at that depth. The Shannon-Weiner Diversity Index for Module Three points to this relationship (Figure 6). Inside the net the oysters start at three to four meters, and after that the diversity values increase steadily. Outside the net, the diversity peaks at three to four meters and then declines steadily.

What the oysters add to the inside of the net is a new kind of structural complexity, one with crevaces and a much larger surface area than the simple nylon mesh. The oyster shell provides an ideal substrate for organisms like sponges, anemones and other filter feeders to take advantage of, and suggests that oysters might be keystone species for this kind of ecosystem (Raj, 2008). Inside the Module Three net, it certainly appears to be greatly affecting the dynamics of the ecosystem.

Outside the net, the diversity might decrease for several reasons. The oysters inside are extremely efficient filter feeders, and could simply be filtering out the majority of usable nutrients coming from the fish (Lehman 1976). Without the constant nutrient input, organisms on the outside of the net might be more resource limited, and less successful. It could also be an issue of space competition, where the oysters attach to the net other organisms cannot. This does not seem likely however, as the oyster's shell serves as a substrate for tens, if not hundreds of different species inside the net.

The species abundance and composition on the artificial structures reinforces this idea that structural complexity begets diversity and abundance. Significantly more individuals per meter colonized the wood surface, which offers microscopic complexity in the grain and fibers of the wood. For larvae that are less than a millimeter long, a wooden surface like the one of the artificial frames is a hugely complex surface to attach to. This is compared to the smooth metal wire that offers less complexity.

## *Conclusion*

To successfully use filter feeders for biofiltration in a mariculture system, understanding their colonization patterns and substrate preferences will be crucial. The three factors in this study that seem most important to filter feeders like barnacles, anemones and oysters are depth, protection and substrate complexity. My data suggests that to recruit the maximum number of these larger biofilters, structures with protected regions and high substrate complexity should be placed in the mariculture bay at three to four meters and below.

This is not to say that doing so will recruit huge numbers of oysters, or that if oysters do recruit they will be able to filter out all the waste from the system. Rather, this study looks at preparing the Bahia Thomas mariculture system for the next round of research into sustainability and waste management. The next step would be to actually test the nutrient concentration in the water and the assmilation rates of the native filter feeders. Artificial structures might be a good way to deal with the waste that mariculture projects so often struggle with, and by considering the pre-existing patterns on in Bahia Thomas we can get a sense of how to harness the power of natural filtration.

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## Figures

Figure 1: A map of Bahia Cuajiniquil, with Bahia Thomas marked with an X.

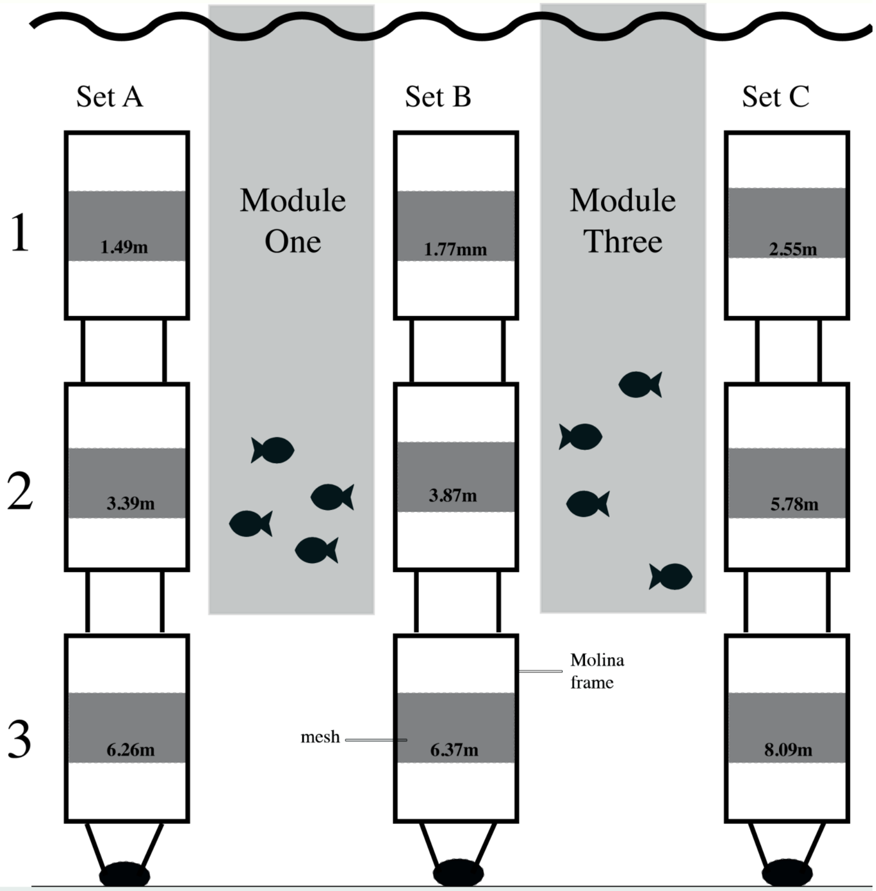

Figure 2: The configuration of arficial structures in Bahia Thomas. Each pen is connected by four nylon ropes, and anchored by a rock at the bottom of the bay. Depths represent the average depth each box was located at during the study. (not to scale).

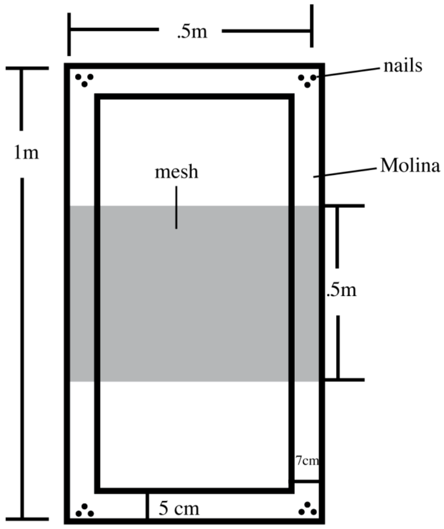

Figure 3: A diagram of the surface counted for 20 minutes for each artificial structure. Frame made of Molina. Grey area represents wire mesh wrapped around the frame. Surface area of wood: .0915m2. Surface area of metal mesh: .03m2.

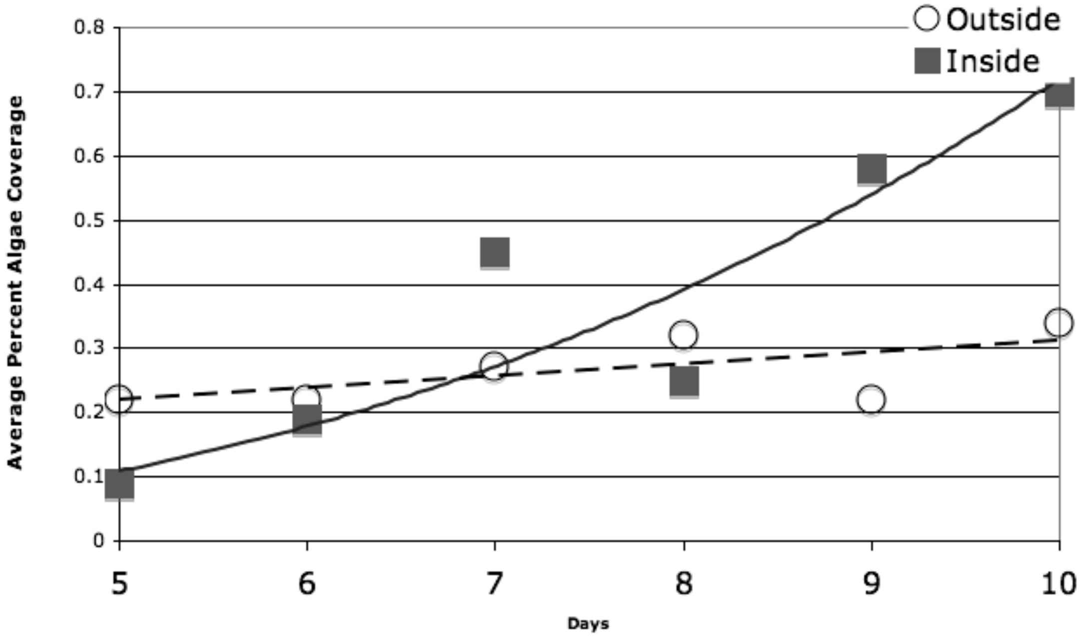

Figure 4: Progression of Algae Coverage with Time, a comparison of the inside and outside surfaces of Module One in Bahia Thomas, Cuajiniquil, Costa Rica from 8 May 2009 to 13 May 2009.

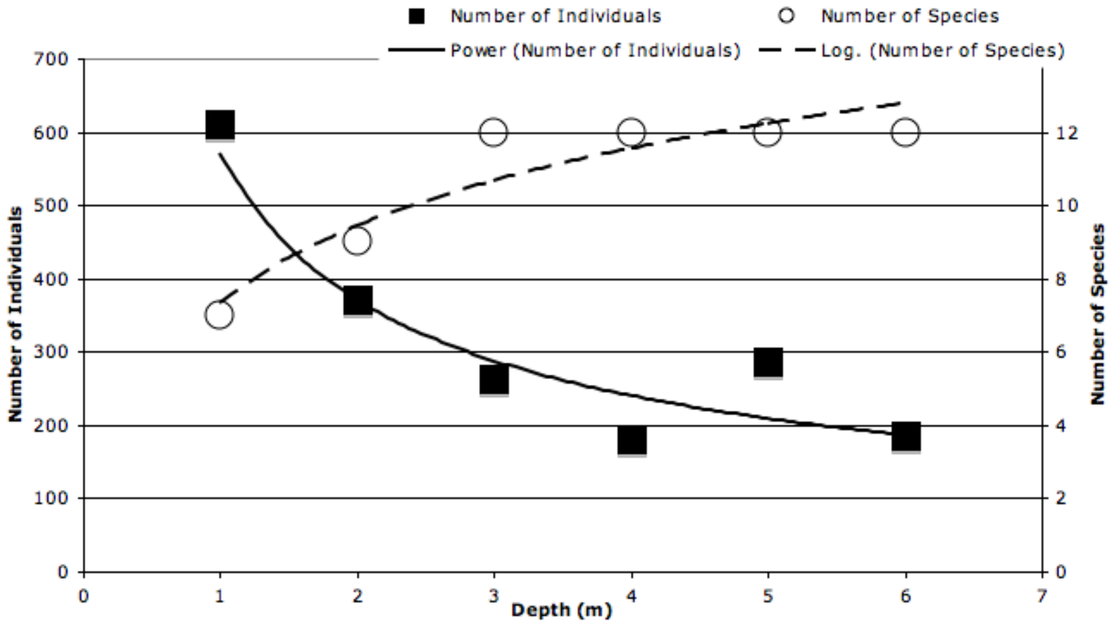

Figure 5: Number of individuals (left x axis) and number of species (right x axis) with increasing depth on Module Three, in Bahia Thomas, Cuajiniquil. Numbers based on inside and outside surface totals grouped by phylum.

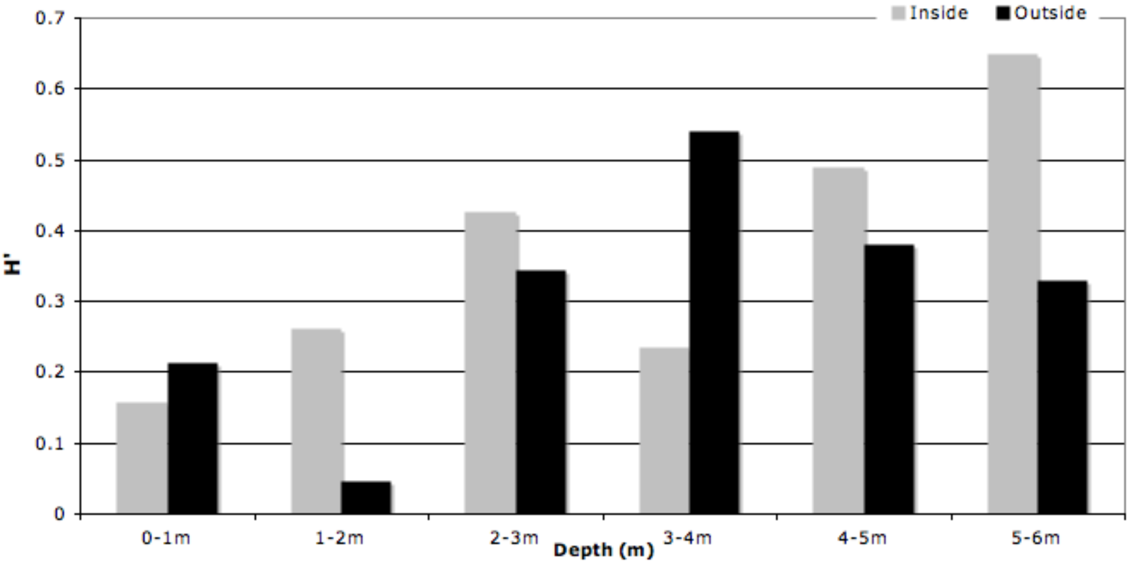

Figure 6: Shannon Wiener Diversity Index (H') for Module Three on both the inside and outside surfaces with depth.

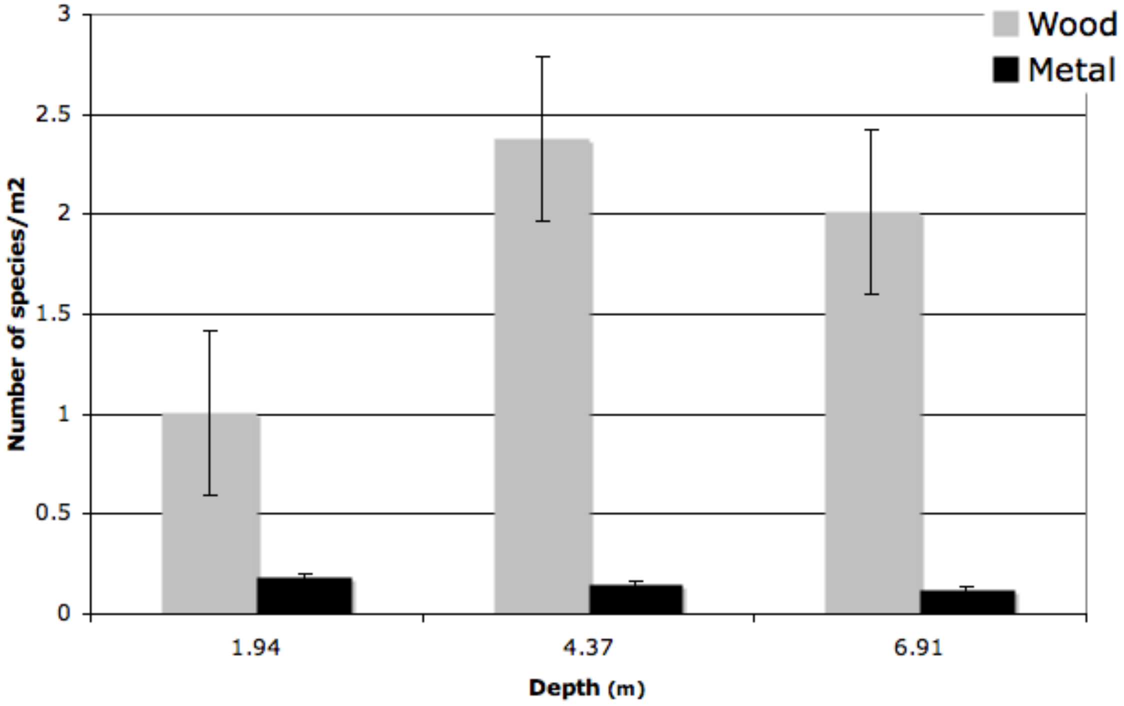

Figure 7: Number of species per m2 on wood surface as compared to metal wire surface on artificial strctures, counted on 16 May 2009

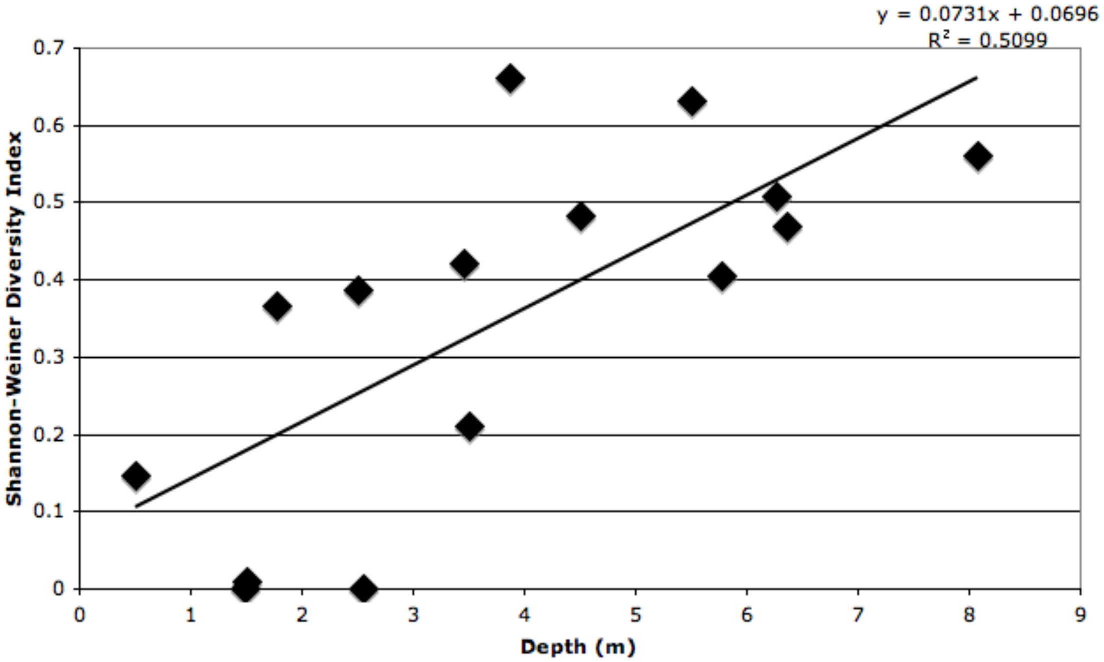

Figure 8: The relationship between diversity and depth within both Module Three and the introduced structures. Diversity calculated using totals grouped by phyla.

## Tables

| Morpho Name | Genus | Species | Group | Boxes | Nets |
|---|---|---|---|---|---|
| crab | | | Arthropoda | x | x |
| barnacles | Megalabalanus | californicus | Arthropoda | x | x |
| anemonies | Aiptasia | tagetes | Cnidaria | x | x |
| polychaete | Anamobaea | orstedii | Annelida | | x |
| white string | Thelepsus | setosus | Annelida | | x |
| oyster | Pinctada | mazatlantica | Arthropoda | | x |
| blue sponge | Rhopalaea | abdminalis | Chordata | | x |
| red anemonies | Parazoanthus | puertoricense | Cnidaria | | x |
| red & white brittle star | Ophiothrix | pumila | Echinodermata | | x |
| red brittle star | Ophiothrix | suensonii | Echinodermata | | x |
| orange sponge | Diplastrella | | Porifera | | x |
| white sponge | Strongylacidon | | Porifera | | x |
| blennie | Acantherriblemaria | exilispinus | Vertebrate | | x |
| serpulid | | | Annelida | x | |
| mysid | | | Arthropoda | x | |
| copepod? | | | Arthropoda | x | |
| urchin | | | Echinodermata | x | |
| snail | | | Mollusca | x | |
| flatworm | | | Plathelminthes | x | |

**Table 1: Guide to morpho-species, their possible genus and species identifications, their phlya and their existence on the box or nets.**

| | 0.5m | 1.5m | 2.5m | 3.5m | 4.5m | 5.5m |
|---|---|---|---|---|---|---|
| Annelida | 0.00 | 10.00 | 0.00 | 0.00 | 0.00 | 3.00 |
| Arthropoda | 57.00 | 28.00 | 12.00 | 8.00 | 31.00 | 9.00 |
| Chordata | 0.00 | 1.00 | 1.00 | 0.00 | 1.00 | 0.00 |
| Cnidaria | 475.00 | 278.00 | 227.00 | 138.00 | 198.00 | 87.00 |
| Echinodermata | 0.00 | 0.00 | 5.00 | 20.00 | 18.00 | 20.00 |
| Mollusca | 1.00 | 0.00 | 1.00 | 0.00 | 24.00 | 49.00 |
| Porifera | 2.00 | 55.00 | 10.00 | 14.00 | 11.00 | 17.00 |
| Platyhelminthes | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vertebrate | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table 2: Abundance of filter feeders organized by Phylum per depth on Module Three.**

## Appendix A: Raw Data from Module One

| | | | | | |
|---|---|---|---|---|---|
| | **Outside** | | | **Inside** | |
| | | | | | |
| **0-1m** | | | | | |
| Days: 5 | Algae Coverage | Anemones | | Algae Coverage | Anemones |
| | 50% | 1.00 | | 25% | 0.00 |
| | 25% | 0.00 | | 10% | 0.00 |
| | 10% | 0.00 | | 10% | 0.00 |
| | 25% | 0.00 | | 0% | 0.00 |
| | 0% | 1.00 | | 0% | 0.00 |
| **Total** | 110% | 2.00 | | 45% | |
| **Average** | 22% | 0.40 | | 9% | |
| | | | | | |
| | | | | | |
| | | | | | |
| **1-2m** | Algae Coverage | Anemones | | Algae Coverage | |
| Days: 6 | 50% | 1.00 | | 15% | |
| | 25% | 0.00 | | 20% | |
| | 10% | 0.00 | | 50% | |
| | 25% | 0.00 | | 0% | |
| | 0% | 1.00 | | 10% | |
| **Total** | 110% | 2.00 | | 95% | |
| **Average** | 22% | 0.40 | | 19% | |
| | | | | | |
| **2-3m** | Algae Coverage | Anemones | | Algae Coverage | |
| **Days: 7** | 25% | | | 50% | |
| | 25% | | | 50% | |
| | 50% | | | 25% | |
| | 10% | | | 50% | |
| | 25% | | | 50% | |
| **Total** | 135% | | | 225% | |
| **Average** | 27% | | | 45% | |
| | | | | | |
| | | | | | |
| **3-4m** | Algae Coverage | Anemones | | Algae Coverage | |
| **Days: 8** | 10% | | | 25% | |
| | 25% | | | 25% | |
| | 50% | | | 25% | |
| | 25% | | | 0% | |
| | 50% | | | 50% | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Total** | 160% | | | 125% | |
| **Average** | 32% | | | 25% | |
| | | | | | |
| **4-5m** | Algae Coverage | Anemones | | Algae Coverage | |
| **Days: 9** | 25% | | | 50% | |
| | 50% | | | 90% | |
| | 10% | | | 75% | |
| | 15% | | | 25% | |
| | 10% | | | 50% | |
| | | | | | |
| **Total** | 110% | | | 290% | |
| **Average** | 22% | | | 58% | |
| | | | | | |
| | | | | | |
| **5-6m** | 10% | | | 100% | |
| **Days: 10** | 10% | | | 50% | |
| | 25% | | | 75% | |
| | 50% | | | 25% | |
| | 50% | | | 90% | |
| | 25% | | | 10% | |
| | | | | | |
| **Total** | 170% | | | 350% | |
| **Average** | 34% | | | 70% | |
| | | | | | |

## Appendix B: Raw Data from Module Three

| | **Inside** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | barnacles | anemonies | orange spong (individuals) | orange sponge %coverage | oyster | crab | | |
| **0-1m** | 9.00 | 50.00 | 0.00 | 0% | 1.00 | 1.00 | | |
| | 5.00 | 72.00 | 0.00 | 0% | 0.00 | 0.00 | | |
| | 11.00 | 47.00 | 0.00 | 0% | 0.00 | 0.00 | | |
| | 7.00 | 76.00 | 0.00 | 0% | 0.00 | 0.00 | | |
| | 4.00 | 74.00 | 2.00 | 5% | 0.00 | 0.00 | | |
| | 3.00 | 49.00 | 0.00 | 0% | 0.00 | 0.00 | | |
| | 6.00 | 75.00 | 0.00 | 0% | 0.00 | 0.00 | | |
| **Total** | 45.00 | 443.00 | 2.00 | 5% | 1.00 | 1.00 | | |
| **Average** | 6.43 | 63.29 | 0.29 | 1% | 0.14 | 0.14 | | |
| | | | | | | | | |
| | | | | | | | | |
| | **Inside** | | | | | | | |
| **1-2m** | barnacles | anemonies | orange sponge (individuals) | orange sponge %coverage | blennies | polychete | | |
| | 2.00 | 37.00 | 18.00 | 20% | 1.00 | 0.00 | | |
| | 2.00 | 40.00 | 9.00 | 10% | 0.00 | 0.00 | | |
| | 0.00 | 35.00 | 2.00 | 5% | 0.00 | 0.00 | | |
| | 1.00 | 30.00 | 4.00 | 5% | 0.00 | 2.00 | | |
| | 1.00 | 60.00 | 1.00 | 5% | 0.00 | 1.00 | | |
| **Total** | 6.00 | 202.00 | 34.00 | 45% | 1.00 | 3.00 | | |
| **Average** | 1.20 | 40.40 | 6.80 | 9% | 0.20 | 0.60 | | |
| | | | | | | | | |
| **2-3m** | **Inside** | | | | | | | |
| | barnacles | anemonies | orange sponge (individuals) | orange sponge % coverage | white sponge | red bstar | orange bstar | oyster |
| | 1.00 | 20.00 | 3.00 | 80.00% | 0.00% | 1.00 | 3.00 | 1.00 |
| | 1.00 | 3.00 | 1.00 | 25.00% | 25.00% | 0.00 | 0.00 | 0.00 |
| | 2.00 | 20.00 | 2.00 | 30.00% | 0.00% | 1.00 | 0.00 | 0.00 |
| | 4.00 | 17.00 | 1.00 | 20.00% | 20.00% | 0.00 | 0.00 | 0.00 |
| | 0.00 | 7.00 | 1.00 | 5.00% | 0.00% | 0.00 | 0.00 | 0.00 |
| **Total** | 8.00 | 67.00 | 8.00 | 160.00% | 45.00% | 2.00 | 3.00 | 1.00 |
| **Average** | 1.60 | 13.40 | 0.32 | 32.00% | 9.00% | 0.40 | 0.60 | 0.20 |
| | | | | | | | | |
| | | | | | | | | |
| **3-4m** | **Inside** | | | | | | | |
| | barnacles | anemonies | orange sponge (individuals) | orange sponge % coverage | white sponge | bstar red&white striped | | |
| | 0.00 | 7.00 | 1.00 | 70% | 5.00% | 3.00 | | |
| | 0.00 | 4.00 | 0.00 | 0% | 10.00% | 0.00 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.00 | 30.00 | 1.00 | 5% | 5.00% | 2.00 | | |
| | 0.00 | 23.00 | 1.00 | 90% | 5.00% | 2.00 | | |
| | 0.00 | 39.00 | 1.00 | 40% | 5.00% | 0.00 | | |
| **Total** | 0.00 | 103.00 | 4.00 | 205% | 30.00% | 7.00 | | |
| **Average** | 0.00 | 20.60 | 0.80 | 41% | 6.00% | 1.40 | | |
| | | | | | | | | |
| **4-5m** | **Inside** | | | | | | | |
| | barnacles | anemonies | orange sponge (individuals) | orange sponge % coverage | white sponge | blue tunicate | bstar red&white | oyster |
| | 3.00 | 24.00 | 0.00 | 0% | 5.00% | 0.00 | 0.00 | 0.00 |
| | 0.00 | 32.00 | 0.00 | 0% | 20.00% | 0.00 | 0.00 | 3.00 |
| | 0.00 | 17.00 | 0.00 | 0% | 0.00% | 0.02 | 5.00 | 7.00 |
| | 5.00 | 14.00 | 1.00 | 60% | 0.00% | 0.00 | 4.00 | 5.00 |
| | 7.00 | 21.00 | 0.00 | 0% | 30.00% | 0.00 | 6.00 | 9.00 |
| **Total** | 15.00 | 108.00 | 1.00 | 60% | 55.00% | 0.02 | 15.00 | 24.00 |
| **Average** | 3.00 | 21.60 | 0.20 | 12% | 11.00% | 0.00 | 3.00 | 4.80 |
| | | | | | | | | |
| | | | | | | | | |
| **5-6m** | **Inside** | | | | | | | |
| | barnacles | anemonies | osp (ind) | osp (%) | white sponge | bstar r&w | oysters | white string |
| | 0.00 | 3.00 | 2.00 | 0.10 | 0.30 | 3.00 | 12.00 | 1.00 |
| | 2.00 | 5.00 | 0.00 | 0.00 | 0.00 | 2.00 | 10.00 | 0.00 |
| | 1.00 | 11.00 | 0.00 | 0.00 | 0.02 | 5.00 | 11.00 | 1.00 |
| | 2.00 | 3.00 | 0.00 | 0.00 | 0.10 | 1.00 | 7.00 | 0.00 |
| | 3.00 | 7.00 | 1.00 | 0.02 | 0.20 | 6.00 | 9.00 | 1.00 |
| **Total** | 8.00 | 29.00 | 3.00 | 0.12 | 0.62 | 17.00 | 49.00 | 3.00 |
| **Average** | 1.60 | 5.80 | 0.60 | 0.02 | 0.12 | 3.40 | 9.80 | 0.60 |
| | | | | | | | | |
| | | | | | | | | |
| | **Outside** | | | | | | | |
| | barnacles | anemonies | | | | | | |
| **0-1m** | 31.00 | 42.00 | | | | | | |
| | 20.00 | 30.00 | | | | | | |
| | 24.00 | 49.00 | | | | | | |
| | 4.00 | 16.00 | | | | | | |
| | 11.00 | 32.00 | | | | | | |
| | 5.00 | 23.00 | | | | | | |
| | | | | | | | | |
| **Total** | 95.00 | 192.00 | | | | | | |
| **Average** | 15.83 | 32.00 | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | **Outside** | | | | | | | |
| **1-2m** | barnacles | anemonies | white sponge | polychaetes | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2.00 | 7.00 | 2.00 | 2.00 | | | | |
| | 5.00 | 10.00 | 0.00 | 1.00 | | | | |
| | 8.00 | 36.00 | 5.00 | 0.00 | | | | |
| | 2.00 | 13.00 | 8.00 | 3.00 | | | | |
| | 5.00 | 10.00 | 6.00 | 1.00 | | | | |
| **Total** | 22.00 | 76.00 | 21.00 | 7.00 | | | | |
| **Average** | 4.40 | 15.20 | 4.20 | 1.40 | | | | |
| | | | | | | | | |
| **2-3m** | **Outside** | | | | | | | |
| | barnacles | anemonies | red anemonies | white sponge | orange sponge | blue tunicate | | |
| | 2.00 | 27.00 | 0.00 | 10% | 10% | 0.00 | | |
| | 1.00 | 28.00 | 0.00 | 10% | 0.00 | 0.02 | | |
| | 0.00 | 40.00 | 0.00 | 0.00 | 5% | 0.00 | | |
| | 0.00 | 20.00 | 30.00 | 0.00 | 5% | 0.00 | | |
| | 1.00 | 15.00 | 0.00 | 0.05 | 5% | 0.00 | | |
| **Total** | 4.00 | 130.00 | 30.00 | 0.25 | 0.25 | 0.02 | | |
| **Average** | 0.80 | 26.00 | 6.00 | 0.05 | 0.05 | 0.00 | | |
| | | | | | | | | |
| | | | | | | | | |
| **3-4m** | **Outside** | | | | | | | |
| | barnacles | anemonies | red anemonies | white sponge | orange sponge | bstar red | bstar red&white stripes | |
| | 2.00 | 10.00 | 0.00 | 0.20 | 0.00 | 1.00 | 0.00 | |
| | 1.00 | 7.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | |
| | 3.00 | 15.00 | 0.00 | 0.00 | 0.90 | 0.00 | 0.00 | |
| | 2.00 | 3.00 | 0.00 | 0.00 | 0.90 | 0.00 | 5.00 | |
| | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 7.00 | |
| **Total** | 8.00 | 35.00 | 0.00 | 0.30 | 2.80 | 1.00 | 12.00 | |
| **Average** | 1.60 | 7.00 | 0.00 | 0.06 | 0.56 | 0.20 | 2.40 | |
| | | | | | | | | |
| **4-5m** | **Outside** | | | | | | | |
| | barnacles | anemonies | orange sponge (individuals) | orange sponge % coverage | white sponge | red bstar | bstar red&white | |
| | 0.00 | 17.00 | 1.00 | 0.05 | 0.05 | 0.00 | 0.00 | |
| | 10.00 | 37.00 | 1.00 | 0.05 | 0.02 | 0.00 | 0.00 | |
| | 0.00 | 9.00 | 1.00 | 0.10 | 0.75 | 1.00 | 2.00 | |
| | 4.00 | 5.00 | 1.00 | 0.85 | 0.00 | 0.00 | 0.00 | |
| | 2.00 | 22.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| **Total** | 16.00 | 90.00 | 4.00 | 1.05 | 0.82 | 1.00 | 2.00 | |
| **Average** | 3.20 | 18.00 | 0.80 | 0.21 | 0.16 | 0.20 | 0.40 | |
| | | | | | | | | |
| | | | | | | | | |
| **5-6m** | **Outside** | | | | | | | |
| | barnacles | anemonies | osp (ind) | osp % | white sponge | bstar red | bstar r&w | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.00 | 14.00 | 2.00 | 0.46 | 0.40 | 0.00 | 1.00 | |
| | 0.00 | 3.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | |
| | 1.00 | 2.00 | 3.00 | 0.05 | 0.10 | 0.00 | 0.00 | |
| | 0.00 | 19.00 | 0.00 | 0.00 | 0.02 | 1.00 | 0.00 | |
| | 0.00 | 20.00 | 1.00 | 0.10 | 0.00 | 0.00 | 1.00 | |
| **Total** | 1.00 | 58.00 | 7.00 | 1.61 | 0.52 | 1.00 | 2.00 | |
| **Average** | 0.2 | 11.6 | 1.4 | 0.322 | 0.104 | 0.2 | 0.4 | |
| | | | | | | | | |
| | | | | | | | | |

## Appendix C: Raw Data from Introduced Structures

| **SET** | **BOX** | **Species** | **# Ind. Wood** | **# Ind. Wire** |
|---|---|---|---|---|
| **A** | **1** | Mysid | 8 | 1 |
| | | Algae | 38 | 1 |
| Initial Depth | 1 | Crabs | 7 | 5 |
| Pull Depth | 1.98 | Flatworm | 5 | 0 |
| | | *Barnacles in 5cm* | 70 | |
| | Total | | 58 | 7 |
| | **2** | Mysid | 4 | 2 |
| | | Algae | 35 | 3 |
| Initial Depth | 2.9 | Crabs | 7 | 2 |
| Pull Depth | 3.88 | Flatworm | 0 | 0 |
| | | Snail | 1 | 0 |
| | | Serpulid | 8 | 0 |
| | | *Barnacles in 5cm* | 93 | |
| | Total | | 55 | 7 |
| | **3** | Mysid | 14 | |
| | | Algae | all over | |
| Initial Depth | 6.1 | Crabs | 12 | |
| Pull Depth | 6.44 | *Barnacles in 5cm* | 72 | |
| | Total | | 26 | 0 |
| **B** | **1** | Mysid | 12 | 1 |
| | | Algae | 53 | 0 |
| Initial Depth | 1 | Crabs | 8 | 1 |
| Pull Depth | 2.54 | Flatworm | 9 | 0 |
| | | Urchin | 1 | 0 |
| | | Copepod? | 1 | 0 |
| | | Anemone | 1 | 0 |
| | | Serpulid | 2 | 0 |
| | | *Barnacles in 5cm* | 73 | |
| | Total | | 87 | 2 |

| | | | | |
|---|---|---|---|---|
| | **2** | Mysid | 4 | 0 |
| Initial Depth | 3.1 | Algae | 68 | |
| Pull Depth | 4.64 | Crabs | 13 | 0 |
| | | Flatworm | 6 | 0 |
| | | Serpulid | 14 | 0 |
| | | Copepod? | 1 | 0 |
| | | Anemone | 8 | 0 |
| | | Gastropod | 17 | 0 |
| | | Crab Zooea | 2 | 0 |
| | | *Barnacles in 5cm* | 63 | |
| | Total | | 133 | 0 |
| | **3** | Mysid | 26 | 9 |
| Initial Depth | 5.6 | Algae | 42 | 7 |
| Pull Depth | 7.14 | Crabs | 18 | 0 |
| | | Flatworm | 6 | 0 |
| | | Serpulid | 18 | 0 |
| | | Copepod? | 1 | 0 |
| | | Worm Casing | 4 | 0 |
| | | Gastropod | 3 | 0 |
| | | Crab Zooea | 10 | 0 |
| | | *Barnacles in 5cm* | 82 | |
| | Total | | 128 | 16 |
| **C** | **1** | Mysid | 4 | 0 |
| Initial Depth | 2 | Algae | 24 | 0 |
| Pull Depth | 3.11 | Crabs | 6 | 1 |
| | | Flatworm | 7 | 0 |
| | | Anemone | 12 | 0 |
| | | Crab Zoea | 1 | 0 |
| | | Gastropod | 1 | 0 |
| | | Copepod? | 3 | 0 |
| | | *Barnacles in 5cm* | 77 | |
| | Total | | 58 | 1 |
| | **2** | Mysid | 4 | 1 |
| Initial Depth | 5.23 | Algae | 55 | 0 |
| Pull Depth | 6.34 | Crabs | 6 | 0 |
| | | Flatworm | 13 | 0 |
| | | Anemone | 10 | 0 |
| | | Copepod? | 5 | 0 |
| | | *Barnacles in 5cm* | 90 | |
| | Total | | 93 | 1 |
| | **3** | Mysid | 11 | 6 |
| Initial Depth | 7.53 | Algae | 136 | 0 |
| Pull Depth | 8.64 | Crabs | 21 | 3 |

| | | | | |
|---|---|---|---|---|
| | | Flatworm | 6 | 5 |
| | | Anemone | 5 | 0 |
| | | Serpulid | 8 | 0 |
| | | Gastropod | 10 | 0 |
| | | Copepod? | 1 | 0 |
| | | *Barnacles in 5cm* | 21 | |
| | Total | | 198 | 14 |