Predation on the invasive sponge *Mycale armata* in Kaneohe Bay, Oahu.

Alfred Hart
University of Hawaii at Manoa
Department of Zoology
Faculty Advisor: Dr. John Stimson

Background

Mycale armata is a recent introduction to Hawaii. It is a native of the Indo-Malay region and the Great Barrier Reef. It was first described as a fouling organism in Pearl Harbor on the Hawaiian island of Oahu in 1996 and has since spread to Kaneohe Bay, also on Oahu. In Hawaii, *Mycale armata* can grow into large lobate forms and has been observed overgrowing native corals, particularly *Porites compressa*, suggesting a paucity of sponge predators. Despite its potential to smother native corals and alter coral reef diversity, it is not known what controls or limits its distribution and abundance. Studies of fish gut contents revealed that in the Caribbean the relatively few fish spongivores belonged to specialized teleost families including angelfish, parrotfish, boxfish, and filefish (Pawlik, 1998). Pawlik's experiment clearly showed the importance of sponges in the diet of certain fish families and the significance of predation by spongivorous fish on the distribution and abundance of at least chemically undefended sponge species. Some common widely distributed spongivores are absent from the Hawaiian marine environment and research is needed to identify possible alternative spongivores that will have an impact on *M. armata* abundance (Appendix A). Worldwide, many species of angelfish are known to be sponge specialists. However, only two angelfish (*Holocanthus arcuatus* and *Centropyge potteri*) occur on Hawaii's reefs (Hobson, 1974) and neither is common or found within the range of *M. armata*. To predict accurately the potential of *M. armata* to spread outside the bay and its capability to overgrow corals, we need to know what natural predators might control its distribution and abundance.

The Hawksbill turtle (*Eretmochelys imbricate*) is a well documented sponge specialist that feeds almost exclusively on sponges (Meylan, 1988). While the diet of green sea turtles (*Chelonia mydas*) is primarily composed of seagrasses and algae, in the Central Gulf of California, Mexico green turtles augment their diet with sponges (Seminoff et al., 2002) and sponge fragments were found in all gastric lavage samples from green turtles in Palm Beach, Florida (Makowski et al., 2005). A study of the stomach contents of 243 green turtles in Nicaragua found that animal matter accounted for 1.4% of the dry weight of all samples and sponges constituted 2/3 of all dry animal matter (Mortimer, 1981). Furthermore, the reported values underestimate sponge importance in turtle diet since contributions were determined by dry weight and sponge material of given dry weight occupies greater volume than plant matter of equal weight (Mortimer, 1981). The stomach contents of 4 of 94 green turtles in Brazil were found to contain sponges and overall, sponges were the third most common animal group (Ferreira, 1968). Sponge also composed the only animal tissue found in the stomachs of four green turtles from Honduras (Carr, 1952). The sponge *Chondrilla nucula* was a component of fecal samples collected from green turtles in Union Creek in the Bahamas (Bjorndal, 1980). Bjorndal (1990) investigated the potential for small amounts of animal matter contributing significantly to green turtle nutrition through analysis of the digestibility of the chicken liver sponge, *Chondrilla nucula*, in three size classes of green turtles in the southern Bahamas. The greatest difference for nutrient composition between *C. nucula* and the turtles typical diet of *Thalassia testudinumis* the significantly higher concentration of nitrogen in the sponge (Bjorndal, 1990). The small quantities of sponge ingestion are surprising given that Bjorndal (1980) indicated that the low level of nitrogen available in the typical diet of small green turtles may limit growth (Bjorndal, 1990). It has been indicated however that intake of sponges may be limited by slica spicule irritation (Bjorndal, 1990). Bjorndal (1990) concluded that the low intake and low digestibilities of *C. nucula* indicate that sponges are not an important component in green turtle nutrition with the exception of perhaps nitrogen in small turtles. However, ingested sponge tissue may have a more significant role in providing trace mineral, vitamin, or essential amino acid requirements for green turtles inhabiting benthic feeding grounds (Bjorndal, 1990).

Heithaus et al. (2002), using animal-borne video cameras attached to green sea turtles in Shark Bay, Western Australia, discovered that green turtles frequent habitats of high sponge and rock abundance where they engage in self rubbing bouts on sponges and rocks suggesting that where cleaning fish are absent, these sponge-rubbing areas are important habitats for turtles. Within Kaneohe Bay, a green sea turtle has been seen feeding on M*ycale armata* and Balazs (1980) and Russell and Balazs (2000) recorded sponges as a component of the diet of green sea turtles, having observed them in their mouths during live captures, in stomach contents and fecal pellets, and on necropsy. However, *M. armata* has yet to be identified in sponge samples from sea turtle stomachs. Sponges are an important component in green sea turtle ecology. Therefore, I hypothesize that at least to some extent the green sea turtles, that are common in the mid to north areas of Kaneohe Bay, are slowing or preventing establishment of *Mycale armata* beyond the south bay and therefore will control sponge abundance.

Methods

Survey

The first approach was to census reefs for turtles and sponges to see if either a direct or inverse correlation exists between their abundance and distribution on reefs. Turtles rest on the slopes of reefs in the bay. A snorkeler can swim the perimeter of a reef, just outside the reef crest and above the reef slope, and count resting turtles and estimate the amount of sponge on the slope. In order to survey the many patch reefs rapidly a surface-tow method was also employed in which a snorkeler is pulled behind a boat around the outside reef crests of patch reefs. During the tow the snorkeler recorded the number of turtles observed, as well as turtle resting locations, and made observations of *Mycale armata* cover. There are about 50 patch reefs and many kilometers of fringing reef that can be studied in this way. This study surveyed about 25 ~100 m long sections of fringing and patch reef. An inverse relationship between this potential sponge predator and *M. armata* would support the hypothesis that green sea turtle feeding controls sponge distribution and abundance. There are indications that distribution of sponges within Kaneohe Bay may be inversely related to green sea turtle abundance.

Exclusion Cages

My surveys of the sponge on patch reefs in Kaneohe Bay found large lobes and almost no signs of attacks on the sponge or observations of spongivory. However, assessment of spongivory was hampered by the ability of the sponge to rapidly regenerate epidermis tissue over injured areas giving the appearance of a normal surface and no signs of feeding. In a series of experiments to determine if Green Sea Turtles are natural predators of *M. armata*, I selected several reefs in the middle to north bay to survey for sponge abundance as well as observe the presence of turtles and turtle resting areas. From my surveys, Reef 21 or Wass reef (Figure 1), a 70 m circumference patch reef, was chosen for tests of spongivory by green sea turtles using mesh cages designed to keep out turtles and fish of various sizes. Reef 21 (Wass reef) is an ideal location because of the presence of *M. armata*, which was in relatively low abundance, and of green sea turtles, typically two on any given visit; although up to five have been seen.

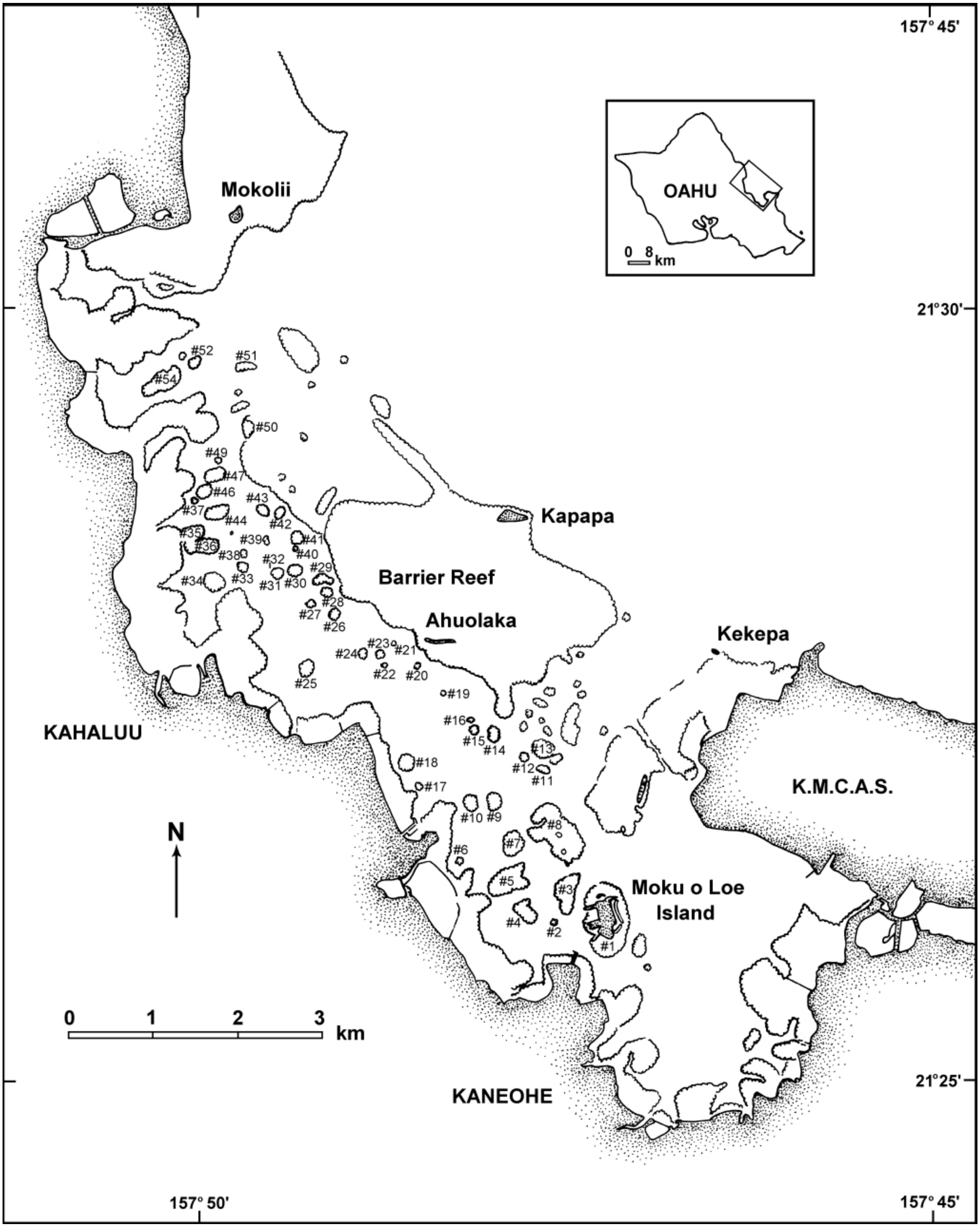

Figure 1: Map of Kaneohe Bay with reef numbers indicated.

Experiment Run 1:

Sponges were prepared using the methods from previous experiments. They were weighed and placed in spongivore exclusion cage treatments. For Run 1, three caging treatments called Open, Coarse, and Fine Mesh were used with 8 replicates of each treatment. The Open treatment does not provide the sponge any protection from predators as the sponge was just placed on the reef on top of a metal-mesh platform. The Coarse Mesh treatment was designed to exclude turtles and was a square metal cage constructed from fencing materials with square holes of 15.2 cm x 15.2 cm and overall was approximately 27,000 cubic cm in volume. To further restrict turtle access, a larger top was attached that overhangs the Coarse Mesh cage by approximately 10 cm. The final treatment was Fine Mesh, which consists of cages with a less than 2.5 cm diameter mesh. The sponge, on Vexar® platform, was attached to the bottom face of all cages. Cages were left on Wass reef for seven weeks to allow predators time to acclimate to cage presence and feed on sponges. At the conclusion, the cages were brought into the lab and sponge samples immediately weighed using the buoyant mass technique. Concurrent with the caged sponges, 6 sponges were kept in seawater tanks at the Point Lab and their weights compared with that of the field-placed sponges. The purpose of the exclusion cages was to determine if predators, namely green sea turtles, are feeding on the sponges, as determined by subsequent changes in the sponges' buoyant weights. Minitab 14 was used for all statistical analyses.

Experiment Run 2:

The success of Run 1 prompted a repeat of the experiment but with an addition of a control reef. Reef 2 was selected because of the abundance of *M. armata* and absence of observed turtles. While no turtles have been observed on Reef 2, fish are quite abundant and it was believed that predation of experimental sponges on Reef 2 would indicate a fish predator instead of turtles. As before, the treatments Open, Coarse, and Fine Mesh cages were used with 8 replicates of each treatment. However, the cages were divided between Wass Reef and Reef 2 such that each reef received 4 replicates of each treatment. Intact sponges from Run 1 were reused in Run 2 and comprised half of the sponges used. Identified as "Old", these sponges were equally divided across treatments and sites. A lab treatment was not used in Run 2. Cages were left on both reefs for three weeks.

Experiment Run 3:

Results of Run 1 and 2 found that many of the Coarse Mesh cages were overturned on Wass Reef, adding greater access. Consequently, a Mid Mesh cage treatment was added. For Run 3, the four treatments were Open, Coarse, Mid and Fine Mesh as defined by the size of the openings in the caging materials. The Mid Mesh cage treatment has openings that are 5.1 cm x 10.2 cm, which was thought to be too narrow for a turtle's head to reach in and consume the sponge contents. Cages and caging materials were limited during Run 3 and required partitioning of cages. Five replicates of all 4 treatments were used on Wass Reef. However, on Reef 2, 2 replicates on the Coarse Mesh treatment, 6 replicates of the Fine Mesh treatment, 4 replicates of the Open treatment, and none of the Mid Mesh treatment were used. Cages were left on both reefs for two weeks.

Results

Experiment Run 1- 3/11/06 to 4/30/06

My initial studies at Wass reef showed that uncaged sponges (Open treatment) were completely or nearly completely consumed (Figure 2) and that six of the eight sponges in the Open treatment had the wires that held the sponge in place completely bitten through. No other treatment in Run 1 had wires cut. Sponges in cages of narrow mesh (Fine Mesh), too small for turtles to enter, were unharmed and their buoyant weights were very close to original weights. The Coarse Mesh cages (openings of squares with 15.2 cm sides) were somewhat variable in excluding spongivores with some sponges showing no signs of predation. At least one Coarse Mesh treatment cage had been overturned and the sponge within had suffered heavy grazing (Figure 3). Table 1 gives the basic descriptive statistics for the percent change of buoyant weight for sponges at the conclusion of the experiment. ANOVA indicated that the Treatment variable was highly significant and Tukey pairwise comparisons indicated that the Open treatment was significantly different from all other treatments (Table 2). Coarse and Fine Mesh cage treatments were not significantly different from the Lab treatment which indicates that sponges were protected from predation and not adversely impacted during transport to Wass Reef or from the cages themselves.

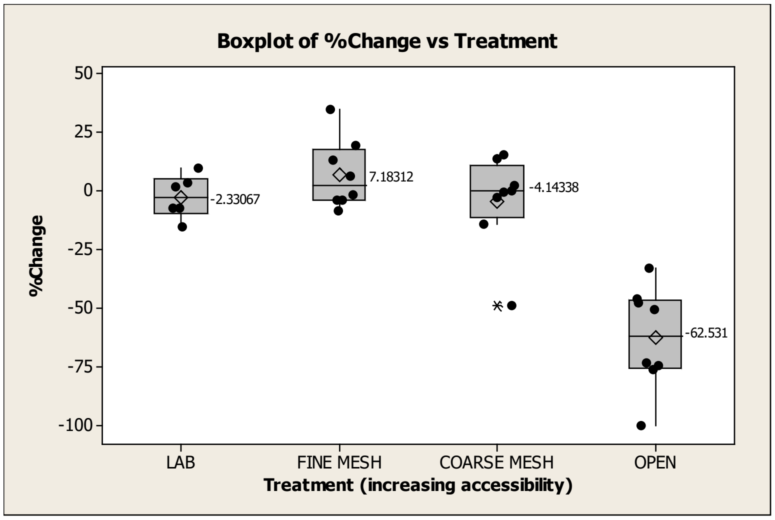

Figure 2: Boxplot of percentage change in buoyant mass of *M. armata* from Wass Reef for Experiment Run 1. The boxplot clearly indicates that sponges in the Open treatment were heavily predated whereas sponges in the other treatments appear to have survived without grazing. The outlier, indicated by the * in the Coarse Mesh treatment was an overturned cage that allowed grazing of the sponge within. Individual data points are indicated with the symbol ● and the mean is indicated by ◊, along with its value.

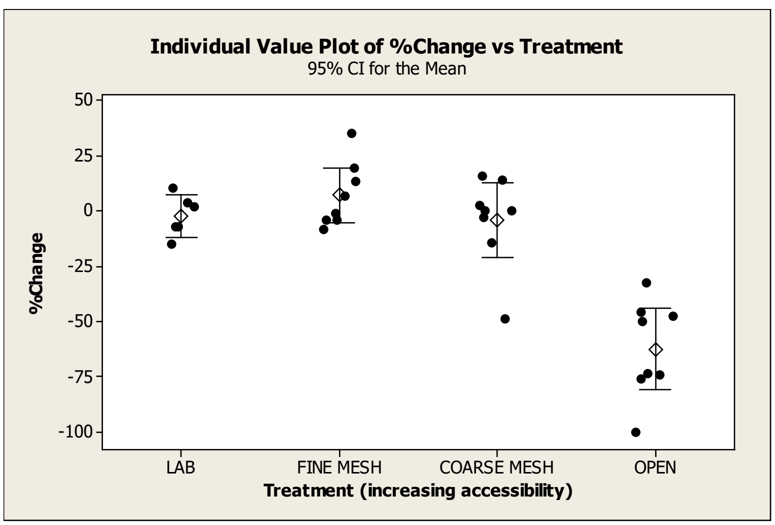

Figure 3: Individual value plot of % change in *M. armata* weight versus Treatment with confidence intervals indicated; again showing the heavy to complete predation for sponges in the Open treatment and the outlier for the Coarse Mesh treatment corresponding with the overturned cage. Individual data points are indicated with the symbol ● and the mean is indicated by ◊, along with its value.

Table 1: Descriptive Statistics for %Change by Treatment in Run 1.

Variable	Treatment	Mean	SE Mean	StDev	Minimum	Median	Maximum
%Change	LAB	-2.33	3.75	9.19	-15.17	-2.61	10.18
	FINE MESH	7.18	5.24	14.81	-8.15	2.58	35.31
	COARSE MESH	-4.14	7.19	20.34	-48.77	-0.00100	15.75
	OPEN	-62.53	7.78	22.02	-100.00	-61.88	-32.56

Table 2: One-way ANOVA of % Change versus Treatment showing overall significance of the Treatment variable, followed by Tukey pairwise comparisons indicating Open as the only significantly different treatment.

```
Source     DF     SS    MS      F      P
Treatmnt    3  23863  7954  25.07  0.000
Error      26   8249   317
Total      29  32112
S = 17.81   R-Sq = 74.31%   R-Sq(adj) = 71.35%

                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level         N    Mean  StDev   +---------+---------+---------+---------
COARSE MESH  8   -4.14  20.34                         (----*-----)
FINE MESH    8    7.18  14.81                              (----*----)
LAB          6   -2.33   9.19                         (-----*-----)
OPEN         8  -62.53  22.02    (----*----)
                                 +---------+---------+---------+---------
                               -75       -50       -25         0
Pooled StDev = 17.81

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Treatmnt
Individual confidence level = 98.91%

Treatmnt = COARSE MESH subtracted from:
Treatmnt    Lower  Center   Upper  ---------+---------+---------+---------+
FINE MESH  -13.11   11.33   35.76                  (----*----)
LAB        -24.58    1.81   28.20                (----*-----)
OPEN       -82.82  -58.39  -33.95    (----*----)
                                   ---------+---------+---------+---------+
                                          -50         0        50       100

Treatmnt = FINE MESH subtracted from:
Treatmnt   Lower  Center   Upper  ---------+---------+---------+---------+
LAB       -35.91   -9.51   16.88              (----*----)
OPEN      -94.15  -69.71  -45.28  (----*----)
                                  ---------+---------+---------+---------+
                                         -50         0        50       100

Treatmnt = LAB subtracted from:
Treatmnt   Lower  Center   Upper  ---------+---------+---------+---------+
OPEN      -86.59  -60.20  -33.81    (----*----)
                                  ---------+---------+---------+---------+
                                         -50         0        50       100
```

Experiment Run 2- 5/6/06 to 5/27/06

As in Experiment Run 1, many Coarse Mesh cages were overturned and sponges in them suffered greater grazing of tissue compared to intact cages of this treatment. It appears as if something is preying on *M. armata* on Wass Reef and that this predator can overturn and consume sponges in cages with 15.2 cm square mesh size. While this does not exclude the possibility of a fish predator, some of the sponges had the Bell wires that held the sponge in place completely bitten through which would have required a strong-jawed predator. Two sponges in the Open treatment and one in the Coarse Mesh treatment had their wires bitten through at Reef 21 (Wass Reef) and two sponges in the Open treatment at Reef 2 also had their wires cut. Again, the sponges in the Open treatment suffered the greatest predation with many being nearly completely eaten (Figure 4). While this experiment ran for a shorter period of time compared to Run 1, it appears that the sponges in the Coarse Mesh treatment experienced increased grazing compared to Run 1 which may simply indicate that predators had learned how to enter cages. Sponges in the Coarse Mesh cages showed percent changes close to the Open treatment whereas the sponges in the Fine Mesh treatment were again unharmed. Table 3 shows the descriptive statistics for percent change for each treatment; results are pooled for both sites.

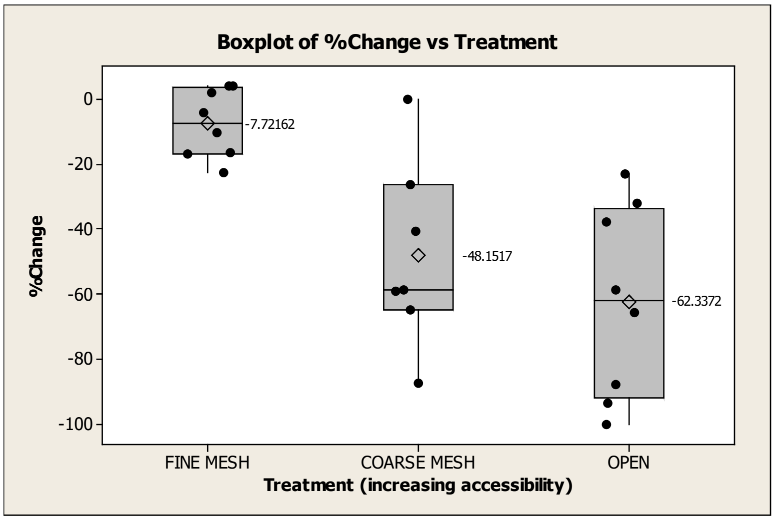

Figure 4: Boxplot of percent change in buoyant mass of *M. armata* from both Wass Reef and Reef 2 for Run 2. The boxplot indicates that sponges in both the Open and Coarse Mesh treatments were more predated than the Fine Mesh treatment. Individual data points are indicated with the symbol ● and the mean is indicated by ◊, along with its value.

Table 3: Descriptive Statistics for %Change versus Treatment

Variable	TRT	Mean	SE Mean	StDev	Minimum	Median	Maximum
%Change	FINE MESH	-7.72	3.70	10.47	-22.65	-7.49	3.80
	COARSE MESH	-48.2	10.8	28.6	-87.5	-58.6	-0.0400
	OPEN	-62.3	10.4	29.5	-100.0	-62.1	-23.2

A general linear model was run for percent change to *M. armata* buoyant weight during Run 2 to determine which fixed-value factors were significant (Table 4). As Table 4 indicates, the Treatment, Old/New, and Site factors were all found to be significant. The differences in treatment outcomes between reef sites can be seen in the boxplots of Figure 5. The sponges in the Open treatment seems to be more highly predated on Wass Reef than Reef 2, but on both reefs these sponges were grazed unlike the protected sponges in the Fine Mesh treatment. Sponges in the Coarse Mesh treatment were also grazed but slightly more on Wass Reef where cages appear to be overturned more frequently. Furthermore, as the individual value plot of Figure 5 shows, one of the Coarse Mesh cages was not recovered and was believed to have been tossed into deeper water.

Table 4: General Linear Model of %Change versus Treatment, Old/New sponge, Site (reef); all factors are significant.

Factor	Type	Levels	Values
TRT	fixed	3	COARSE MESH, FINE MESH, OPEN
Old/New	fixed	2	New, Old
Site (reef)	fixed	2	2, wass

Analysis of Variance for %Change, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TRT	2	12770.0	14222.1	7111.1	17.74	0.000
Old/New	1	1544.4	2165.0	2165.0	5.40	0.032
Site (reef)	1	2998.1	2998.1	2998.1	7.48	0.014
Error	18	7213.8	7213.8	400.8		
Total	22	24526.3				

S = 20.0191   R-Sq = 70.59%   R-Sq(adj) = 64.05%

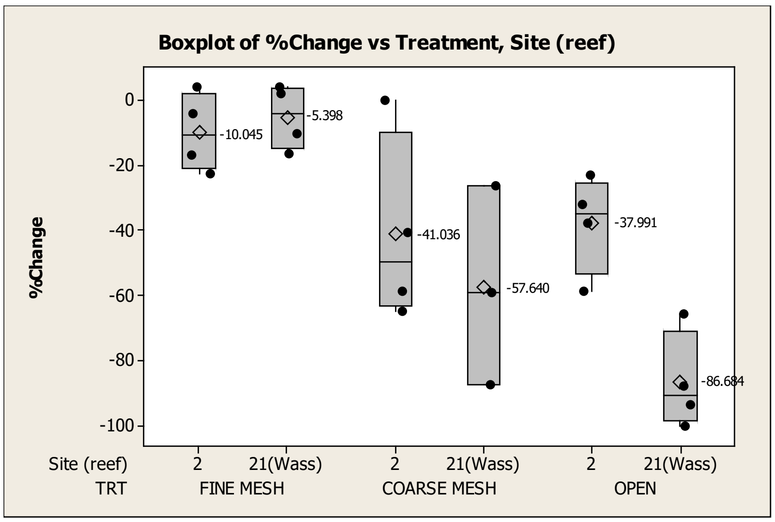

Figure 5: Boxplot of percentage change in buoyant mass of *M. armata* versus treatment and reef for Run 2. The boxplot indicates that sponges in both the Open and Coarse Mesh treatments were more predated than the Fine Mesh treatment. It also indicates that for both the Open and Coarse Mesh treatments the percentage loss to sponge tissue was greater at Reef 21 (Wass reef) than at Reef 2. Individual data points are indicated with the symbol ● and the mean is indicated by ◊, along with its value.

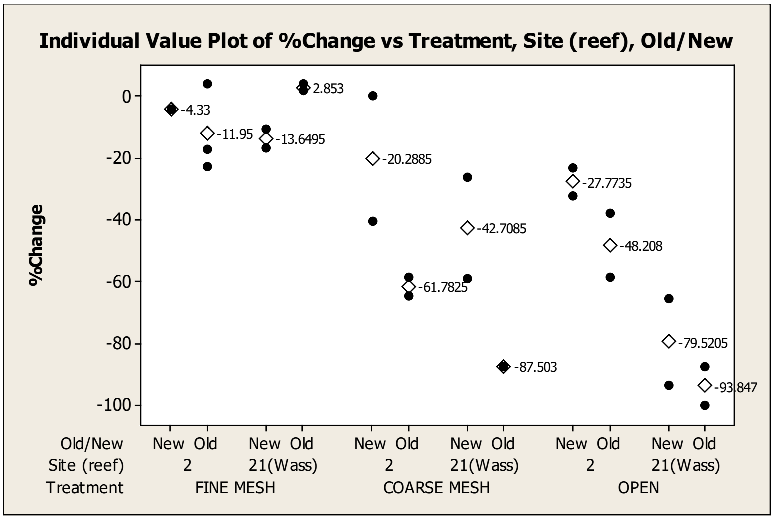

Figure 6: Individual value plot of percentage change in buoyant mass of *M. armata* versus cage treatment, Site (reef), and Old/New sponge for Run 2. The plots indicate that sponges in both the Open and Coarse Mesh treatments are more predated than the Fine Mesh with Open experiencing the greatest loss to tissue. It also appears that predation is greatest on Reef 21 (Wass reef) and that reused (old) sponges experienced different predation and growth rates over newly prepared sponges. For the Open and Coarse Mesh treatments individual plots for Old sponges had greater loss to tissues or higher grazing while in the Fine Mesh treatment the Old sponges seem to maintain their weight better compared to newly prepared sponge samples. Individual data points are indicated with the symbol ● and the mean is indicated by ◊, along with its value.

Experiment Run 3- 6/3/2006-6/17/2006:

Wass Reef

For Run 3 on Wass Reef, the Mid Mesh cage treatment was added to keep turtles out but allow fish (namely the Moorish Idol-a known spongivore) to swim through the openings. The descriptive statistics for the results of both reefs appear in Table 5. Boxplots in Figure 7 show that sponges in the Mid Mesh treatment were not grazed and their weights remained relatively constant and consistent with the Fine Mesh treatment. Conversely, the sponges in the Open and Coarse Mesh treatments were again heavily grazed. Predation on the Open treatment would have been even greater but at least one Open platform was found to be overturned, thereby pinning the sponge between the reef and the metal platform and creating a barrier to predation. One Mid Mesh treatment cage and one Fine Mesh treatment cage could not be located on the reef and were not included in the analyses (Figure 7). ANOVA (Table 6) for % change to sponge buoyant weight on Wass Reef reported the Treatment variable as highly significant and Tukey pairwise comparisons showed that the Coarse and Mid Mesh treatments, the Fine Mesh and Open, and the Mid Mesh and Open treatments were each significantly different from one another.

Table 5: Descriptive Statistics for %Change

Results for Site (reef) = 2

Variable	Treatment	Mean	SE Mean	StDev	Minimum	Median	Maximum
%Change	Fine Mesh	-7.38	3.19	7.82	-16.41	-8.17	3.73
	Coarse Mesh	-25.5	14.8	20.9	-40.3	-25.5	-10.8
	Open	-41.5	15.1	30.2	-76.6	-40.5	-8.64

Results for Site (reef) = 21 (Wass Reef)

Variable	Treatment	Mean	SE Mean	StDev	Minimum	Median	Maximum
%Change	Fine Mesh	-1.90	1.99	3.99	-7.58	-0.851	1.69
	Mid Mesh	0.618	4.02	8.03	-7.74	0.0890	10.03
	Coarse Mesh	-55.2	18.5	41.3	-100.0	-51.6	-9.76

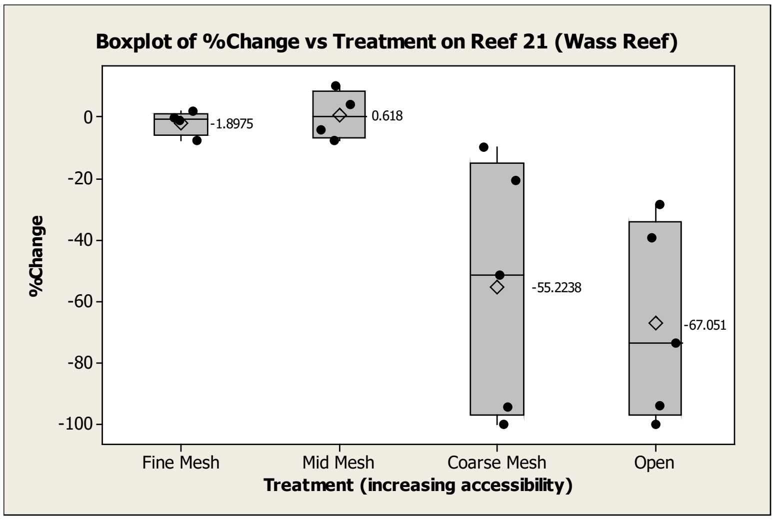

Figure 7: Boxplot of % change in *M. armata* weight for each of the four cage sizes at Wass Reef. Sponges in the Fine Mesh cage treatment did not experience predation. Furthermore, the prediction that Mid Mesh treatment cages would exclude the predator of Runs 1 and 2 was confirmed as sponges in the Mid Mesh treatment were also unharmed. The Open treatment experienced the greatest predation followed closely by the Coarse Mesh treatment. Individual data points are indicated with the symbol ● and the mean is indicated by ◊, along with its value.

Table 6: One-way ANOVA of % Change versus Treatment for Wass Reef with Tukey comparisons

Source	DF	SS	MS	F	P
Treatment_wass	3	16629	5543	6.96	0.004
Error	14	11147	796		
Total	17	27776			

S = 28.22   R-Sq = 59.87%   R-Sq(adj) = 51.27%

```
                                     Individual 95% CIs For Mean Based on
                                     Pooled StDev
Level        N    Mean  StDev  -------+---------+---------+---------+--
Coarse Mesh  5  -55.22  41.27     (-------*--------)
Fine Mesh    4   -1.90   3.99                    (-------*--------)
Mid Mesh     4    0.62   8.03                     (-------*--------)
Open         5  -67.05  31.99  (-------*-------)
                               -------+---------+---------+---------+--
                                    -70       -35         0        35
Pooled StDev = 28.22
```

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Treatment_wass
Individual confidence level = 98.85%

```
Treatment_wass = Coarse Mesh subtracted from:
Treatment_wass   Lower  Center   Upper
Fine Mesh        -1.68   53.33  108.34
Mid Mesh          0.83   55.84  110.85
Open            -63.69  -11.83   40.04

Treatment_wass  --------+---------+---------+---------+-
Fine Mesh                         (-------*------)
Mid Mesh                          (-------*-------)
Open                     (------*-------)
                --------+---------+---------+---------+-
                      -70         0        70       140

Treatment_wass = Fine Mesh subtracted from:
Treatment_wass    Lower  Center   Upper
Mid Mesh         -55.47    2.52   60.50
Open            -120.16  -65.15  -10.14

Treatment_wass  --------+---------+---------+---------+-
Mid Mesh                   (-------*--------)
Open             (-------*-------)
                --------+---------+---------+---------+-
                      -70         0        70       140


Treatment_wass = Mid Mesh subtracted from:
Treatment_wass    Lower  Center   Upper
Open            -122.68  -67.67  -12.66

Treatment_wass  --------+---------+---------+---------+-
Open            (-------*-------)
                --------+---------+---------+---------+-
                      -70         0        70       140
```

Reef 2

The sponges in the Open treatment on Reef 2 were also grazed (Figure 8), although not at the same level of grazing as Wass Reef. Due to a limit on the number of cages available for this experiment, only 2 Coarse Mesh cages were used on Reef 2, but these also showed increased grazing over the Fine Mesh treatment (Figure 8). Figure 9 shows the percentage change in *M. armata* buoyant weight for all treatments and sites for Run 3. The results indicate that sponges in the Open and Coarse Mesh treatments were predated upon but that the level of predation at Wass reef was greater than at Reef 2. In contrast, sponges in the Fine and Mid Mesh treatments were unharmed. The level of grazing on sponges in the Open and Coarse Mesh treatments on Reef 2 is surprising given the abundance of *M. armata* on this reef and the relatively few signs of grazing observed on sponges during surveys of the reef. ANOVA (Table 7) of % change for Reef 2 did not indicate the treatment cage-mesh was significant, but this is probably because of the limited number of cages used for this site ($n = 2$ for Coarse Mesh treatment). Unlike previous experiments, only one sponge, from the Coarse Mesh treatment on Reef 2, had the wire cut which may simply be because of the shorter duration of sponges on the reef.

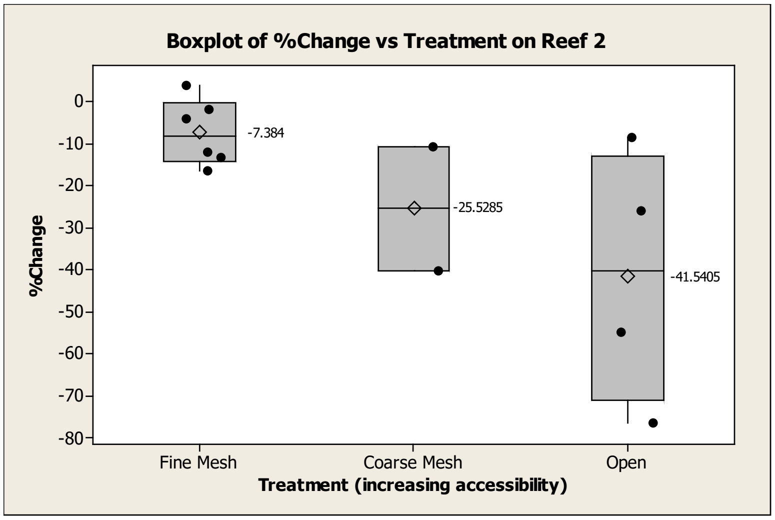

Figure 8: Boxplot of % change in *M. armata* weight for each of the four cage sizes at Reef 2. The Fine Mesh cage treatment did not experience predation. The Open treatment experienced the greatest predation followed closely by the Coarse Mesh treatment. Individual data points are indicated with the symbol ● and the mean is indicated by ◊, along with its value.

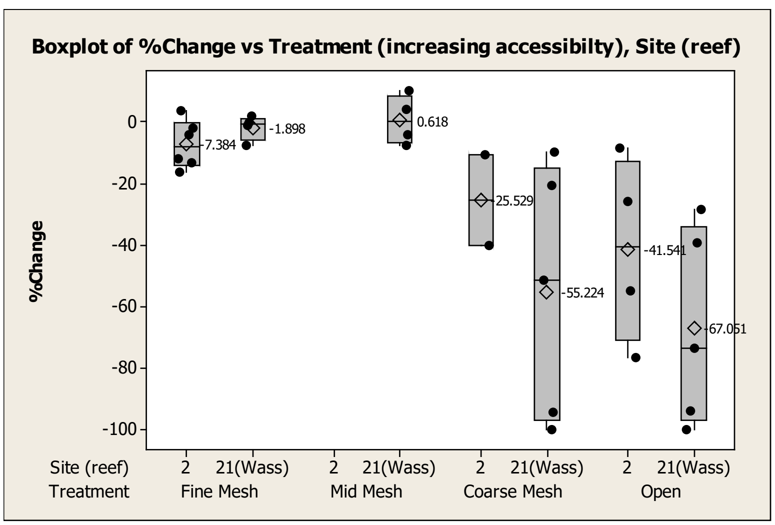

Figure 9: Boxplot of % change in weight for all treatments and sites of Run 3. The results indicate that sponges in Open and Coarse Mesh treatments were predated upon but that the level of predation at Wass reef was greater than at Reef 2. In contrast, sponges in Fine and Mid Mesh treatments were unharmed. Individual data points are indicated with the symbol ● and the mean is indicated by ◊, along with its value.

Table 7: One-way ANOVA of %Change versus Treatment for Reef 2 with Tukey Comparisons

```
Source        DF    SS    MS     F      P
Treatment_2    2  2833  1417  3.67  0.068
Error          9  3471   386
Total         11  6305
S = 19.64   R-Sq = 44.94%   R-Sq(adj) = 32.71%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level       N    Mean  StDev  --+---------+---------+---------+-------
Coarse Mesh 2  -25.53  20.87      (---------------*---------------)
Fine Mesh   6   -7.38   7.82                     (--------*--------)
Open        4  -41.54  30.16  (----------*----------)
                              --+---------+---------+---------+-------
                              -60       -40       -20         0
Pooled StDev = 19.64

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Treatment_2
Individual confidence level = 97.91%

Treatment_2 = Coarse Mesh subtracted from:
Treatment_2   Lower  Center  Upper    +---------+---------+---------+---------
Fine Mesh    -26.64   18.14  62.93                (------------*------------)
Open         -63.51  -16.01  31.49      (------------*-------------)
                                      +---------+---------+---------+---------
                                    -70       -35         0        35

Treatment_2 = Fine Mesh subtracted from:
Treatment_2   Lower  Center  Upper    +---------+---------+---------+---------
Open         -69.56  -34.16   1.25    (---------*---------)
                                      +---------+---------+---------+---------
                                    -70       -35         0        35
```

Conclusions

The results of these exclusion cage experiments clearly indicate that *M. armata* is being grazed and that the predator can be excluded from sponges when cages made of mesh with holes 5.1 cm x 10.2 cm are used. Cages with holes of 15.2 cm x 15.2 cm were only successful in excluding the predator when their orientation with a large overhang top was intact. When overturned, predators were able to gain access to sponges. Results of experiments on Reef 21 seem to support the hypothesis that green sea turtles are preying on *M. armata*. Turtles certainly would be capable of overturning the Coarse Mesh cages and biting though the wire used to secure sponges to cages. The Mid Mesh cages are believed to have holes large enough to allow fish such as the Moorish Idol to pass through but were successful in excluding predators which further supports turtles as the predator since they would be incapable of entering cages of this size. However, since direct observations of turtles feeding on sponges has not been made and relatively few spongivores have been described among the Kaneohe Bay icthyofauna, I cannot conclusively say that green sea turtles are the predator of interest.

The results of Experiment Run 2 showed that the experimental sponges on Reef 2 were also being preyed on although to a lesser extent than on Reef 21. One explanation is that while sea turtles have not been observed on Reef 2, there may be occasional visits by turtles and therefore feeding to a lesser extent than the resident turtles on Reef 21. Conversely, perhaps a fish species is responsible for the predation observed on both reefs and the reduced predation on Reef 2 experimental sponges is a result of the abundance of *M. armata* on Reef 2, rather than a reduced number of predators. It is difficult to imagine that a fish that is able to overturn cages and bite through the wire attaching the sponge has gone unnoticed. However, relatively few studies of spongivory exist and information on sponge-feeding fishes is incomplete, especially for Hawaii. Therefore, additional research and new techniques are needed to conclusively identify or disprove green sea turtles as predators of *M. armata*.

Cited:

Balazs, G.H. 1980. Synopsis of biological data on the green turtle in the Hawaiian Islands. U.S. Dept. of Commerce, NOAA, NMFS, SFC. Honolulu, Hawaii. NOAA-TM-NMFS-SWFC; 7.

Bjorndal, K.A. 1980. Nutrition and Grazing Behavior of the Green Turtle *Chelonia mydas*. *Marine Biology* 56: 147-154.

Bjorndal, K.A. 1990. Digestibility of the sponge *Chondrilla nucula* in the green turtle, *Chelonia mydas*. *Bulletin of Marine Science* 47: 567-570.

Carr, A.F. 1952. Handbook of turtles. Cornell Univ. Press, Ithaca, New York. 542 pp.

Ferreira, M.M. 1968. Sobre a alimentacao da aruana, *Chelonia mydas*, ao longo da costa do estado do Ceara. *Arq. Estac. Biol. Mar* 8:83-86.

Hays Brown, C., and W.M. Brown. 1982. Status of sea turtles in the southeastern Pacific: emphasis on Peru, p. 235-240. *In*: Biology and conservation of sea turtles. K.A. Bjorndal (ed.). Smithsonian Institution Press, Washington, D.C.

Heithaus, M.R., J.J. McLash, A. Frid, L.M. Dill, and G.J. Marshall. 2002. Novel insights into green sea turtle behaviour using animal-borne video cameras. *Journal of the Marine Biological Association of the United Kingdom* 82: 1049-1050.

Makowski, C., J.A. Seminoff, and M. Salmon. 2006. Home range and habitat use of juvenile Atlantic greent turtles (*Chelonia mydas* L.) on shallow reef habitats in Palm Beach, Florida, USA. *Marine Biology* 148: 1167-1179.

Mortimer, J.A. 1981. The Feeding Ecology of the West Caribbean Green Turtle (Chelonia mydas) in Nicaragua. *Biotropica* 13 (1): 49-58.

Meylan, A.B. 1988. Spongivory in Hawksbill Turtles: A Diet of Glass. *Science* 239(4838): 393-395.

Russell, D.J. and G.H. Balazs. 2000. Identification manual for dietary vegetation of the Hawaiian green turtle *Chelonia mydas*. U.S. Dep. Commerce, NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-294, 49 p.

Seminoff, J.A., A. Resendiz, and W.J. Nichols. 2002. Diet of East Pacific Green Turtles (*Chelonia mydas*) in the Central Gulf of California, Mexico. *Journal of Herpetology* 43 (3): 447-453.

Appendix A: Known Spongivorous Fish of Hawaii