A survey of the cockle *A. antiquata*, Chumbe Island

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Abstract:

A survey of the cockle *Anadara antiquata*'s population was performed on the intertidal zone of Chumbe, a small island located off of Zanzibar, Tanzania. Cockle abundance and size were measured along transects laid parallel to shore at four sites, two sites on the west side and two on the east. The marine and intertidal environments on the western side of the island are protected under Chumbe Island Coral Park (CHICOP), a privately managed Marine Protected Area (MPA). However, small-scale artisanal fisheries including cockle collection by women still occur on the unprotected east side. This study will attempt to evaluate the effect of the no-take MPA on cockle populations and their interactions with associated biota. Results will indicate whether the MPA on the western side has had an effect on cockle abundance, size and distribution since extraction ceased in 1994. Additionally, the study will provide insight on the flora, fauna and sediment types that tend to be associated with *A. antiquata* in these two environments.

Introduction:

This study examined the distribution and abundance of the edible cockle *Anadara antiquata* on the protected and unprotected sides of Chumbe Island in Zanzibar, Tanzania. Chumbe Island Coral Park (CHICOP), gazetted by the Zanzibari government in 1994, includes a reef sanctuary that protects all marine habitats on the western side of Chumbe Island. The eastern side of the island is still exploited by both shallow water and intertidal fisheries. Local women from the neighboring island of Unguja travel by boat during spring tides to a sand bank on the eastern side of the island to gather mollusks, including *A. antiquata,* in the intertidal zone. The women only gather on Chumbe during the northeast monsoon season; during the South East monsoon, they collect mollusks on a nearby island (Jiddawi, personal communication).

A. antiquata is a burrowing bivalve commonly found in sandy and muddy intertidal zones of the Western Indian Ocean (Richmond 1997). *A. antiquata* has historically been collected, primarily by women, along the coast of East Africa, and continues to be an important food source as well as a commercial commodity. (Richmond 1997, Kasigwa and Mahika 1991). In Zanzibar, women typically gather bivalves for about six days during spring low tides, working an average of three hours per day. Though *A. antiquata* is the most frequently collected species, women collect all species of edible mollusk found in the intertidal zone (Cohen 2005, Steinhoff 2001). A recent study on population structure of *A. antiquata* revealed a population age structure that indicates resilience of cockle to fishing pressure, with one peak in abundance at juvenile age and another for mature cockles (Mzighani 2005). However, in a study of mollusk collecting in two Zanzibari villages, Cohen (2005) reported that recently some women have had to move further offshore in the intertidal zone to collect sufficient amounts of bivalves, suggesting that the fishery may be unsustainable.

Most studies of intertidal fisheries have focused on rocky shores, where it has been found that humans act as keystone predators with harvesting activities which lead to cascading effects down food webs (see review Castilla 1999). Hockey and Bosman (1986) found that harvesting by humans on a rocky shore in South Africa resulted in diminished or absent populations of exploited species, as well as smaller sizes of individuals of the same species. However, overall species diversity patterns followed the intermediate disturbance hypothesis, leading to greater species richness in exploited areas. Similarly, human exclusion studies in the rocky intertidal zone of Chile found smaller average sizes of individuals of the targeted *Fissurella picta* in exploited areas as compared to protected areas. In addition, it was found that elimination of harvesting of the limpet *Fissurella picta* leads to dramatic decreases in macroalgal abundances as well as decrease in size of the unexploited limpet *Siphonaria lessoni* (Moreno et al 1984). Should intertidal fisheries in the soft bottom communities have similar large-scale effects, they should be managed carefully to avoid overexploitation or altering of ecologically important habitats, such as seagrass beds.

Those studies that exist on the effects of fisheries on soft bottom communities have rendered more variable results. A study of the intertidal fishery on Inhaca Island, Mozambique found no difference in abundance, density, species richness or several other structural parameters between exploited and unexploited areas. This suggests that the burrowing nature of the exploited species provides refuge which prevents overexploitation (de Boer and Prins 2002). In contrast, studies of the yellow clam fishery in Uruguay found that a temporary closure of the fishery led to a rapid recovery of clam populations that in turn led to recruitment failure due to density-dependent factors. This suggests that the fishery may be beneficial to clam populations by preventing overpopulation (Brazeiro and Defeo 1999). A sympatric wedge clam was also found to be affected by the fishery, likely due to disturbance of sediment by fishers as they dig: density of the wedge clam had an inverse relationship with fishing effort (Defeo and de Alava 1995). Sizes of targeted *Anadara spp.* in seven countries in the Tropical East Pacific Region were smaller in exploited areas than unexploited areas. However, despite intense harvesting pressure, stocks were not found to be depleted because cockles were being harvested after reaching sexual maturity, and considerable refuge area existed in nearby dense mangrove root structures which were inaccessible to humans (MacKenzie 2001).

If the *A. antiquata* fishery alters abundance or distribution of this cockle, it may have subsequent effects on surrounding species, as *A. antiquata* may also have ecological importance as a creator of structural diversity within sandy beach ecosystems. The shells of infaunal cockles of the genus *Katelysia* spp. build complexity into the benthic environments which affects population- to ecosystem-level processes. Especially in aggregation, they provide refuge and attachment surfaces for other benthic species and alter the intertidal substrate in such a way that solute and particle transport in near-bed flow is changed. In addition, cockles are ubiquitous and produce large amounts of shell, which serve as long-term carbon sinks that play into global nutrient cycling patterns. It is likely that as a burrowing bivalve, *A. antiquata* plays a similar role in ecosystem engineering which strongly affects the surrounding biotic assemblages (Gutierrez et al 2003).

Several strategies have been proposed for management of exploited intertidal communities including seasonal closures, size limits, and no take zones (NTZs) (Brazerio and Defeo 1999, MacKenzie 2001, Ashworth et al 2003). NTZs have been lauded as a viable form of fisheries management for tropical fisheries where classical fisheries management techniques often fail. Size limits and seasonal closures are more appropriate for single species fisheries where there is a good deal of knowledge on reproductive strategy and status of exploited stocks. NTZs offer protection of a reproductive stock, preservation of habitat and simplified enforcement (Roberts and Polunin 1991). Though much of the philosophy behind NTZs was created to suit offshore fisheries, the intertidal fisheries in Zanzibar are similar in that they are primarily artisanal and indiscriminate in terms of the species exploited. The success of MPAs in fisheries of mobile organisms relies in part on spillover of adult populations from MPA boundaries to replenish fished stocks outside the protected area; however, the likelihood of adult spillover of sessile creatures such as *A. antiquata* is low. Thus, the management of the fishery through MPAs relies on replenishment of stocks through larval export. A study on the role of no-take zones (NTZs) on a small-scale reef-top gathering fishery in South Sinai, Egypt found that populations of the exploited sessile giant clam (*Tridacna* spp.) were greater within NTZs than in adjacent exploited areas; the presence of a larger population has implications of enhanced larval export to nearby fished areas. (Ashworth 2004). Likewise, if greater abundance of *A. antiquata* is found within the protected area on Chumbe, it will further support the notion that no-take MPAs are an appropriate form of fisheries management for exploited sessile creatures.

Distribution of cockles can also be attributed to abiotic and biotic factors other than human exploitation. Studies of cockles in the Eastern Scheldt (The Netherlands) have shown zonation patterns based on emersion time and current speed (Kater et al. 2006). Seagrass beds often host a larger abundance of infauna than sandy areas due to stabilization of sediment and protection from burrowing predators (Nakamura & Sano 2005, Orth et al 1984) Sediment type can also play a large role in cockle populations, as substrates with different sized particles allow varying levels of physical stability and oxygen flow. Such factors control the distribution of many intertidal species and it is likely that *A. antiquata* is similarly distributed according to abiotic factors. An assessment of *A. antiquata* distribution across the protected and unprotected sides of Chumbe Island will provide both a picture of the undisturbed distribution of the cockle as well as of the nature and intensity of the intertidal fishery.

This study surveys populations of *A. antiquata* on the protected and unprotected sides of Chumbe Island. In doing so we attempt to address the following questions: (I) what is the difference, if any, in abundance or size of *A. antiquata* between the protected and unprotected sides of the island? (II) What are the associated species typically found with *A. antiquata,* if any, and how are they affected by the fishery and the presence of the MPA? (III) What substrate types, in terms of seagrass cover and sediment type, are associated with high cockle densities?

In answering these questions, we hope to assess the effectiveness of MPAs on *A. antiquata* fisheries in Zanzibar, gain insight into the ecology of *A. antiquata* and its associated biota and abiota in an undisturbed setting, and guide future management schemes.

Study Area:

Chumbe Island is a small coral rag island situated about eight miles from the southwest coast of Unguja Island, one of the two main islands that make up the Zanzibar Archipelago. The archipelago is found Africa, east of Tanzania in the Western Indian Ocean. Chumbe lies between the latitudes 617’17”S and 617’S and sits on longitude 3910’45”E. The island is oriented in a north-south direction and is about 1.3 kilometers long and 0.3 kilometers wide.

Chumbe Island is uninhabited except for a privately owned ecotourism resort whose staff quarters, common house and seven bungalows are located near on the southwestern side of the island. The island is covered in coral rag forest which is home to such endangered species as the Ader’s Duiker and coconut crab. Both this forest and the adjacent fringing coral reef on the western side of the island were gazetted as a protected area by the Government of Zanzibar in 1994. The marine side of this protected area, Chumbe Island Coral Park (CHICOP), is the only privately-owned marine protected area in the world and boasts exceptional biodiversity of coral and associated fish species.

The intertidal area which separates coral reef from the steeply eroded cliffs on both sides of this island has historically been exploited for food resources. However, since the initiation of CHICOP, all extraction from the western side has ceased while some gathering still occurs on the unprotected eastern side.

Methods:

Abundance and size distribution of cockles, substrate type and associated species were measured in four sites on the protected and unprotected sides of Chumbe Island, with two sites on the protected side and two on the unprotected side (Figures 14 and 15). Each site consists of a series of either four or five 100m transects laid approximately parallel to shore, with five meters between each transect. Locations of transects were recorded using GPS coordinates from both ends of the transect when possible. A 1m x 1m quadrat of plastic tubing and cord delineating 100 squares of 100cm^2 each was laid every ten meters along each transect. A total of 190 square meters of the intertidal zone were surveyed. All *A. antiquata* and other associated mollusks, gastropods and echinoderms found within the quadrat were recorded. All associated species present were noted in each quadrat, and their abundances were recorded in all but two transects. Photographs were taken of unknown species for later identification. Individual cockles were placed into size classes based upon width using a plywood board with holes of varying diameter corresponding to each size class (Table 1).

Size Class	Cockle Width (cm)
1	0-1
2	1 - 1.5
3	1.5 - 2
4	2 – 2.5
5	2.5 – 3
6	3 – 3.5
7	3.5 – 4
8	4 – 4.5
9	4.5 – 5
10	5 – 5.5
11	5.5 – 6
12	6 – 6.5
13	6.5 - 7

Table 1. Size classes and corresponding actual *A. antiquata* width ranges.

In addition, substrate type was observed by visually estimating cover of seagrass and categorizing it on a scale from zero to five, where zero indicates no seagrass and five indicates very dense cover. The sediment was evaluated at each quadrat and described as either fine sand, sand or coarse sand. During spring tide when the intertidal zone was exposed, quadrats were evaluated in walking surveys; during neap tides, quadrats were evaluated by snorkeling and diving to the bottom to retrieve specimens.

Two sample t-tests were run using Minitab to compare mean density and mean size between each of the four sites. A p-value of less than 0.01 was considered significant. Data was pooled across the four sites and two sample t-tests were run to compare mean density in seagrass beds versus sandy areas and between each sediment type. Species diversity and evenness was evaluated for each site using the Shannon-Wiener index.

Results:

Density: In total, 718 *A. antiquata* individuals were collected at the four sites on Chumbe Island's western and northeastern intertidal zones. The highest cockle density was observed at Protected Site 1 (7.425 individuals/m^2), followed by Unprotected Site 2 (4.300 individuals/m^2), Unprotected Site1 (3.780 individuals/m^2), and the lowest density was found at Protected Site 2 (0.340 individuals/m^2) (Figure 1). Mean *A. antiquata* density for each site is shown in Figure 1.

A two-sample t-test comparing the densities at Protected Sites 1 and 2 found a significant difference between densities at the two sites. P-values for each comparison can be found in Table 4 in Appendix III. There was no significant difference found between *A. antiquata* density between the two unprotected sites. Thus, data was pooled from the two unprotected sites, but not for the two protected sites. Significant differences were found between *A. antiquata* density at Protected Site 1 and each of the two unprotected sites. Significant differences were also found between *A. antiquata* density at Protected Site 2 and each of the unprotected sites.

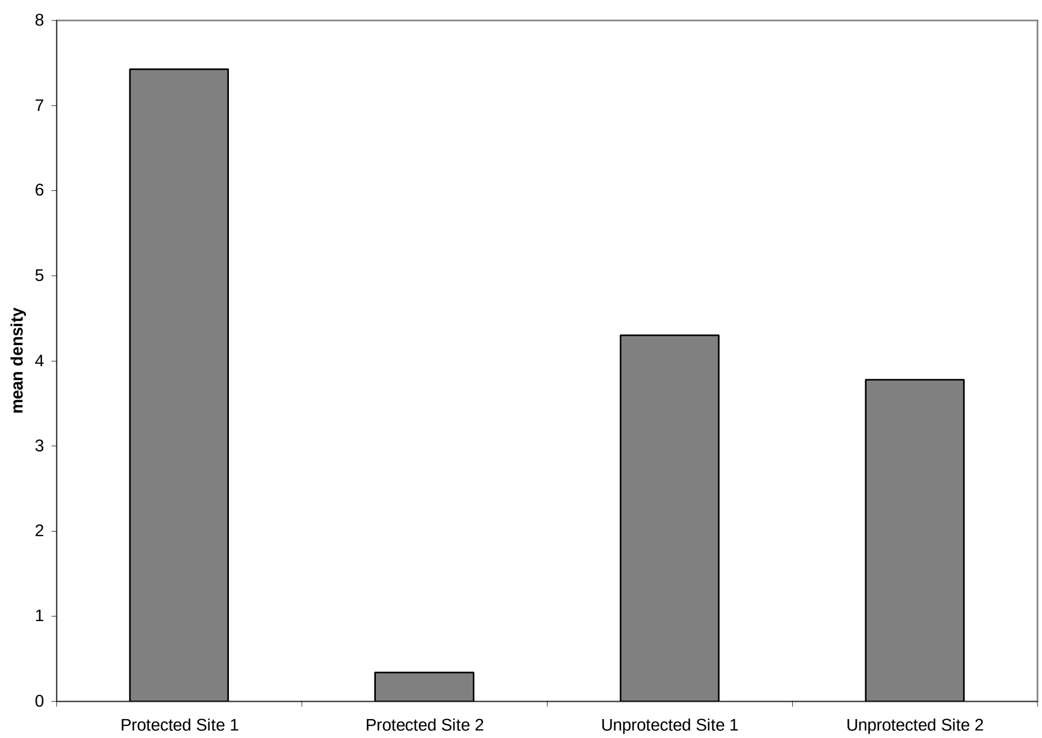

Figure 1. Mean *A. antiquata* density at each of the four sites.

Size: The mean size class for each site is represented in Figure 2. The largest mean cockle size was found on Protected Site 2 (size class 9.471), followed by Protected Site 1 (size class 7.936), Unprotected Site 1(size class 7.214) and finally Unprotected Site 2 (size class 7.037). Two-sample t-tests revealed significance between all combinations of individual sites except between Unprotected Sites 1 and 2. P-values for each comparison can be found in Table 5 in Appendix III. Figure 3 shows the distribution of size classes for all sites, which reveals a pattern that resembles a normal distribution with a peak between size classes eight and nine. Histograms representing distribution of size class for each site individually are found in Appendix I.

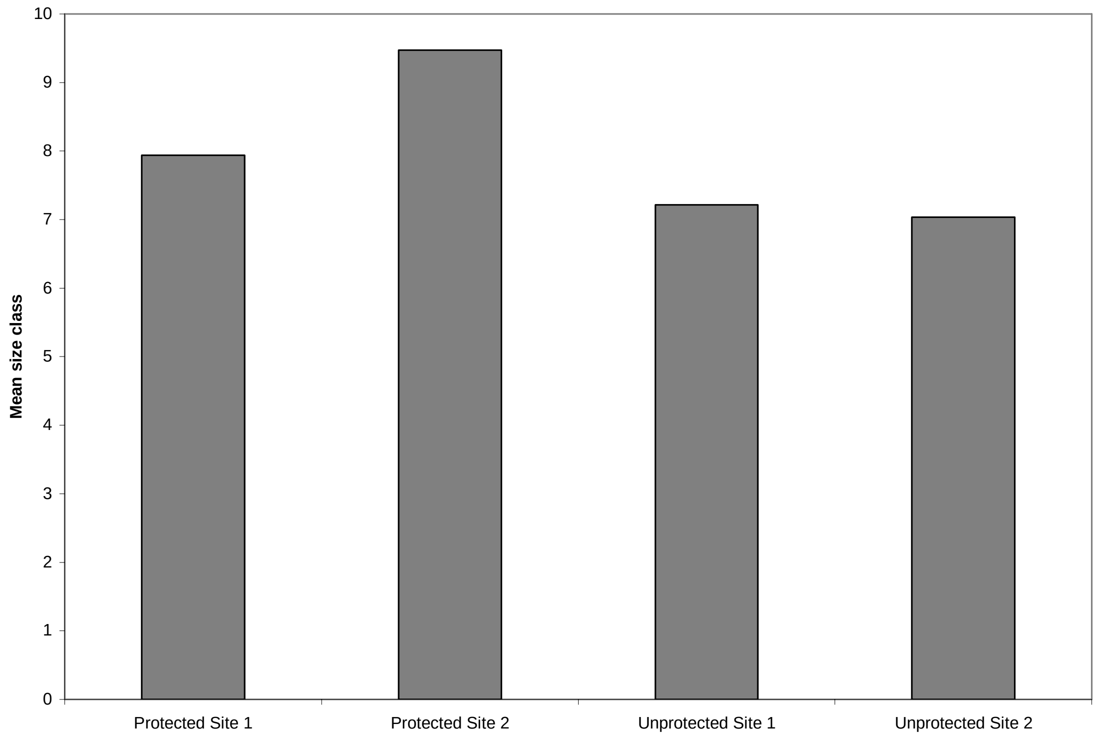

Figure 2. Mean size class of *A. antiquata* at each site.

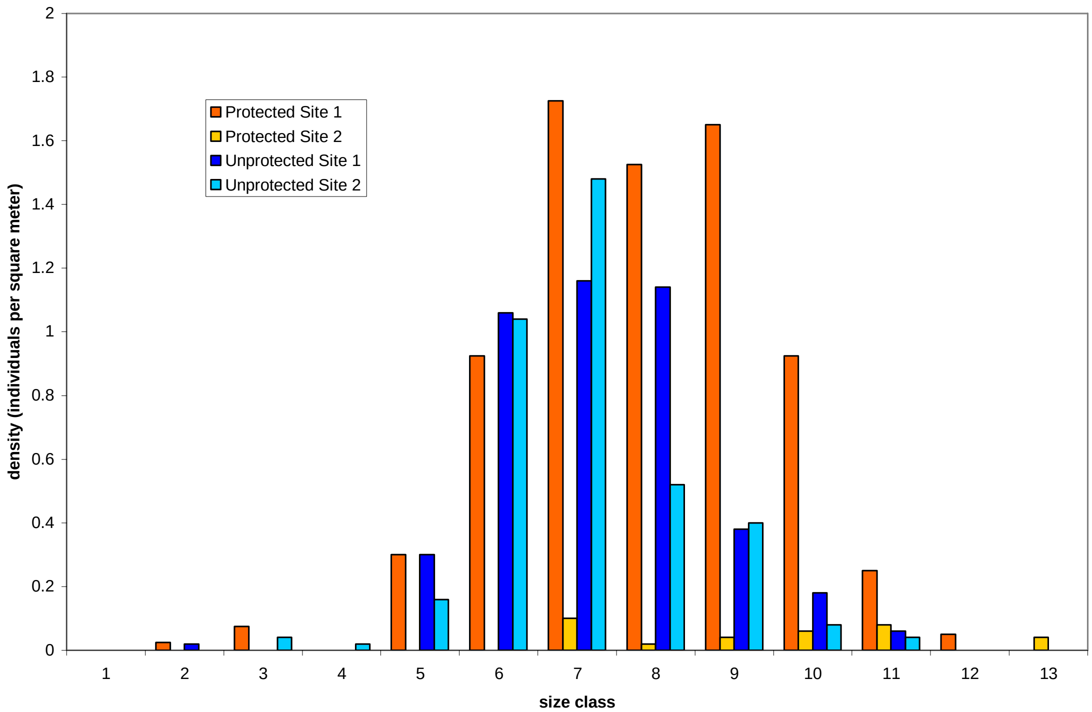

Figure 3. Mean densities of all size classes at all four transects.

Substrate: Figure 4 shows the distribution of mean cockle density in relation to seagrass cover in all four sites. When all quadrats containing seagrass (ratings 1-5) were pooled and compared to those with no seagrass (rating 0), a high level of significance was found (p = 0.000). The mean cockle density in quadrats with seagrass was 4.32 individuals per square meter, while in quadrats with no seagrass the mean cockle density was 1.75 individuals per square meter.

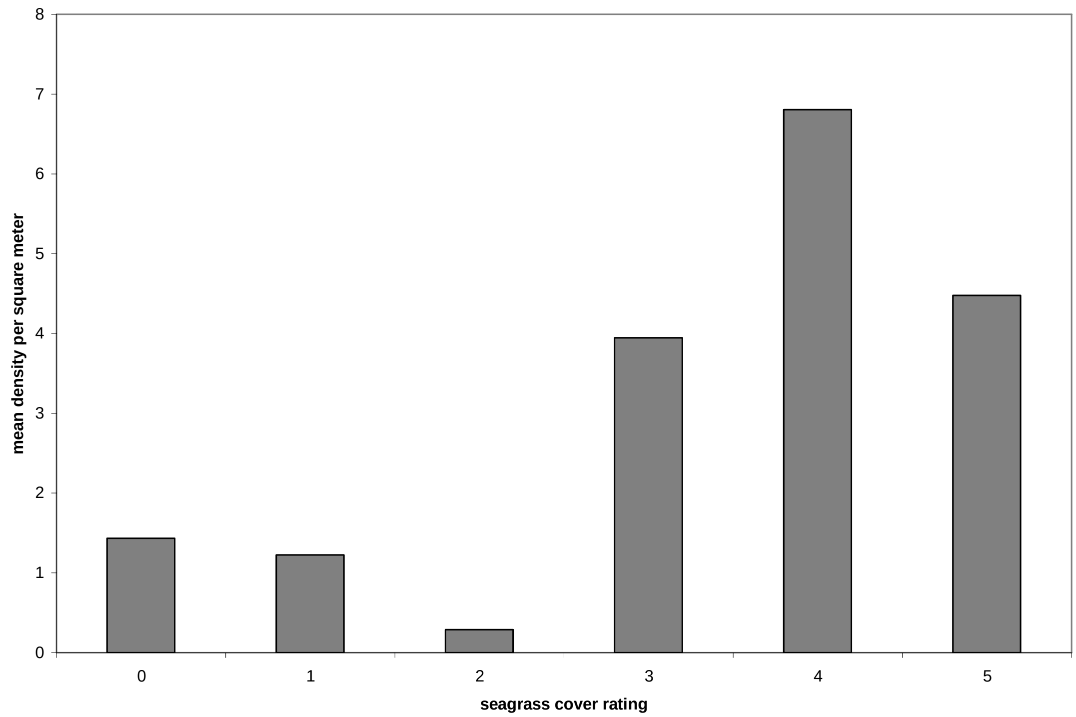

Figure 4. Mean density for each seagrass rating at all four sites.

Figure 5 shows the distribution of sediment type versus cockle density over all sites combined. Across all sites, the most cockles were found in sand (5.49 individuals/m^2), followed by coarse sand (3.31 individuals/m^2) and fine sand (2.73 individuals/m^2). No significance was found between any of the sediment types; although with p-values of 0.017 and 0.022 respectively, sand versus fine sand and sand versus coarse sand nearly met this study's parameter of significance. The difference between cockle densities in fine and coarse sand generated a p-value of 0.520.

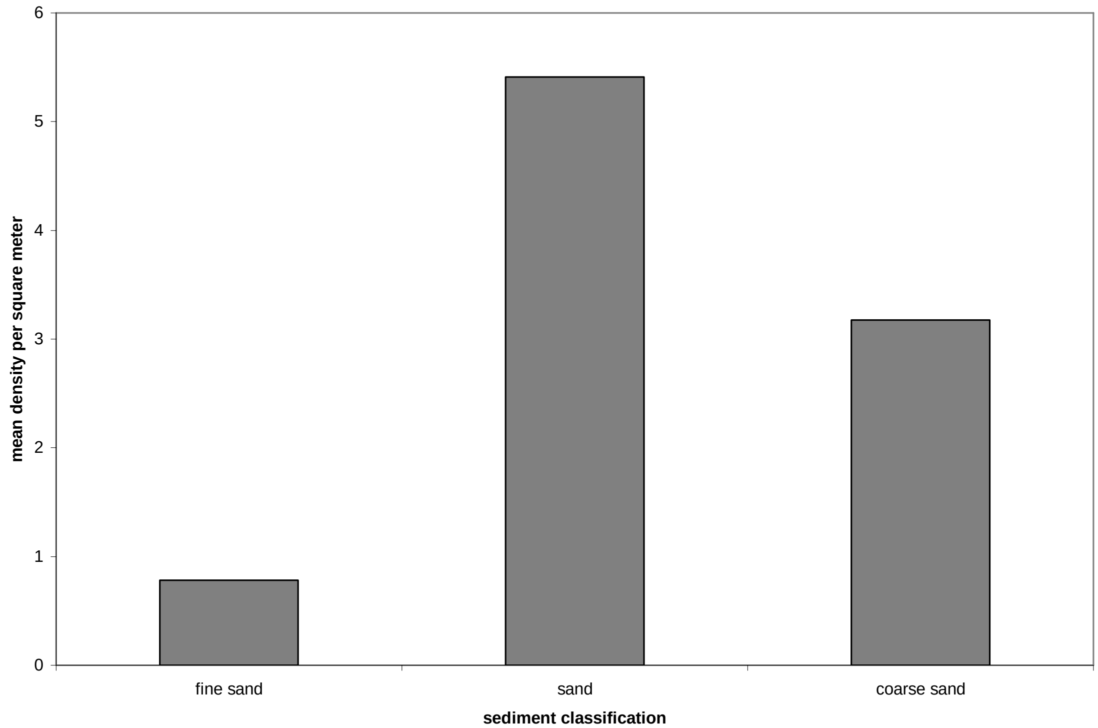

Figure 5. Pooled mean cockle density for each sediment type.

Associated species: A total of 71 associated species were found in all quadrats. The three most abundant species, discluding the mussel *Modiolus phillipinarum,* the pen shell *Pinna muricata* and the oyster *Pinctada radiata*, were *Gafrarium pectinatum* (266 individuals), *Trachycardium pectiniforme* (82 individuals) and *Arca sp* (81 individuals). *M. phillipinarum*, *P. muricata* and *P. radiata* were excluded from species counts because they were often in densities too high to measure and are difficult to extract from the substrate. The three most abundant species for each site are summarized in Table 2. It should be noted that for two transects in Unprotected Site 1, presence of associated species was recorded, but not abundance. Thus, species abundance for Unprotected Site 1 is calculated as the minimum number of individuals possibly found per species: for the two transects with incomplete data (Transects 7 and 8), one individual of each species is counted for each quadrat that it was found in. Thus, reported species abundances may be smaller than actual species abundances.

Table 2: Three most abundant associated species at all four sites.

Protected Site 1		**Protected Site 2**		**Unprotected Site 1**		**Unprotected Site 2**	
Species	Abundance	Species	Abundance	Species	Abundance	Species	Abundance
G. pectinatum	129	*G. pectinatum*	115	*Arca sp.*	56	*Arca sp.*	25
T.pectiniforme	38	*N. coronatus*	18	*T. pectiniforme*	29	*E. mathaei*	11
G. quecketti	22	*T. pectiniforme*	8	*G. pectinatum*	19	*T. pectiniforme*	7

The two protected sites were dominated by *G. pectinatum*, which made up 49.04% and 72.78% of all associated species for Protected Sites 1 and 2, respectively. In contrast, *G. pectinatum* made up a much smaller percentage of overall associated species in the two unprotected sites, comprising 11.24% and 3.09% of all associated species for Unprotected Sites 1 and 2, respectively. The two unprotected sites instead had a high proportion of *Arca sp.* which comprised 33.13% and 25.77% of all associated species for Unprotected Sites 1 and 2, respectively. *Arca sp.* was completely absent from both protected sites.

Shannon-Weiner indices show the highest species diversity (*H')* and evenness (*E*) at Unprotected Site 2, and the lowest species diversity and evenness at Protected Site 2. Highest species richness (*S*) was found at Unprotected Site 1 and lowest species richness at Protected Site 2. Overall, diversity and evenness were higher on the unprotected sites and lower on the protected sites. Values for species richness, diversity and evenness for each site are listed in Table 3. Species diversity and evenness were calculated twice for Unprotected Site 1, once excluding and once including the two transects with incomplete data sets. Excluding the two transects skewed the value towards lower diversity due to a smaller measured species richness, while including the two transects could skew the value towards artificially high evenness. *M. phillipinarum, P. muricata* and *P. radiata* were excluded from calculations of *H'* and *E* at all sites due to lack of data on abundance.

Table 3: Values for species richness (*S*), species diversity (*H'*) and species evenness (*E*) for all sites.

	Protected Site 1	Protected Site 2	Unprotected Site 1 (Excluding T7 & T8)	Unprotected Site 1 (Including T7 & T8)	Unprotected Site 2
S	30	16	27	35	34
H'	1.965	1.110	2.174	2.433	2.883
E	0.596	0.420	0.675	0.702	0.824

Discussion:

Density: Cockle density was found to be significantly different between all surveyed sites, with the exception of the difference between the two unprotected sites. Because P2's *A. antiquata* population differed so drastically from those found in other surveyed areas, P1's data was used to represent the protected area in comparison to the unprotected area. Protected Site 1 and the two unprotected sites are found on the same seagrass bed, thus abiotic and biotic factors affecting *A. antiquata* distribution are likely to be similar.

There was a significantly higher density of cockles found in Protected Site 1 than both unprotected sites, suggesting that exploitation of cockles does have an effect on cockle density. Unlike de Boer and Prins (2002), it was not found that a burrowing lifestyle gave enough of a refuge to avoid significant population decline due to human harvesting. However, the cockle densities at the two unprotected sites did not appear to be severely depleted. During the two spring tides that occurred during this study, no women were observed collecting cockles near the island. This is in line with reports that women only collect cockles on Chumbe during the northeast monsoon season (this study was conducted in April during the southeast monsoon) (Jiddawi, pers. comm.). The collection period most recent to the time of this study was about three months prior, when as many as 60 people were observed gathering cockles near the two unprotected sites (Nyange, pers. comm.). Mzighani (2005) found that population age structures of *A. antiquata* suggest a high level of resilience to fishing pressure, thus the recovery period during the southeast monsoon may allow cockle populations to resist overexploitation.

The significantly lower density of *A. antiquata* in Protected Site 2 is a point of interest that suggests control by strong abiotic and biotic variables rather than human disturbance. It was observed that the seagrass bed surveyed in Protected Site 2 remained immersed even at spring low tide, while all three sites on the north end of the island had periods of emersion during this time. Density of cockles in the Eastern Schelt reaches a peak at emersion times of 40%-60%, despite the fact that emersion times above 50% are found to decrease cockle growth rates. It is thought that at emersion times of below 60%, predation replaces emersion time as the controlling factor in cockle density (Kater et al

2006). Though emersion is physically stressful on intertidal organisms, it provides a refuge from predators, such as fish, that can only hunt at high tides. Predation is more important in subtidal benthic infaunal communities – such as Protected Site 2 – where no such periodic refuge exists (Virnstein 1977). It is possible that the low density of cockles in Protected Site 2 can be explained by a higher predation pressure due to the greater depth of suitable habitat.

Size: Regarding the mean size of *A. antiquata* individuals in the four sites, there is a similar pattern as with density between protected and unprotected sites. The lack of significance between the two unprotected sites is not surprising because of their close proximity to each other. The significant difference between Protected Site 1 and the two unprotected sites could be a result of size-selective collection favoring larger individuals, thus skewing the size distribution of the remaining population toward smaller cockles. This result is in accordance with studies from rocky shores that found larger average sizes of exploited species in protected areas (Hockey and Bosman 1986, Moreno et al 1984), and similar to findings by MacKenzie (2001), who found a larger average size of *Anadara* species in lightly exploited areas when compared to heavily exploited areas. Because *A. antiquata*'s fecundity increases in proportion to size, a smaller average size would result in a population with reduced fecundity. Though the smaller cockles are less fecund, the mean cockle size on the unprotected side of Chumbe Island is higher than that which is associated with sexual maturity. Male *A. antiquata* mature at 31mm shell length and female *A. antiquata* mature at 35mm shell length (Mzighani 2005); mean size classes for Unprotected Site 1 and Unprotected Site 2 were 7.214 and 7.037 respectively, or about 35mm to 40 mm in length. Therefore, it is likely that there are enough mature cockles to replenish the fished population, especially with potential larval inputs from larger cockles within the MPA.

It is also of interest that cockles at Protected Site 1 are significantly larger than those at Protected Site 2. This discrepancy suggests that emersion time is a contributing factor to cockle size as well as density. It has been demonstrated that the mangrove cockles *Anadara similes* and *Anadara tuberculosa* grow faster when constantly submerged (MacKenzie 2001). This phenomenon could account for the larger mean size of *A. antiquata* individuals in Protected Site 2 because this area is submerged more often than the other three sites. Additionally, juvenile and small infaunal bivalves are most vulnerable to predation, while larger cockles escape predation either by burrowing deeper into the substrate or simply being too large for fish to consume (Virnstein 1977, MacKenzie 2001, Flach 2002). If predation is more important in Unprotected Site 2 due to shorter emersion times, faster growing cockles could be selected for, leading to a size distribution skewed towards individuals of larger sizes.

Substrate: When cockle populations are assessed independently of protection, the presence of seagrass appears to have a measurable affect the density of this infaunal species. The significant p-value for these two variables indicates a positive correlation between seagrass cover and cockle density. This is in accordance with Nakamura and Sano (2005), who found greater infaunal densities and biomass in seagrass beds than in sandy areas. Seagrass may provide *A. antiquata* with protection from predation as the presence of rhizomes impedes the burrowing of predators (Orth et al 1984). Seagrass also acts to anchor intertidal sediments, which adds stability and structure to soft-bottom environments (Orth et al 1984, Nakamura and Sano 2005).

Kasigwa and Mahika (1991) report that *A. antiquata* prefer sandy and muddy habitats; however, the relationships between cockle density and size of sand particles in this study were not significant. It is likely that presence or absence seagrass is a much stronger controlling factor than type of sand.

Associated Species: The conspicuous dominance of two different associated species in the protected and unprotected sites, *G. pectinatum* and *Arca sp*. respectively, suggests that intertidal exploitation of *A. antiquata* has effects that reach beyond the population structure of the exploited species. Unfortunately, too little is known about the biology of these two species to explain why disturbance through mollusk gathering would lead to a higher density of *Arca sp.* and lower density of *G. pectinatum.*

The higher diversity index values in the unprotected sites suggest that, as Hockey and Bosman (1986) found for rocky shores, exploitation of the Chumbe intertidal zone increases species diversity in accordance with the intermediate disturbance hypothesis.

Removal of *A. antiquata* and other edible species could open up niche space for species that may otherwise be outcompeted. In addition, methods of harvesting in soft-bottom communities often involve a considerable displacement of sediment. In the case of yellow clam harvesting in Uruguay, displacement of sand was found to have negative effects on population densities of a nonexploited sympatric species of wedge clam (Defeo and de Alava 1995). However, yellow clams were harvested with shovels which are more destructive than the hand-gathering techniques that are used in the Chumbe intertidal zone. In fact, it is possible that displacement of sediment during harvesting creates a greater diversity of microhabitats leading to greater species diversity.

Conclusion:

A. antiquata, a soft-bottom, burrowing bivalve, is valuable both commercially and as a source of protein in Zanzibar, Tanzania (Kasigwa and Mahika 1991, Cohen 2005). In order to better understand the effects that abiotic and biotic factors including human gathering have on this species, its population was surveyed on the protected and unprotected sides of Chumbe Island.

Significant differences were found in mean size and density between all sites except Unprotected Sites 1 and 2, suggesting that exploitation has an effect on population structure and distribution of *A. antiquata*. However, in spite of the smaller average sizes and lower densities in the exploited area, the fishery does not appear to be in danger of overexploitation – perhaps due to the seasonally rotating exploitation of Chumbe and the nearby island. The larger average size and higher density of *A. antiquata* in the protected area indicate a healthy population that can potentially provide larval inputs to outside exploited areas. Significant differences in mean size and density between the two protected sites are likely attributable to the shorter emersion time in Protected Site 2, which leaves cockles more vulnerable to predation.

As suggested by the highly significant differences in cockle population structure between the two protected sites, a number of abiotic and biotic factors other than human exploitation likely control cockle distribution. Among these, presence of seagrass is particularly important. When pooled across sites, data from areas with seagrass had significantly higher cockle densities than those without seagrass. The presence of seagrass provides stability of sediment as well as protection from predation for infaunal creatures; our results are in line with other studies on infaunal density in seagrass beds (Orth et al 1984, Nakamura and Sano 2005). No significance differences were found in cockle densities between sediment types, suggesting that seagrass presence is a much stronger controlling factor on cockle density than sediment type. In accordance with the intermediate disturbance hypothesis, greater species richness, species diversity and species evenness were found in the two unprotected sites.

This study serves to provide important baseline data on the exploited species *Anadara antiquata* and its associated species. The fishery for *A. antiquata* on Chumbe

Island appears to be sustainable, aided both by the presence of the Chumbe Island Coral Park and a seasonal closing of the fishery during the South East monsoon. We hope that the data from this report will help guide management practices in the future.

Recommendations:

Because of the fluctuating nature of cockle populations, especially in relation to human predation and changes in seagrass composition and location, follow-up studies in a different season or over a longer duration could yield interesting results. Other abiotic factors such as water temperature, salinity, sunlight and depth could be closely observed to find any effects on cockle populations. In addition, a more focused study on infaunal diversity could provide important baseline data on the status of a little studied community.

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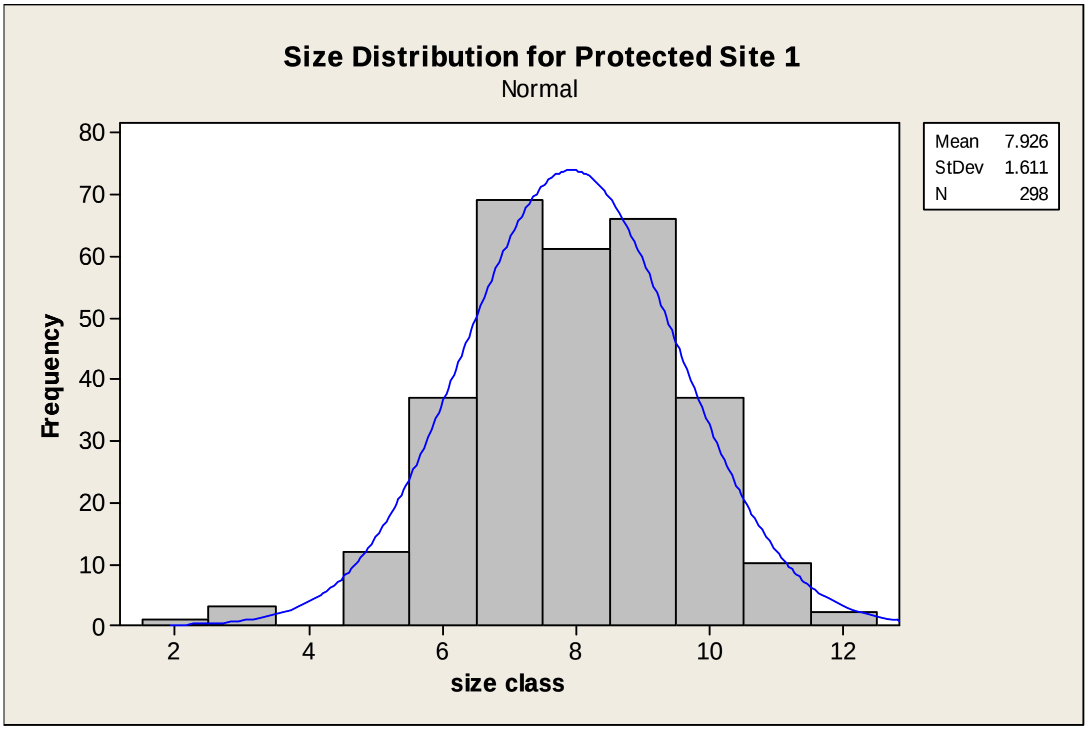
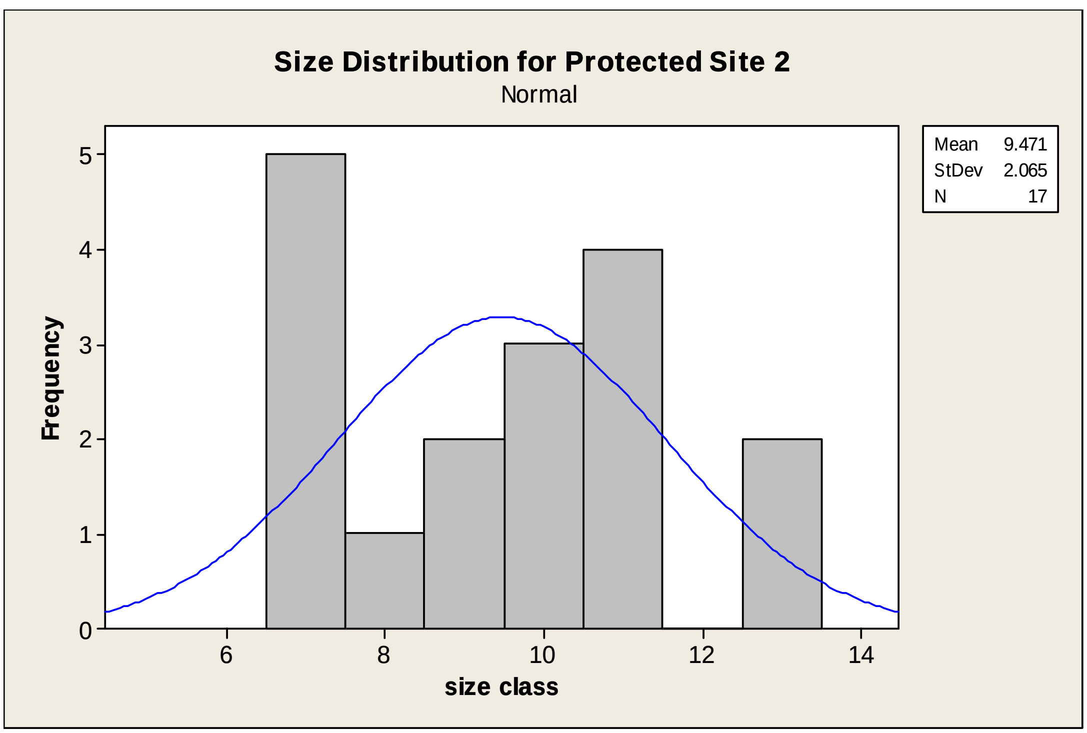
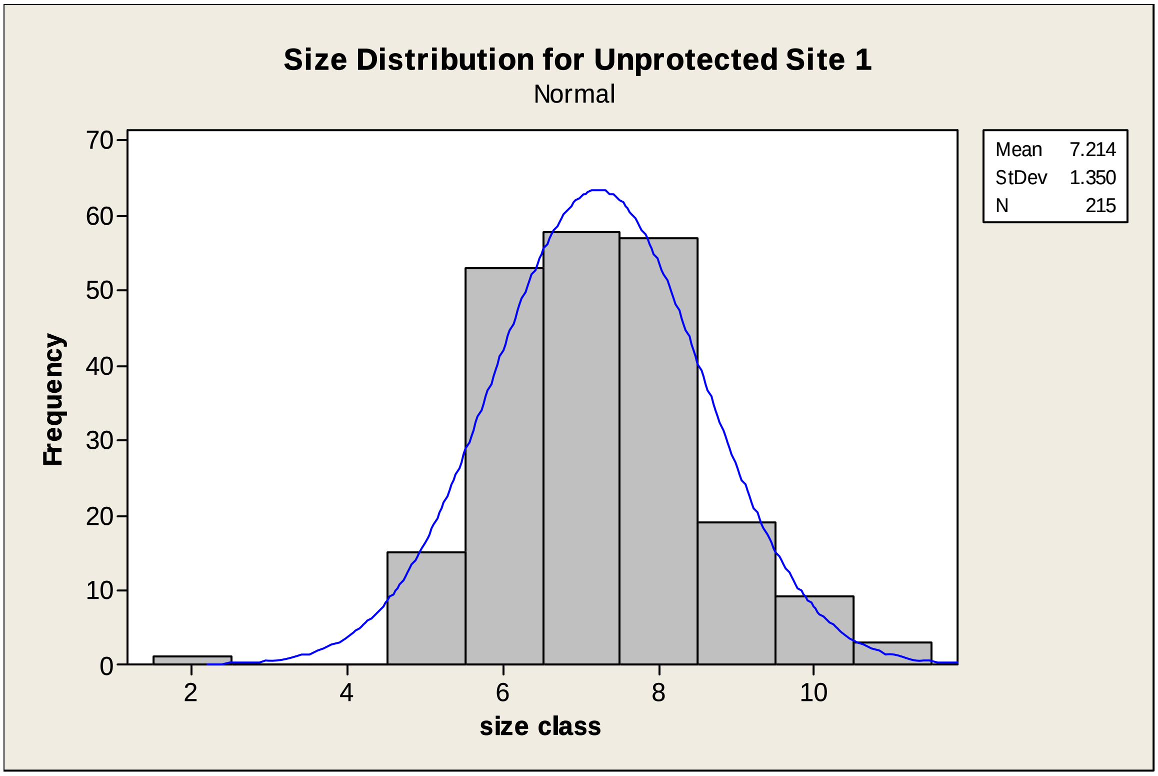
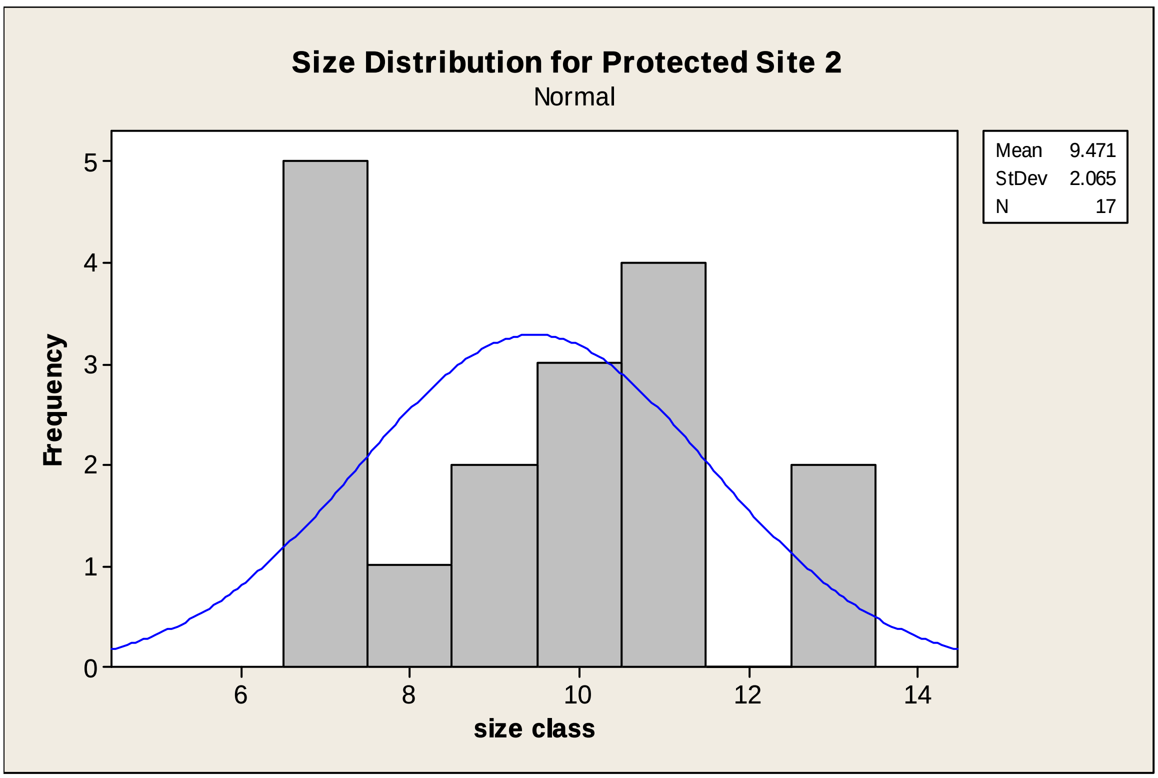
Appendix I:

Figures 6-9: Histograms Showing Frequency of Size Classes at Each Site





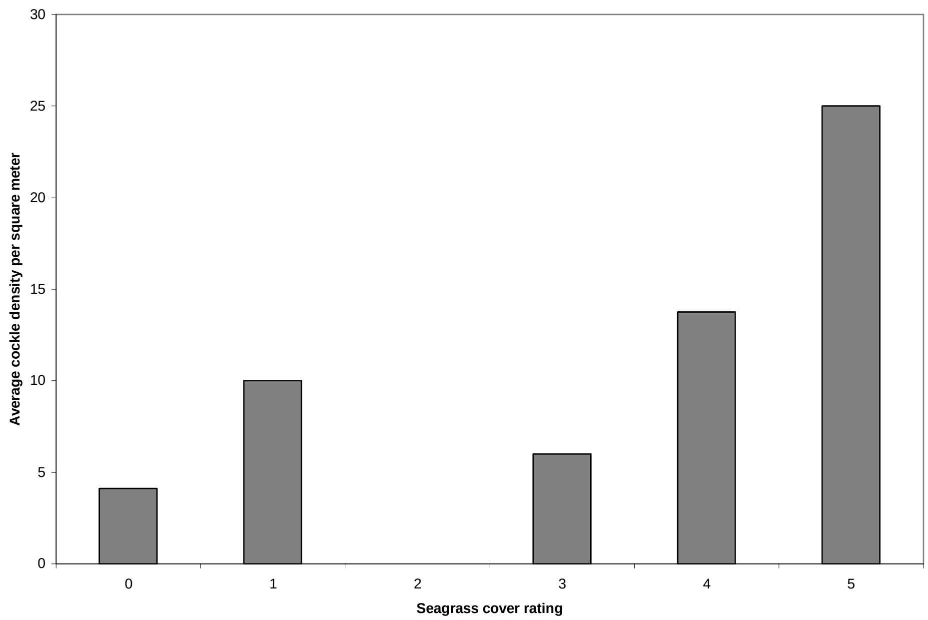

Size Distribution for Unprotected Site 1
Normal
Frequency
70
60
50
40
30
20
10
0
2
4
6
8
10
size class
Mean 7.214
StDev 1.350
N 215


Size Distribution for Protected Site 2
Normal
Frequency
5
4
3
2
1
0
6
8
10
12
14
size class
Mean 9.471
StDev 2.065
N 17

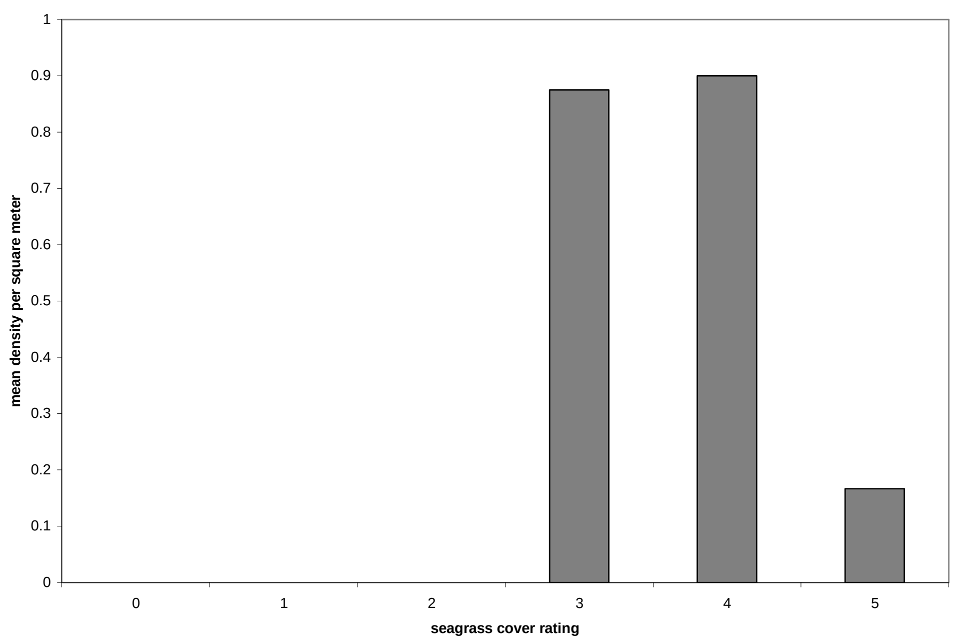
Appendix II:

Figures 10-13: Mean cockle density versus seagrass cover at each site

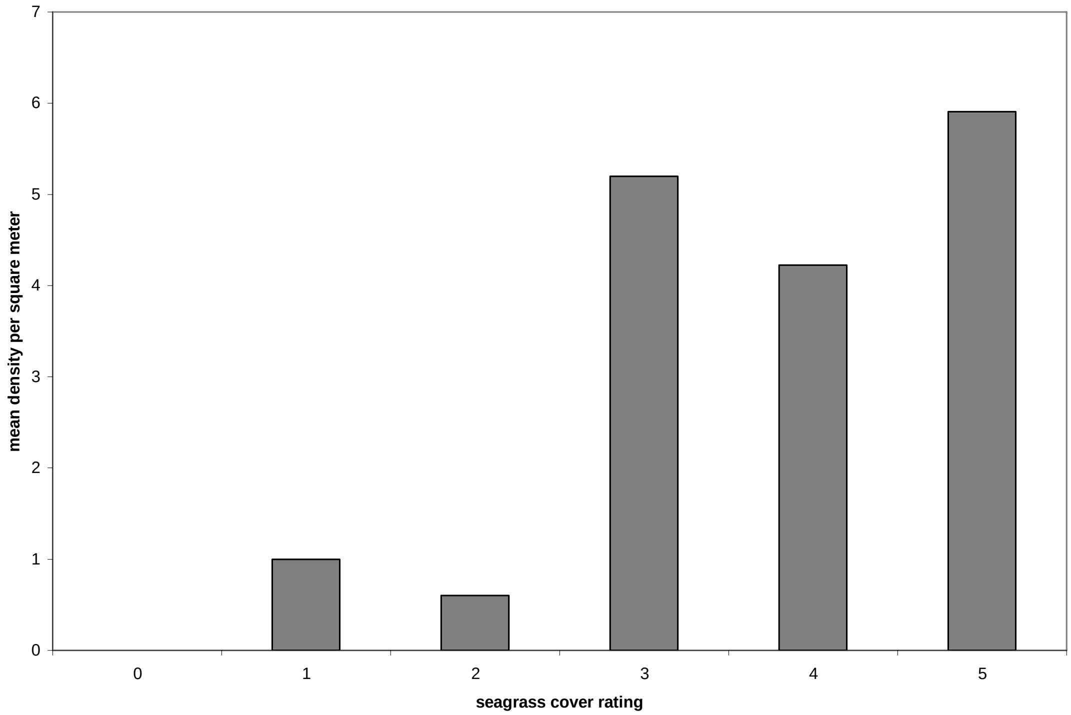
Protected Site 1



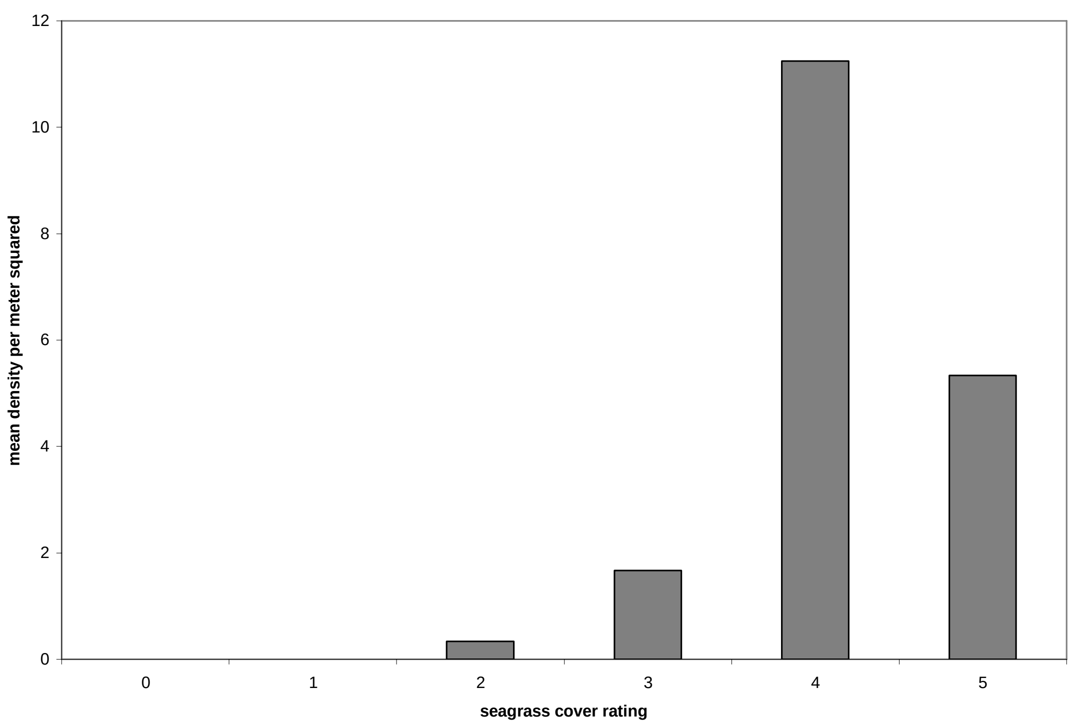
Protected Site 2



Unprotected Site 1



Unprotected Site 2



Appendix III:

Tables of p-values for two sample t-tests comparing mean size and density between sites

Table 4. P-values for two sample t-tests comparing mean density of *A. antiquata* between the four sites. A * indicates significance at a level of $P < 0.01$

	Protected Site 1	Protected Site 2	Unprotected Site 1
Protected Site 1	x		
Protected Site 2	0.000*	x	
Unprotected Site 1	0.005*	0.001*	x
Unprotected Site 2	0.009*	0.000*	0.634
Pooled Unprotected Sites	0.003*	0.000*	

Table 5. P-values for two sample t-tests comparing mean size class of *A. antiquata* between the four sites. A * indicates significance at a level of $P < 0.01$

	Proctected Site 1	Protected Site 2	Unprotected Site 1
Proctected Site 1	x		
Protected Site 2	0.008*	x	
Unprotected Site 1	0.000*	0.000*	x
Unprotected Site 2	0.000*	0.000*	0.174
Pooled Unprotected Sites	0.000*	0.000*	

Appendix IV

Total cockle abundance sorted by size class for each site.

Table 6: Protected Site 1

Size class	Abundance
1	0
2	1
3	0
4	0
5	15
6	53
7	58
8	57
9	19
10	9
11	3
12	0
13	0
Total:	215

Table 7: Protected Site 2

Size class	Abundance
1	0
2	0
3	0
4	0
5	0
6	0
7	5
8	1
9	2
10	3
11	4
12	0
13	2
Total:	17

Table 8: Unprotected Site 2

Size class	Abundance
1	0
2	1
3	0
4	0
5	15
6	53
7	58
8	57
9	19
10	9
11	3
12	0
13	0
Total:	215

Table 9: Unprotected Site 2

Size class	Abundance
1	0
2	0
3	2
4	1
5	8
6	52
7	74
8	26
9	20
10	4
11	2
12	0
13	0
Total:	189

Appendix V

Total associated species for each site. (P designates presence at an unmeasured abundance)

Table 10: Protected Site 1 Associated Species

	Transect 1	Transect 2	Transect 3	Transect 4	Total
Mollusca: Bivalvia					
G. pectinatum	33	9	32	55	129
T.pectiniforme	11	8	9	10	38
G. quecketti	0	3	2	17	22
Circe sp.	0	4	6	4	14
A. rubicundum	0	1	3	4	8
C. scripta	1	1	4	2	8
C. Tigerina	1	3	1	1	6
C. brassica	1	0	0	2	3
Veneridae sp B	0	0	1	2	3
B. gubernaculum	0	0	1	1	2
L. castrensis	0	0	0	2	2
P. tiara	0	0	2	0	2
Veneridae sp C	0	0	1	1	2
A. edentula	0	0	0	1	1
C. papyracea	0	1	0	0	1
L. lima	1	0	0	0	1
M. lilacea	0	0	0	1	1
M. ovalina	0	0	0	1	1
Pitar sp.	1	0	0	0	1
T. virgata	0	0	0	1	1
Veneridae sp A	1	0	0	0	1
M. phillipinarum	P	P	P	P	P
P. muricata	0	P	P	P	P
P. radiata	P	P	P	P	P
Mollusca: Gastropoda					
N. coronatus	1	2	5	1	9
B. ampulla	0	0	0	2	2
V. vulpecula	1	0	1	0	2
F. subintermedia	0	0	1	0	1
Nerita sp	0	0	1	0	1
S. decorus decorus	1	0	0	0	1

Total:	263

Table 11: Protected Site 2 Associated Species

	Transect 15	Transect 16	Transect 17	Transect 18	Transect 19	Total
Mollusca: Bivalvia						
G. pectinatum	7	10	30	41	27	115
T. pectiniforme	0	2	2	4	0	8
Pitar spp.	0	0	0	1	1	2
A. edentula	0	1	0	0	0	1
A. rubicundum	0	0	1	0	0	1
C. tigerina	0	0	0	1	0	1
P. hebraea	0	0	0	1	0	1
M. phillipinarum	0	0	0	P	0	P
P. muricata	0	P	0	P	0	P
Mollusca: Gastropoda						
N. coronatus	2	0	15	0	1	18
B. ampulla	0	0	0	1	2	3
C. bifasciatus	1	0	0	0	0	1
T. maculata	0	0	0	1	0	1
Terebridae spp.	0	0	1	0	0	1
V. furbinellus	0	0	0	1	0	1
Arthropoda: Crustacea						
Paguroida spp.	2	0	2	0	0	4
					Total	158

Table 12: Unprotected Site 1 Associated Species

	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Total
Mollusca: Bivalvia						
Arca sp.	4	7	P	P	42	53
T. pectiniforme	11	7	P	P	6	24
C. Brassica	11	1	0	0	0	12
G. pectinatum	1	5	P	P	5	11
G. quecketti	4	1	P	0	0	5
A. rubicundum	0	0	0	P	2	2
P. hebraea	0	2	P	P	0	2
Veneridae sp B	0	0	0	0	2	2
C. hiraseana	1	0	0	0	0	1
C. scripta	0	0	P	0	1	1
L. castrensis	0	1	0	0	0	1
L. lima	0	0	0	0	1	1
T. literatus	0	0	P	0	1	1
C. punctata	0	0	P	P	0	P
G. diverticatum	0	0	0	P	0	P
M. phillipinarum	P	P	P	P	P	P
P. muricata	P	P	P	P	P	P
P. radiata	P	P	P	P	P	P
Mollusca: Gastropoda						
S. decorus decorus	1	3	0	0	0	4
C. isabella	0	0	0	0	1	1
C. ramosus	0	1	0	0	0	1
Conus sp.	0	0	0	0	1	1
H. harpa	0	1	0	0	0	1
Nerita sp.	0	0	0	0	1	1
O. tabularis	0	0	0	0	1	1
P. trapezium	1	0	P	0	0	1
T. arcolata	0	0	0	0	1	1
Terebra sp.	0	0	0	0	1	1
Unidentified snail	0	1	0	0	0	1
S. gibberulus	0	0	P	0	0	P
Unidentified snail B	0	0	0	P	0	P
Unidentified snail C	0	0	0	P	0	P
V. vulpecula	0	0	P	0	0	P
Arthropoda: Crustacea						

Paguroida spp.	3	1	P	0	1	5
Echinodermata: Echinoidia						
B. luzonicus	0	0	P	0	0	P
					Total	135

Table 13: Unprotected Site 2 Associated Species

	Transect 10	Transect 11	Transect 12	Transect 13	Transect 14	Total
Mollusca: Bivalvia						
Arca sp.	5	1	9	8	2	25
T. pectiniforme	4	1	1	1	0	7
C. brassica	0	1	1	3	1	6
B. gubernaculum	0	0	1	2	0	3
G. pectinatum	1	0	0	0	2	3
L. lima	0	0	0	0	3	3
G. quecketti	1	0	0	0	1	2
Pitar sp.	1	1	0	0	0	2
A. rubicundum	0	1	0	0	0	1
P. tiara	0	1	0	0	0	1
M. phillipinarum	P	P	P	P	P	P
P. muricata	P	P	P	0	P	P
P. radiata	P	P	P	P	P	P
Mollusca: Gastropoda						
S. gibberulus	1	0	0	3	1	5
N. arachnoidea	1	0	1	0	0	2
N. gualtariana	0	0	0	1	1	2
O. tabularis	2	0	0	0	0	2
C. bifasciatus	1	0	0	0	0	1
C. geographus	0	0	0	1	0	1
C. marmoreus	0	0	1	0	0	1
Cephalaspidea sp	0	0	0	1	0	1
L. auricula	0	0	0	0	1	1
P. trapezium	1	0	0	0	0	1
R. asper	0	0	0	0	1	1
S. decorus decorus	0	0	0	0	1	1
S. gemmata	0	0	0	0	1	1
Strombidae spp	0	1	0	0	0	1
T. areolata	0	0	0	0	1	1
T. maculata	0	0	0	0	1	1
V. tubifarum	1	0	0	0	0	1
V. vulpecula	1	0	0	0	0	1
Arthropoda: Crustacea						
Paguroida spp.	0	0	4	1	0	5
Echinodermata: Holothuroidea						

H. conusalba	1	0	0	0	0	1
Echinodermata: Echinoidea						
E. mathaei	0	0	0	7	4	11
Cypeasteridae sp.	0	0	0	1	0	1
E. auritus	0	0	0	0	1	1
Echinodermata: Ophiuroidea						
Ophiurida sp.	0	0	0	0	P	P
					Total:	97

Appendix VI

Approximate locations of transects in relation to seagrass beds.

Figure 14: Northern Sites:

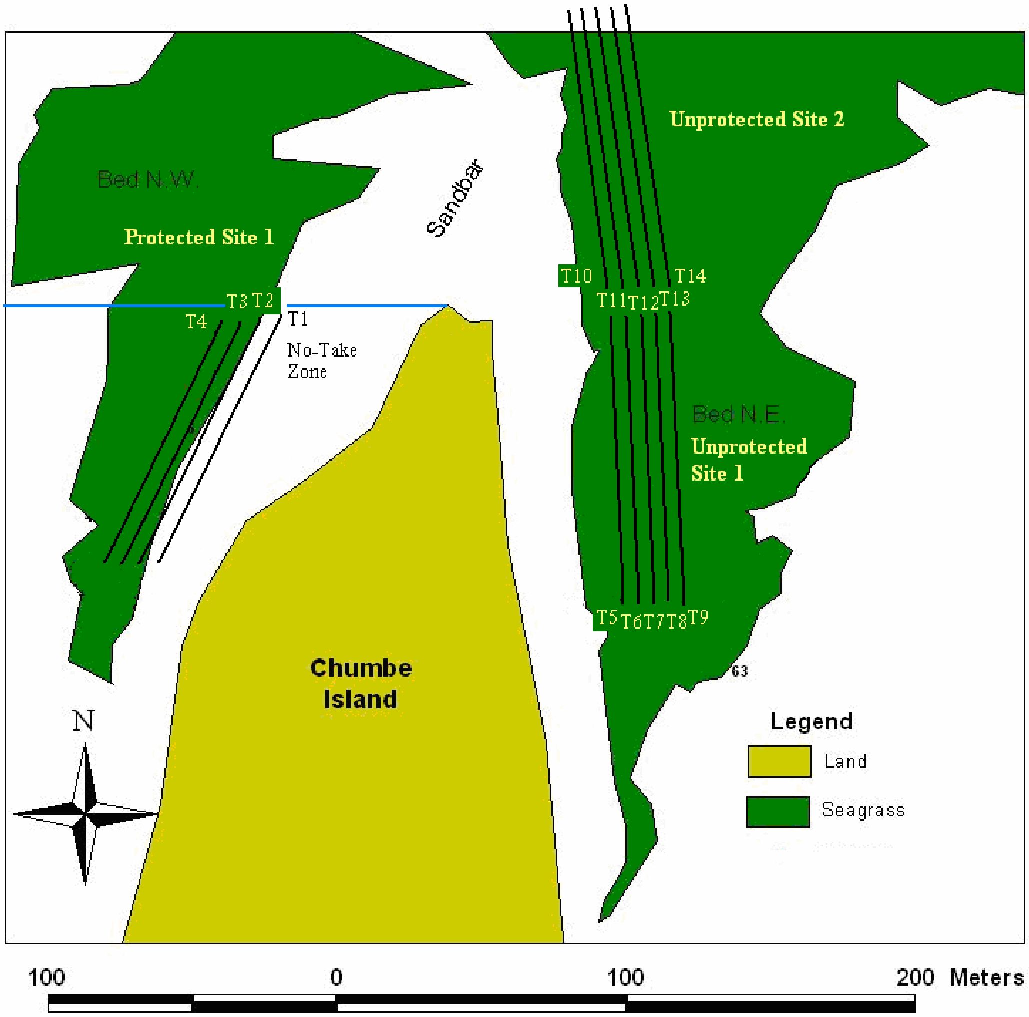
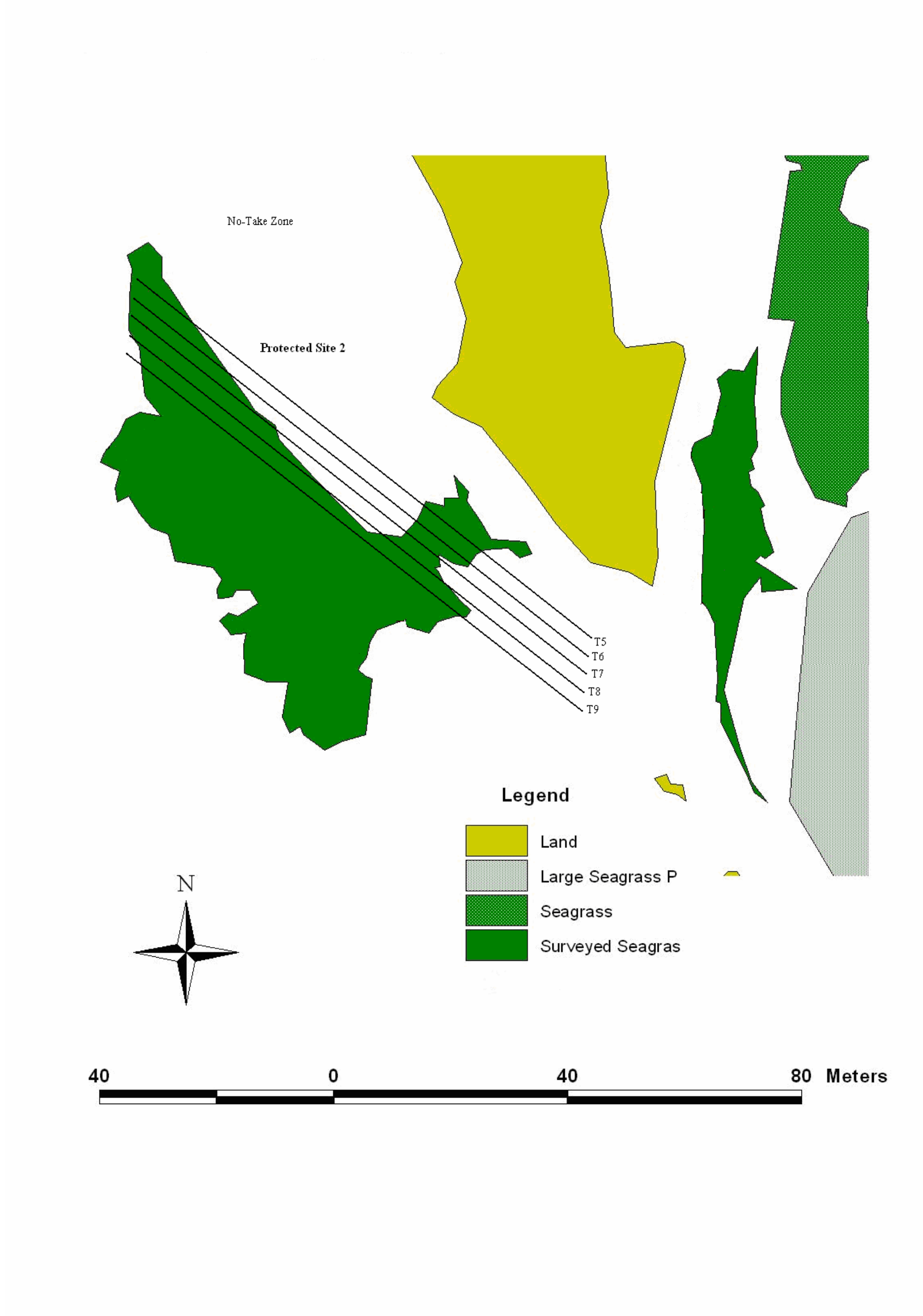


Figure 15: Protected Site 2:



Maps of seagrass from: Hayford, J and M Perlman. 2006. "Chumbe Seagrass Distribution and Composition. SIT, Zanzibar, Coastal Ecology, unpub.

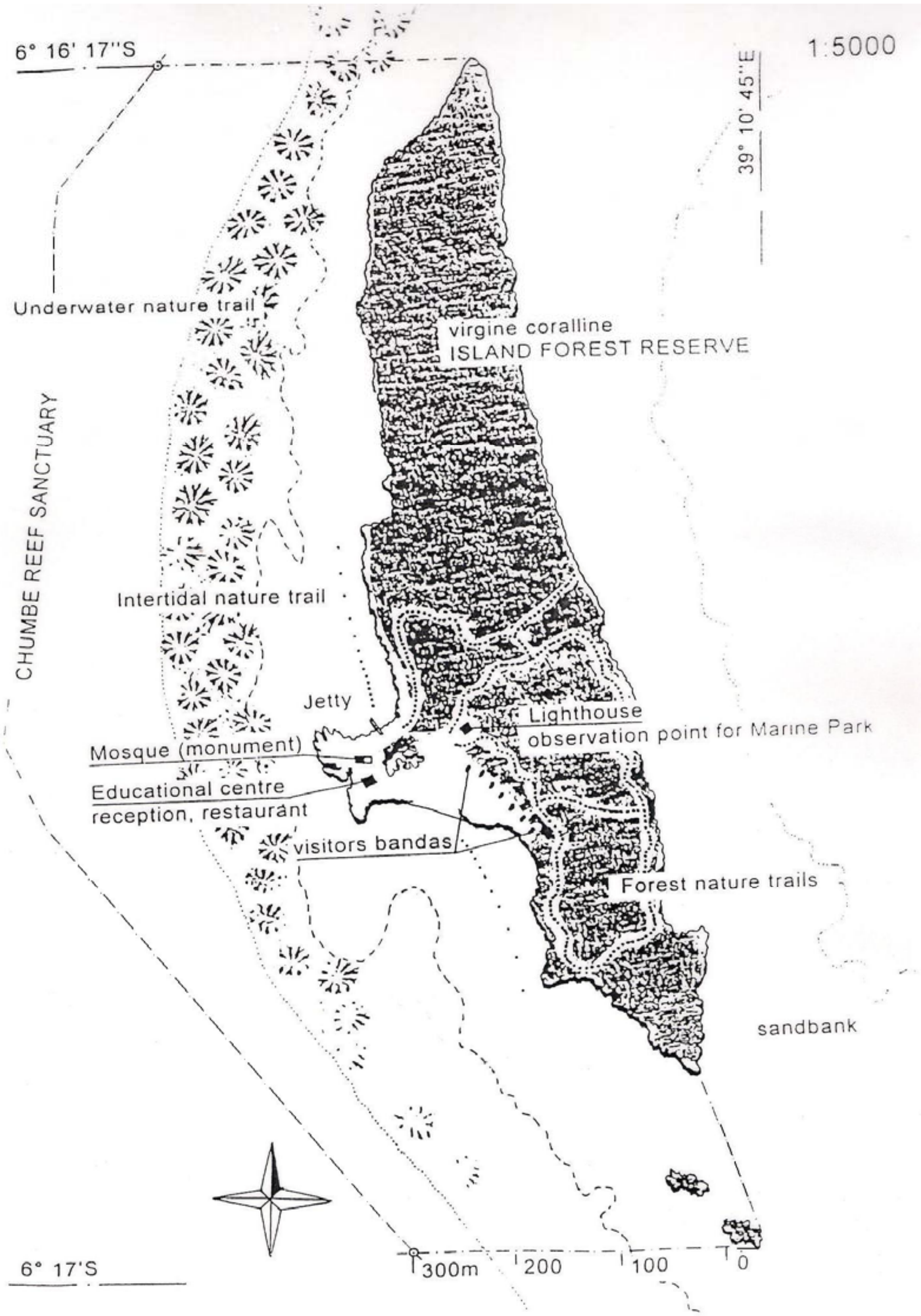
Appendix VIII

Table 14: GPS Coordinates of Transects

Transect	North End	South End
	S06 16.456	S06 16.406
3	E39 10.567	E39 10.586
	S06 16.404	S06 16.457
2	E39 10.586	E39 10.5707
	S06 16.917	
8	E39 10.670	
	S06 16.416	S06 16.471
7	E39 10.670	E39 10.666
	S06 16.419	
5	E39 10.668	
	S06 16'26.7	S06 16'25.4
11	E39 10'39.1	E39 10'40.4
	S06 16'20.9	S06 16'23.3
12	E39 10'38.9	E39 10'40.6
	S06 16'55.0	
12	E39 10'35.1	
		S06 16'57.4
19		E39 10'37.4
	S06 16'20.8	S06 16.240
10	E39 10'38.4	E39 10.400
	S06 16'20.7	S06 16.236
13	E39 10'38.9	E39 10.406
	S06 16'20.6	S06 16'23.3
14	E39 10'39.9	E39 10'40.9

Appendix IX

Map of Chumbe Island Coral Park



Appendix X

Map of Chumbe in Relation to Zanzibar

Source: www.imagineafrica.co.uk/Zanzibar/Zanzibar_Map. Accessed May 13, 2007.