Spring 2010

# Paradise Lost? Impact of Tourism and Public Use on the Mnemba House Reef

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# PARADISE LOST?

*Impact of Tourism and Public Use on the Mnemba House Reef*

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***Abstract:*** With the increasing popularity and promotion of marine park tourism, coral reef ecosystems may be subject to stresses beyond their sustainable thresholds. Mnemba Island's house reef was surveyed to assess impacts of public use and efficacy of current protection measures. The study was conducted with objectives of characterizing physical damage and providing a holistic overview of reef conditions. To obtain relative impact profiles in the area, line transects were carried out in two different zones - one more frequented by private island guests and one more frequented by boat tour operators. Benthic coral cover and damage, biological indicators (fish populations and sea urchin abundance), and proximal human activity were documented over a two-week period. While instances of tissue damage were comparable at both sites, it was found that the boat-side had a significant amount of unhealthier, bleached, and dead coral as well as rubble and algal growth. More anchor breakage and sediment damage were also observed on the boat-side. All these factors indicate that overall health on the boat-side is compromised, and suggests that coral in that section are more vulnerable and less resilient as a result of higher human activity. The findings demonstrate negative impacts of human activity on coral status, and demand immediate further action in protecting the reef as a whole. Recommendations were made for future monitoring and management in an effort to balance human usage without causing permanent environmental degradation.

***Introduction:***

In Zanzibar, tourism comprises a major sector of the nation's economy. Marine tourism in particular is currently being developed as a viable means of economic diversification, accentuating foreign exchange reserve and stimulating the local economy (Zanzibar Tourism Profile, 1.10). The quality of the marine environment and maintenance of coral community structure is therefore critical to the tourism industry. When a reef's level of use exceeds its carrying capacity or ability to cope with sustainable change, tourism may destroy the very natural resources on which it depends.

| | |
|---|---|
| Snorkeling and diving | physical damage (breakage, lesions), stir up sediment, disturb marine life |
| Boat traffic | physical damage from anchoring, boat groundings, pollution from fuel, disturb marine life |
| Fishing | physical damage from anchoring and poling, contribute to over-exploitation of reef fish stocks |
| Tourist development resort development, construction, and operation* (*not addressed in study) | potential indirect damage through increased sedimentation, nutrient enrichment, boat traffic, runoff and waste disposal |

*Table 1: Negative impacts of tourism that cause major stresses to coral reefs*

Coral reefs are "oases" of diversity and biomass in the oceanic desert, providing the foundations of marine ecosystems and food webs (Done, Ch.15). Modern reef habitats are dominated by reef-building hard coral colonies of Order Scleratinia, Phylum Cnidaria (Choat & Bellwood 1991), characterized by the topographical framework of calcium skeletons. Coral are colonial organisms that have endosymbiotic zooxanthellae, photosynthetic single celled dinoflagellate algae which exist within cells of animal calcifiers (Done Ch.15). Subsequently, coral have high sunlight requirements and primarily occur in nutrient-poor water less than 30m in depth (Richmond 1997). Like most ecosystems, reef environments are subject to natural variation, and can be depleted or destroyed by natural or anthropogenic forces. Therefore it is important to discriminate between environmental disturbance versus symptoms driven or amplified by human activity, a factor this study investigates.

Types of environmental and anthropogenic damage include:

| | |
|---|---|
| Breakage | • Physical broken coral (i.e.. anchor damage, poling damage) |
| Bleaching | • Tissue present but with reduced or absent pigmentation (due to expulsion of zooxanthellae from cells)<br>• Can affect discrete patches or whole colony<br>• Associated with environmental stress: thermal, light, salinity |
| Sediment damage | • Sediment accumulates on live coral, leaves dead, fouled skeleton underneath<br>• Diffuse amorphous area of tissue loss<br>• Water is typically highly turbid and sediment visible on benthic surfaces |
| Tissue loss | • Large areas of peripheral loss of coral tissue, possibly as a result of coalescing lesions |
| Lesions | • Circular to diffusely shaped areas of tissue loss<br>• Focal or multifocal<br>• Could be result of physical abrasion or disease |
| Predation*<br>*(* omitted in study to focus on human impacts)* | • Characterized by removal of tissue and underlying skeleton<br>• Distinctive, regular scars: can be scrapes or gouges or radiating bands depending on fish and invertebrate species<br>• Presence of corallivores in surrounding area |
| Discoloration | • Pigmentation response: multifocal or diffuse areas of pink, purple or blue brightly colored tissue discoloration.<br>• Tissue on corallite walls may appear swollen or thickened, may form lines, bumps, spots, patches, or irregular shapes<br>• Considered an **inflammation response** of the coral host to a variety of stressors (i.e.. competition, boring fauna, algal abrasion), **recovery response** not progressive tissue loss<br>• Indication of compromised coral health<br>• Common on porites (bright pink or purple pigmentation) |
| Algal overgrowth | • Colonization and overgrowth of living coral tissue by algae<br>• Abrasion may cause a pigmentation response though not always present |

*Table 2: Negative impacts of tourist activity (adapted from Beedeb and Raymundo)*

Mnemba Island is an exclusive “primitive luxury” ecotourism site that limits the flow of tourists per year (Mnemba Island website). Only 20 guests are allowed on the island at one time (Mnemba Island website). It is privately leased and includes a 200m

No-Take Area around the entirety of the island; no fishing or mooring is allowed (Tyler 2005). As of November 2002, Mnemba and its surrounding reefs were also gazetted as a Marine Conservation Area (MIMCA). MIMCA is a partnership between &Beyond, the Zanzibar government, and local communities to protect the reefs and marine life. Daily levies from generated revenue are channeled to community funds, with aims to improve prosperity and living conditions of local Kijini and Matemwe communities (Mnemba Island website). Its current status prohibits destructive fishing on all of the Mnemba atoll. Patrolling of the waters surrounding the island began in June 2003, but primarily to collect funds from tourists rather than to enforce its No-Take status (Tyler 2005). According to hotel staff and dive companies, guests are also verbally briefed on reef etiquette (Kamiya pers comm, One Ocean interview).

Overfishing decreases coral reef fish populations and causes degradation of reef habitat, but also triggers ecological phase shifts by removing key functional groups (Tyler 2005). The fishing methods observed around Mnemba are mainly non-industrial, utilizing artisanal methods and employing traditional gear of nets and hand line, as well as spearguns.

In theory, there should only be minimal snorkeling damage from Mnemba guests and visitors by boat. However, through interviews and personal observation, it is evident that despite its protected status, these rules are not necessarily adhered to and are haphazardly enforced in practice. Boats were observed mooring very close if not directly on the reef; clumsy swimming and both purposeful and accidental contact with coral was common among snorkelers. Fishing was also observed mainly on the boat side but also near the guest-side at high tide. Breakage was observed from fishermen poling, therefore effects of fishing were also included in this study. Given this, what are the effects of human activity on the house reef as quantified in terms of coral composition, damage and presence of biological indicators? Are current management measures effective in preventing reef degradation and sustaining a stable community structure? It was hypothesized that coral on the boat-side would be less fit, and exhibit more instances of anthropogenic damage due to higher tourist density, boat traffic, and public use.

The first part of this paper covers the objectives and rationale for study, and discusses the conceptual framework on which assessment is based. The context and background of the site is then outlined, followed by methodology and experimental design. The final sections present and discuss key findings, concluding with discussion of practical implications of the current situation and makes further recommendations for future management.

A study of Mnemba's house reef is necessary to determine whether current protection is adequate and effective, and is also important to further identify key research priorities. Application of these research findings to management objectives will provide a quantitative and predictive understanding of how to best preserve ecosystem function. This will provide a baseline to evaluate the compatibility of marine protection and tourism in multiple-use areas, and help determine further management measures specific to Mnemba.

***Study Site***

Mnemba Island is located 4.5km off the northeastern coast of Unguja Island in the West Indian Ocean (S 05° 49.218'E 039° 22.959'), and has an approximate area of 1km2 and a circumference of 1.5km (Mnemba Island website). With warm water temperatures of 27˚C and high visibility conditions of 20-60 meters, the island is well known for its diving and snorkeling, also boasting approximately 4 times the range of fish species than the Caribbean (Mnemba Island website).

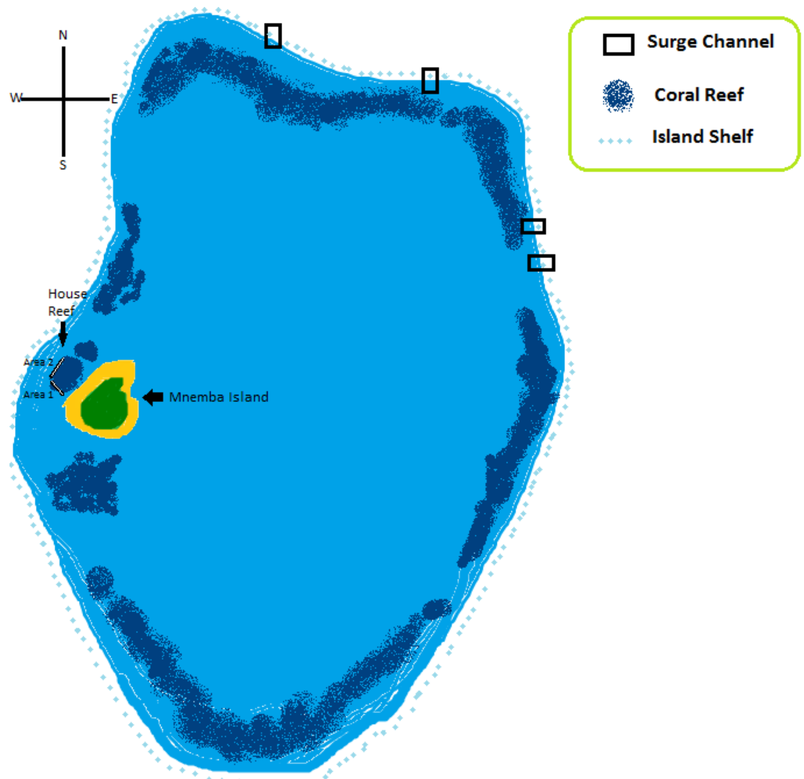


*Figure 1: Mnemba Island, house reef and surrounding waters*

Mnemba Island's house reef is an offshore patch reef, a comparatively small reef outcrop isolated within a lagoon/embayment. The house reef circumscribes rock islands and sandbanks, with highest coral density around its perimeter. For purposes of this study, the house reef was divided into two zones based on varying levels/types of human activity along the reef edge. The "Guest-side" is closer to shore with a beach entry access point, while boat visitors moor by the seaward "Boat-side". While snorkeler movement is obviously unrestricted and overlaps the two zones, there tends to be a greater number of visitors on the boat–side while the guest-side is mainly just frequented by Mnemba guests

(Kamiya, Lang, Procopakis pers. comm). Mnemba's relative exclusivity and protected status present an important case study to elicit broad information and initial understanding of human impact and effectiveness of management in this area. The different usage areas of Mnemba also provide a good opportunity for baseline comparison: does one zone show more damage than the other and is this a result of increased human activity? As both sides are frequented by guests but in varying capacity, the relatively more pristine guest-side is not a strict control but still provides a general indication of the effects of boat use and higher tourist density.

*Fig 2: Study area of Mnemba's House Reef with Guest-side and Boat-side zones*

This study was carried out over a period from April 2nd to April 20th. Zanzibar's seasons vary with the southeast *(kusi)* monsoon characterized by lower air temperatures and stronger winds from April to September, and the northeast monsoon *(kaskazi)* from November to March (Jiddawi & Ohman 2002). There are also short rains *(vuli)* in November and Dec and long rains *(masika)* from March to June (Ngoile 1990).

Surrounding waters have a permanent northbound current, known as East African Current, which can reach 4.5 knots during the southeast monsoon. Nearshore currents are mainly generated by the tidal cycle (Ngoile 1990).

## *Methods*

### *Procedure*

Field studies were conducted as a rapid descriptive assessment of the Mnemba house reef. A preliminary general survey was conducted by snorkeling around the reef, with aims to assess areas of use/damage and to determine what relevant parameters should be included in the investigation. The house reef area was then divided into two zones as outlined in the *Study Site* section above. Over a two-week period, twenty 25m x 4m belt transects were carried out in a random-stratified sampling scheme, with ten in each zone. Because samples were not intended as permanent monitoring sites, GPS coordinates were not necessary for replication of exact transect locations. Transects were laid out in a flat plane across the substrate, without measuring rugosity or coral topography. A margin of at least 1m was allowed as a buffer between each transect, ensuring no overlap and reducing redundancy in data. Visual assessments of coral cover, damage, fish populations and sea urchin abundance were carried out by snorkeling the length of the transects.

<u>Coral Survey</u>: Percent coral cover was estimated for the entirety of each transect, the four categories being live coral, dead coral, rubble, and macroalgae.

| | | |
|---|---|---|
| **Hard coral** | Phylum *Cnidaria*, Class *Anthozoa*, Subclass *Hexcorallia*, Order *Scleratinia*<br><br>Rigid calcareous skeleton, variety of structures and colors<br><br>Live: tissue present<br>Dead: tissue decayed/gone, algal growth | Dominant part of healthy reef habitat, provides bulk of reef structure; shelter for reef fish, food for corallivores<br><br>Common species recorded: *Acropora* spp (branching, tabular), *Porites, Pavona* |
| **Rubble** | Fragments of dead coral<br>Local / nonlocal / anthropogenic | Indication of reef degradation, human disturbance |
| **Fleshy macroalgae** | Red, green, brown algae<br>Macroscopic seaweeds, non-vascular plants | Compete with coral for light and space, indicator of pollution and overfishing<br><br>Common species observed: *Sargassum* spp. *Ulva* spp |

*Table 3: Coral cover variables identified along transect (adapted from Tyler 2005)*

In addition to coral cover, colony counts of coral damage and health by species were also taken along each transect. Identifying type and scope of damage in context of its zone helps in diagnosing responsible factors. Major coral species were documented and divided into four distinct groups consisting of *Acropora* (branching and tabular), *Porites*, and *Pavona*, although specific species were not examined in data analysis. Damage was noted for each coral colony located along the transect: bleaching, lesions, discoloration, tissue loss / sediment damage, and filamentous algal overgrowth. A count of apparent healthy colonies was also taken to provide a proportionate indication of relative health.

Fish Survey: For each transect, an underwater visual census (UVC) of fish density (total individuals and two size categories), richness (number of different species), and indicator species (number of individuals: parrotfish, butterflyfish, triggerfish) were also taken via snorkeling. Fish counts were conducted at least five minutes after each transect was laid out in order for normal activity to resume, minimizing observer interference. In accordance with previous studies, fish length was estimated from the tip of snout to the posterior tip of the caudal fin (Bellwood & Alcala 1988). Fish over 15cm in length from were considered “large” to represent fishable biomass, as the majority of fish in the artisanal fishery are between 10 and 30cm (Richmond 1997). For each zone, six transects were done in the morning (before 12pm) and four were done in the afternoon (after 12pm), minimizing skewing as a result of time of day. Limitations include: As fish are surveyed via snorkeling, inconspicuous species in terms of visibility and behavior are likely to be underestimated and underrepresented in total counts. Fish counts may also subject to differences in fish behavior based on presence of the observer… it was observed that some fish species approached snorkelers as a result of past feeding by boat-tour operators (Muhando pers comm., Bottazzi pers comm., pers. obs).

Urchins: A count of individual urchins was taken along each transect as an indication of grazing and fishing pressures on urchin predators (ie. triggerfish).

*Experimental design*

The assessment protocol of reef status involved characterizing of coral cover as a baseline, then documenting instances of direct damage against this context. Environmental parameters that are associated with ecosystem health, such as species abundance, richness, and presence of biological indicators, further provide indications of human impact. The integrated investigation of these parameters allow for comparison and correlation in diagnosing responsible factors. Due to time constraints on the study period, this study only provides a rapid assessment and could not monitor temporal fluctuations.

In terms of designing a sampling scheme, random sampling was unsuitable due to the need to sample similar benthic habitat as a comparison of two subset areas (guest activity and boat-related activity). The relatively small area of the house reef meant that nearly all areas of appropriate reef habitat could be sampled. Therefore, a stratified random sampling design was used, in which the reef habitat was divided into sections and samples taken randomly within each section. Studies have shown that stratified random sampling is superior to random designs in that it ensures samples are not clustered by chance and are more representative of the site (Waite 2000).

Underwater visual census (UVC) is the accepted non-destructive method of estimating fish density (Tyler 2005). Snorkeling was a viable means of conducting UVC's in Mnemba because depths were relatively shallow and visibility was clear. Transects were chosen as a method of evaluation, as they allow for rapid assessment of coral community structure, condition, and prevalence of damage from a whole colony perspective (Raymundo 2008). It is also the most feasible method of conducting snorkel surveys of fish; other methods like the point-count method, while more precise, require the observer to be stationary and submerged for long periods of time (Tyler 2005).

A determination of coral cover was necessary in evaluating overall reef health and assessing fish density and coral health trends (Bell 1984). Protected areas were shown to have more hard coral, calcareous and coralline algae, greater substrate diversity and topographic complexity than unprotected reefs with greater algal turf and sponge cover. (McClanahan 1990). Damage and other stressors to reefs increase the proportion of rubble and fleshy macroalgae relative to hard coral; percentage cover of live hard coral is therefore a good indicator of stresses on the state of the reef (Wilkinson 2004b). Although all sites were selected to contain coral reef, there remains substantial variation in reef composition due to a mosaic of substrates (Table 3). To minimize habitat variability for comparison, a criterion of at least 20% hard coral was applied to sites in accordance with previous studies (Tyler 2005).

Presence of fleshy macroalgae also provides an indication of reef health. Corals compete poorly with fleshy algae for light and space (Adjeroud 1997, Tyler 2005). The common transition in reef habitat is from coral dominance to fleshy algae dominance, with overfishing of herbivores being the major cited reason (Bellwood et al. 2004). Fleshy frondose algae can also inhibit reef fish populations (McClanahan 2002).

The amount of live coral cover has been shown to significantly affect both species richness and density of individuals (Bell 1984), and plays an important role in structuring fish communities that are important to tourism. Indicator species of corallivorous fish (parrotfish, butterflyfish, triggerfish) provide an indirect indication of coral cover. Scaridae (parrotfish) are major agents of bioerosion on coral reefs (Streelman et al. 2002). Balistidae (triggerfish) are not commonly sold or eaten, but were included because they are depleted in fished areas (McClanahan 2000) and are predators of sea urchins, thereby fulfilling an important functional niche. In particular, orange-striped triggerfish and blackbar triggerfish (*Balistaphus undulates* and *rhicanthus aculeatus)* are dominant sea-urchin predators (McClanahan 2000).

A total count of fish was taken as a measure of density, defined as the number of individuals per unit area (abundance). Greater fish densities and species richness have been documented in marine reserves (McClanahan 1994, Cote et. al 2001), and fishing directly reduces the density, biomass, mean length and species richness (Tyler 2005). Differences in density may simply be due to natural distribution and general health, or may be an indication of removal by fishing. Therefore fish counts are a general indicator of effective protection and presence of fishing. Small and large fish sizes were also recorded, as fish length has been shown to be a better indicator of fishing pressure than density while also approximating fishable biomass (Bellwood and Alcala 1988). Fishing gears are often size selective, and increases in density of smaller size classes or species have also been found as a result of fishing (McClanahan et al. 1999, Chiappone et al. 2000, Graham et al. 2003, Dulvy et al 2004). In addition, species richness was also considered since diversity is important for an ecosystem's ability to buffer disturbance and maintain functions (Tyler 2005).

Urchins: East African sea urchins (*Echinometra matthai*) are also indicators of fishing pressure. Coral cover and topographic complexity are negatively correlated with sea urchin density (McClanahan 1990). Sea urchin populations were found to be 100 times denser, and predation rates on sea urchin were four times lower in unprotected reefs (McClanahan and Muthiga 1988, 1989). Removal of top invertebrate-eating carnivores appears to have cascading effects down ecosystem trophic levels. Also, reefs with high urchin populations are usually devoid of visible macroalgae (grazed before biomass accumulates to any appreciable degree), and coral framework appears to be undermined faster than it can be replaced by coral growth.

***Results***

Sites of clear anthropogenic damage observed from the general preliminary survey are summarized in the below (*Fig 3)*. This broad overview is then quantified by subsequent transect data comparisons between the two sites.


*Figure 3: Summary of major anthropogenic damage in guest-side and boat-side areas of study site (Mnemba house reef)*

***Coral Survey: Cover***

Because transects were laid in roughly consecutive progression from guest-side to boat-side, the general trend of coral cover composition along the reef edge is continuously represented by Fig 4 and 5. While live and dead coral cover show fluctuation, a clear increasing trend in higher percentage of rubble is present along reef fringe from transect G1 to the area from B3 to B8 (the approximate region where highest boat traffic was observed). Rubble cover percentages did not fall below 10% on the boat-side, while they did not exceed 10% on the guest-side. While high levels and fluctuation of macroalgal cover was found on the guest-side, it was consistently below 5% on the boat-side. Live coral comprised the majority of benthic cover, only exceeded by macroalgae in transect G4 (guest-side) and dead coral in transects B5 and B6 (boat-side).

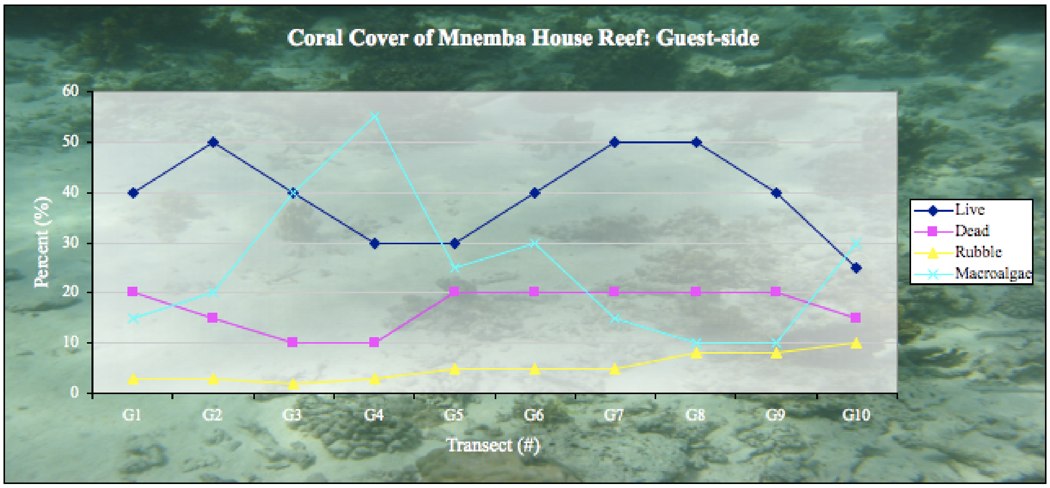


*Figure 4: Coral cover profile of Guest-side along 10 transects*

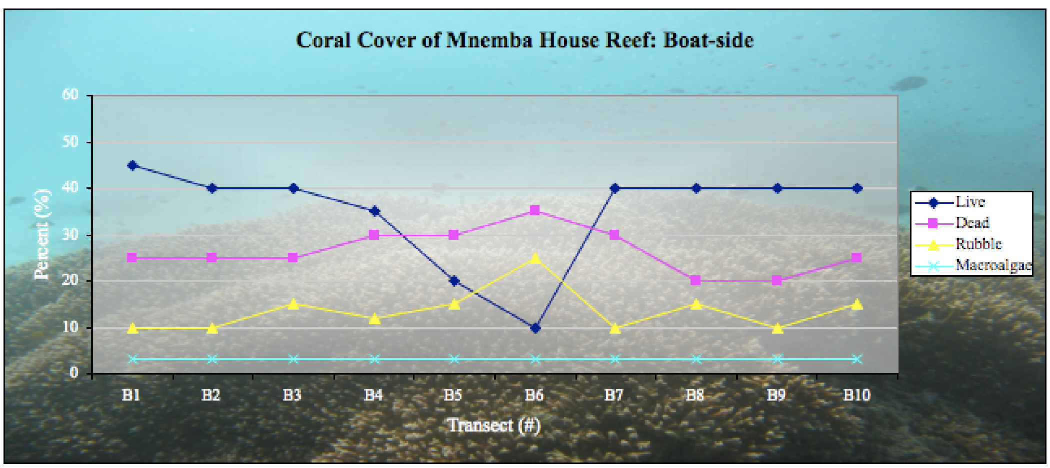


*Fig 5: Coral cover profile of Boat-side along 10 transects*

In comparing levels of benthic cover, higher average amounts of live and macroalgal cover were observed on the guest-side, although only macroalgal cover constituted a significant difference. The boat-side demonstrated higher average cover of dead and rubble cover, which was shown to be statistically significant (Table 4). No overlap in error bars indicates significant difference between the two sites.

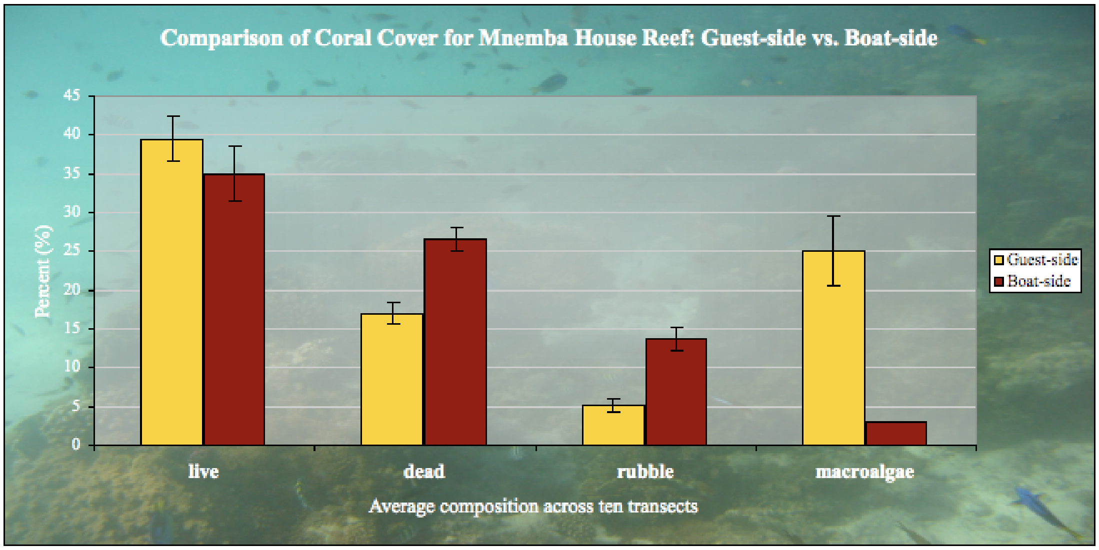


*Figure 6: Coral Cover Comparison*

**Calculated Standard Error for Coral Cover**

| SITE | **live** | **dead** | **rubble** | **macroalgae** |
|---|---|---|---|---|
| **Guest-side** | 2.833333333 | 1.333333333 | 0.840634681 | 4.533823503 |
| **Boat-side** | 3.496029494 | 1.5 | 1.4609738 | 0 |

*Table 4: Error bars shown in graph (Fig 6). Ten data points went into the calculated mean (n=10).*

| **COVER** | **P-Value** |
|---|---|
| **live** | 0.33 |
| **dead** | 0.0002 *** |
| **rubble** | 0.0001 *** |
| **macroalgae** | 0.0001*** |

*Table 5: Calculated using an unpaired T-test for 10 samples. Values <0.05 considered significant (***), although almost significant (**) and low values (*) may also indicate difference with increased samples*

### *Coral survey: Health*

A total of 395 coral colonies were observed over ten transects on the guest-side, and a total of 523 coral colonies were observed over ten transects in the boat-side. In terms of total colony censes, relative health was calculated as a percentage due to different baselines of comparison. The guest-side exhibited slightly higher percentages of healthy and total live coral (Table 6). While only the p-value of healthy coral constitutes a significant difference (Table 7), the p-value of live coral is also very low and almost falls within statistically significant boundaries. A higher percentage of dead coral was found on the boat-side, although the p-value also fell just outside the range of statistical significance. The boat-side also showed a higher percentage of breakage; the p-value was low but not significant.

**Comparison of Percentage Coral Status**

| SITE | healthy | unhealthy | total live | total dead | broken |
|---|---|---|---|---|---|
| **Guest-side** | 46% | 40% | 86% | 12% | 2% |
| **Boat-side** | 39% | 41% | 80% | 16% | 4% |

*Table 6: Calculated percentages from total census counts*

| health / status | P-Value |
|---|---|
| **healthy** | 0.046 *** |
| **unhealthy** | 0.42 |
| **live** | 0.056 ** |
| **dead** | 0.063 ** |
| **broken** | 0.24 * |

*Table 7: Calculated using an unpaired T-test for 10 samples. Values <0.05 considered significant (***), although almost significant (**) and low values (*) may also indicate difference with increased samples*

### *Coral survey: Damage*

Total types and frequencies of damage observed in each section are summarized below.

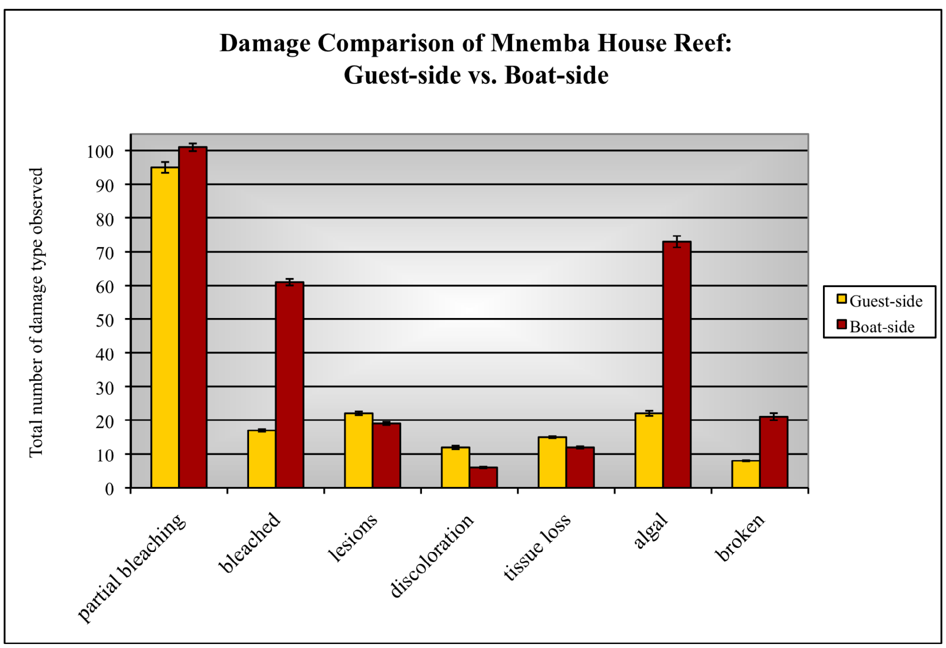


*Fig 7: Error bars calculated from values shown in Table X*

**Calculated Standard Error for Coral Damage**

| SITE | partial bleaching | bleached | lesions | discoloration | tissue loss | algal growth | broken |
|---|---|---|---|---|---|---|---|
| Guest-side | 1.550 | 0.396 | 0.512 | 0.467 | 0.269 | 0.727 | 0.2 |
| Boat-side | 1.169 | 0.936 | 0.407 | 0.221 | 0.291 | 1.640 | 1.048 |

*Table 8: Error bars shown in graph (Fig X). 10 data points went into the calculated mean (n=10).*

| damage | P-Value |
|---|---|
| **partial bleaching** | 0.76 |
| **bleached** | 0.0004*** |
| **lesions** | 0.65 |
| **discoloration** | 0.26* |
| **tissue loss** | 0.46 |
| **algal** | 0.011*** |
| **broken** | 0.24* |

*Table 9: Calculated using an unpaired T-test for 10 samples per site. Values <0.05 considered significant (***), although almost significant (**) and low values (*) may also indicate difference with more samples*

Completely bleached colonies appeared mostly in the boat-zone whereas partial bleaching coral was more common in the guest-side. Although instances of lesions and tissue loss were comparable, tissue loss on the boat-side was identified as a clear result of sediment damage. Discoloration was found primarily on the guest-side, while physical breakage was more common on the boat-side. Of the damage types, data for bleached and algal coral colonies were found to be significant, while discoloration and broken counts also had low p-values (almost significant). To provide a common baseline of comparison, the following figures further show these counts as a percentage of live coral.

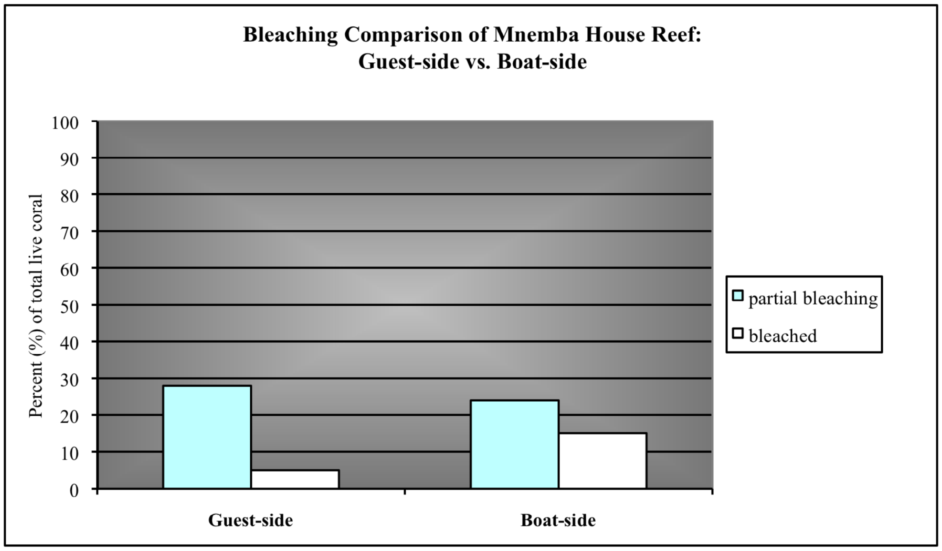


*Figure 8*

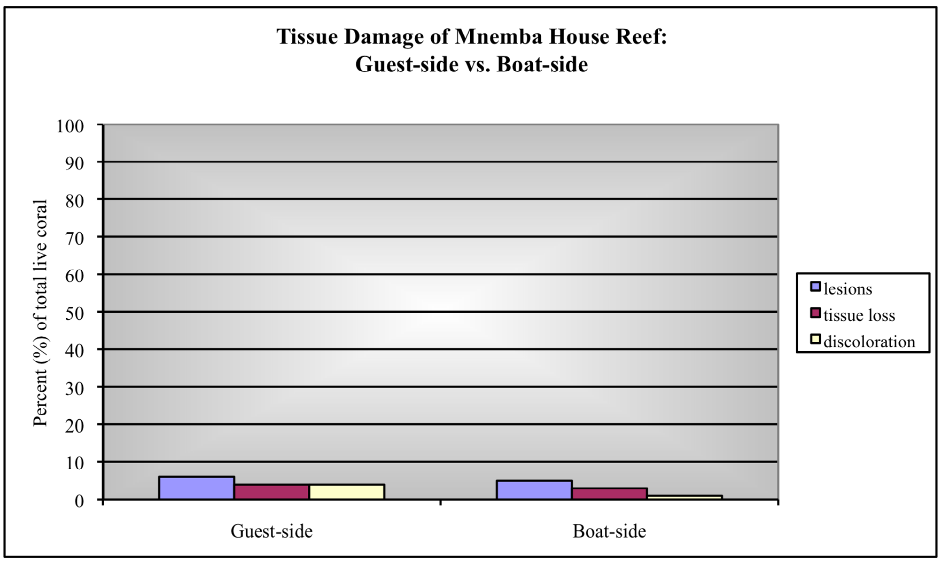


*Figure 9*

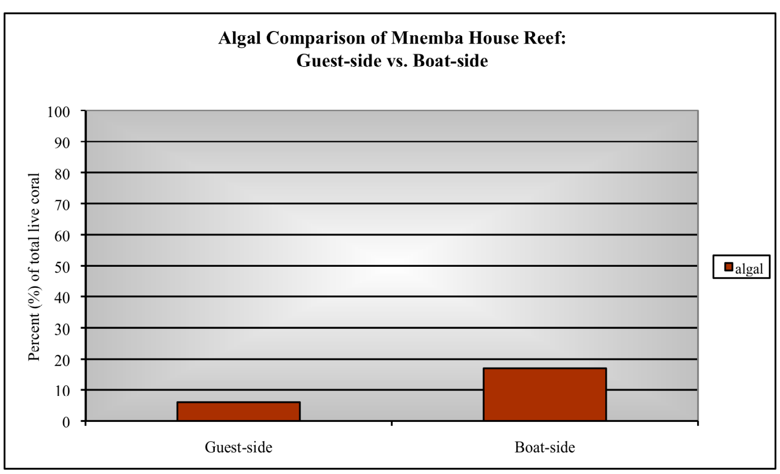


*Figure 10*

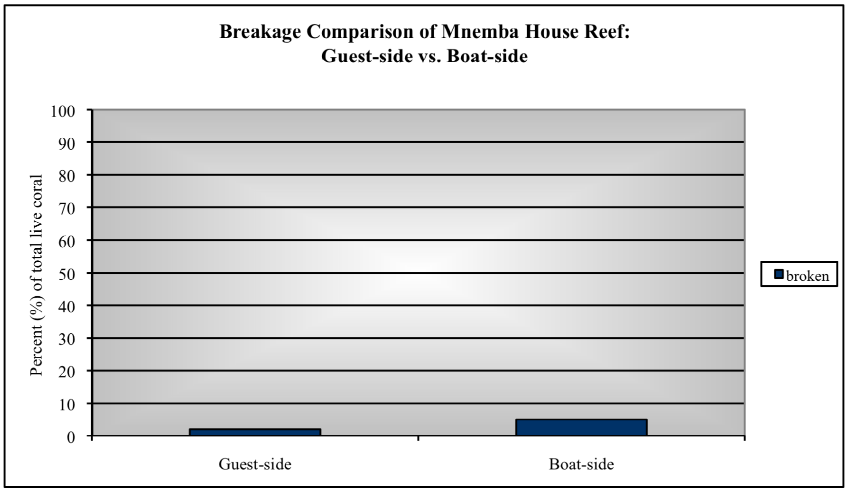


*Figure 11*

*Fish Survey*

According to the results, fish surveys were found to be relatively constant across the two sections. In terms of total count, more individuals were found on the guest-side while a slightly higher number of species was found on the boat-side. The same number of indicator species was present in both sections. No significant differences were found for any of the fish survey categories, although a lower p-value was found for total species diversity (Table 10).

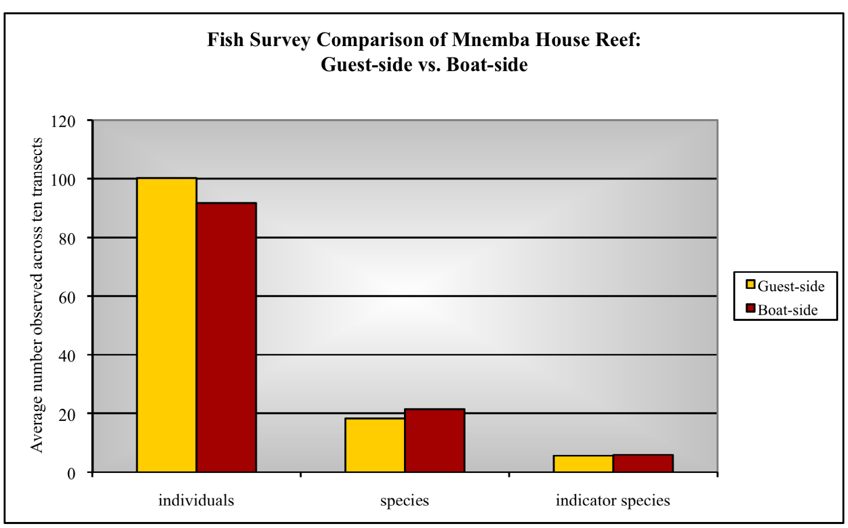


*Figure 12*

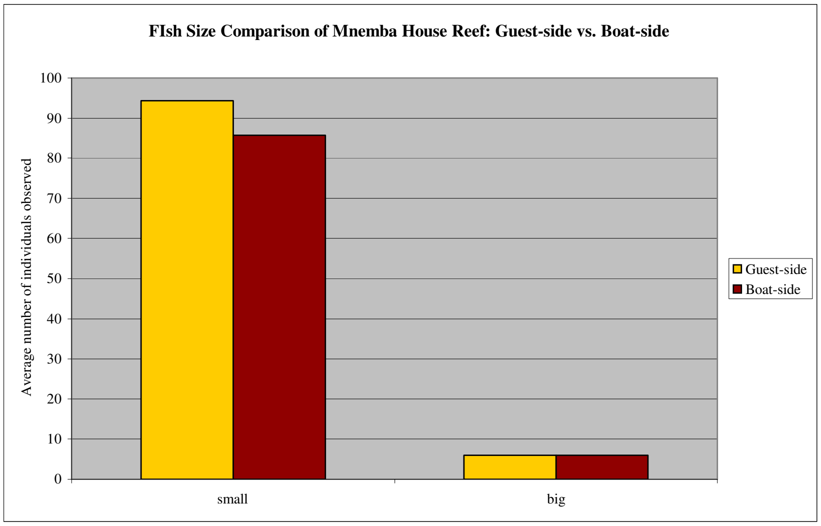


*Figure 13*

| description | P-Value |
|---|---|
| **Small fish (<15cm)** | 0.57 |
| **Big fish (>15cm)** | 1.00 |
| **Total fish** | 0.57 |
| **Total species** | 0.26* |
| **Total indicator fish** | 0.76 |

*Table 10: Calculated using an unpaired T-test for 10 samples per site. Values <0.05 considered significant (***), although almost significant (**) and low values (*) may also indicate difference with more samples*

### *Urchins*

A higher number of urchins were observed on the boat-side, this is almost a significant difference as the P-value is low.

| SITE | # |
|---|---|
| **Guest-side** | 21 |
| **Boat-side** | 41.4 |

*Table 11: Urchin Abundance*

| | P-value |
|---|---|
| **urchins** | 0.1 * |

*Table 12: Calculated using an unpaired T-test for ten samples per site. Values <0.05 considered significant (***), although almost significant (**) and low values (*) may also indicate difference with more samples*

***Discussion***

Because the boat-side is circumstantially subject to greater usage, it was correspondingly hypothesized that there would be a positive correlation of damage. While the data has broadly supported the fact that higher physical damage (i.e.. from anchors and poling) is widely present on the boat-side, this was not consistently the case for overall health or other kinds of damage. This suggests a more complex, nuanced impact of human activity on reef health. While the boat-side section is undoubtedly more compromised as a direct result of boat usage, health and damage data further indicate that not only is there more damage, coral on the boat-side is also less likely to *recover* from damage (anthropogenic or natural), and as a result may also be less resilient / more vulnerable to future disturbances.

The majority of damage implicates boats, with clearly observed areas of anchor damage and at least one clearly identified instance of poling damage on the boat-side. Because snorkelers are present in both sections (albeit possibly in greater density on the boat-side), it was expected that the number of coral abrasions caused by touching or kicking on either side would be similar. Similar frequencies of lesions and tissue loss seem to support that abrasions damage is comparable at both sites.

The bleaching data sheds light on an interesting possibility, pointing to greater boat-side vulnerability. It was found that the boat-side had a significantly more unhealthy and dead coral, rubble, as well as algal growth. The greater amount of dead coral suggests the possibility that live coral cover was once more prevalent on the boat-side. Bleaching is an environmental stress, and the high p-value of partial bleaching (Table 9) possibly suggests that both sections were once subject to equal stress (the 1998 bleaching event?).

It was even expected that there would be more severe bleaching / bleached corals on the guest-side, due to shallower conditions that are more sensitive to temperature changes and possible exposure at low tide. However, the fact that such a high amount of completely bleached coral was found on the boat-side could indicate that coral on the boat-side is weakened as a direct result of more human activity. The idea that the impacts of climate change may depend on the degree of degradation by other factors is supported by Pandolfi et al. 2005. The integrated comparison of data findings suggest greater recovery on guest side due to less anthropogenic stress and better overall health. Further, more discoloration (although not significant, low p-value suggests some difference) was observed on the guest-side. Because discoloration is an inflammation response that is indicative of recovery, this possibly suggests better resilience and recovery on the guest-side with less human activity.

Fish surveys did not yield much significant difference. This may be because the size of territories of some species vary and are probably bigger than the artificially determined zones for purposes of this study. Other factors (such as habitat) should also be taken into account in case of correlation, possibly influencing data. While the data seems to indicate no immediate threat from usage or overfishing, further study is needed to diagnose whether tourist or fishing pressures are indeed affecting the area.

Urchins were not found to be statistically significant across the two sections (although the p-value was low), but as consistent with previous research (see Experimental Design), high urchin populations were observed in areas with little to no macroalgae. In such areas, macroalgal biomass is grazed before it reaches an appreciable degree and coral framework may be undermined faster than it can be replaced by recolonization. Thus, prospects for coral growth are low, as substrates are grazed too frequently for newly settled corals to reach maturity (Tyler 2005).

*Limitations*

Data was collected under the assumption that the sampling scheme was representative of the area as a whole, and that methods were carried out with minimal bias. In taking population censes of non-sessile organisms, aggregating shoals of fish or patchily distributed urchins may have misrepresented numbers. Possible skewing factors also include the factor of habitat variation. Habitat composition and structure is correlated with distribution, density, biomass, and species richness, and is often difficult to factor out in marine reserve studies (Tyler 2005). By selecting similar sites based on coral cover criteria, habitat variance was minimized, yet still present. For a more rigorous investigation of fish surveys, habitat should be measured and factored out of analysis (Tyler 2005), but this was not done due to time constraints of the research period and is not central to the question of study. Some species of fish also continue to aggregate in large shoals even after population decreases, and census counts do not necessarily yield counts indicative of depletion. Increasing the number of transects would increase statistical approximation, and aggregates should be noted in individual/species abundance counts. It should be noted that obtained data also remains subject to other environmental factors such as oceanographic conditions and depth, as well as seasonal variation.

While the data clearly indicates an effect of human activity based on set parameters and assessment protocols, methodology could be further refined to include evaluation of further damage and poor health indicators. For example, since sponges

(*Porifera)* compete with hard coral for space, higher sponge biomass could be surveyed to indicate stressed, damaged, or unhealthy coral colony regions (Tyler 2005). Time was a constraint on the completion of this project; as only three weeks were available for data collection, rate of reef degradation over time could not be assessed. It is recommended that future studies take place over a longer period of time in order to compare damage and determine a rate of reef degradation. For example, in terms of coral cover, macroalgae could be looked at in order to determine if increasing dominance indicates out-competing of hard coral. Size of fish was looked at in order to determine comparable health of two different areas of study, but size of fish could be looked at over a longer time interval in order to correlate changes and factors. To get a better indication of how coral topography is affected, future methods can also examine coral rugosity. It may also be interesting to examine the intermediate disturbance hypothesis (Connell 1978), which holds that a low rate of disturbance has a monopoly of competitively dominant coral, a high rate allows only the most rapid colonizers to dominate, and an intermediate rate favors coexistence of many species.

Long-term coral health is an interplay between environmental factors and human activity. Therefore, a temporal dimension would further help pinpoint thresholds and rates of responses to global change, providing a knowledge base to better manage reefs for sustainable use.

*Recommendations for Management:*

Based on collected data and findings, immediate action is needed to strengthen protection of the Mnemba house reef. The area is designated as a no-take zone but management (MIMCA) focuses the majority of their attention on collection of fees from tourist boat operators rather than approaching local fisherman in regards to their use of the reef. Furthermore, although money collected from boats using the reef is supposed to go to local villages, interviews have revealed that the money is not fulfilling its intended purpose. Measures should be taken in order to ensure that the money reaches its target receivers to build trust amongst stakeholders and better ensure their compliance. Local fisherman and tour boat operators, the major source of current reef degradation, need to be educated on the treatment of fragile reef ecosystems so as to ensure the reef remains healthy. Understanding sustainable amounts of use leads to increased coral health and a more profitable future fish abundance for fisherman. Buoy moorings should be placed at the top of the house reef, making anchoring on the reef neither necessary nor an option. This could significantly decrease the amount of breakage and rubble present at reef fringes. Tourists who snorkel the reef and dive in the area should also be educated as to the effects of mistreatment of coral. During the high season the house reef can receive upwards of twenty tourist snorkeling boats per day. Riegel and Velimov (1991) found that on reefs with high frequency of visitors, major tissue loss, algal overgrowth and coral breakage were significantly higher than on reefs with a low frequency of visitors (Medio 1996). A study found that a single environmental awareness briefing reduced the rate of divers contact with reef substrates from 1.4 to 0.4 contacts per dive per seven minute observation period (Medio 1996). Many uninformed tourists stand-on or touch the coral not knowing that they are in fact causing immense amounts of damage to the fragile ecosystem. Simply informing tourists of the consequences of their actions for the reef could significantly decrease the amount of damage.

***Conclusion***

The complex interconnectivity of natural and anthropogenic forces requires constant evaluation of management effectiveness on reef systems. While instances of tissue damage were similar at both sites, it was found that the boat-side had a significant amount of unhealthier, bleached, and dead coral as well as rubble and algal growth. Anchor damage from boat tourism was implicated as a major source of anthropogenic disturbanc, causing breakage and generating rubble. The results indicate that Mnemba's house reef is compromised as a result of human activity, and further measures must be taken to mitigate current damage as well as pre-empt future damage (anthropogenic or natural). While this study only provides a baseline snapshot of the house reef in a short window of time, it is hoped that future monitoring efforts and research will continue to identify key issues to improve sustainable management of this critical natural resource.

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Zanzibar Tourism Profile (Reference Binder 1, SIT Office)

***Appendix***

Coral Cover - Guest Side:

| Transect | live | dead | rubble | seaweed | total | other |
|---|---|---|---|---|---|---|
| G1 | 40 | 20 | 3 | 15 | 78 | 22 |
| G2 | 50 | 15 | 3 | 20 | 88 | 12 |
| G3 | 40 | 10 | 2 | 40 | 92 | 8 |
| G4 | 30 | 10 | 3 | 55 | 98 | 2 |
| G5 | 30 | 20 | 5 | 25 | 80 | 10 |
| G6 | 40 | 20 | 5 | 30 | 95 | 5 |
| G7 | 50 | 20 | 5 | 15 | 90 | 10 |
| G8 | 50 | 20 | 8 | 10 | 88 | 12 |
| G9 | 40 | 20 | 8 | 10 | 78 | 22 |
| G10 | 25 | 15 | 10 | 30 | 80 | 20 |
| avg | **39.5** | **17** | **5.2** | **25** | | |

Coral Cover -Boat Side:

| Transect | Live | Dead | Rubble | Seaweed | Total | Other |
|---|---|---|---|---|---|---|
| B1 | 45 | 25 | 10 | 3 | 83 | 17 |
| B2 | 40 | 25 | 10 | 3 | 78 | 22 |
| B3 | 40 | 25 | 15 | 3 | 83 | 17 |
| B4 | 35 | 30 | 12 | 3 | 80 | 20 |
| B5 | 20 | 30 | 15 | 3 | 68 | 32 |
| B6 | 10 | 35 | 25 | 3 | 73 | 27 |
| B7 | 40 | 30 | 10 | 3 | 83 | 17 |
| B8 | 40 | 20 | 15 | 3 | 78 | 22 |
| B9 | 40 | 20 | 10 | 3 | 73 | 27 |
| B10 | 40 | 25 | 15 | 3 | 83 | 17 |
| avg | **35** | **26.5** | **13.7** | **3** | | |

Guest Side Totals:

| | | |
|---|---|---|
| **total coral** | **395** | |
| **total unhealthy** | **159** | 40.25% |
| **total healthy** | **181** | 45.82% |
| **total live** | **340** | 86.08% |
| **total dead** | **47** | 11.90% |
| **total broken** | **8** | 2.03% |

Boat Side Totals:

| | | |
|---|---|---|
| **total coral** | **523** | |
| **total unhealthy** | **215** | 41.10% |
| **total healthy** | **203** | 38.81% |
| **total live** | **418** | 79.92% |
| **total dead** | **84** | 16.06% |
| **total broken** | **21** | 4.02% |

Coral Damage Guest-Side:

| Transect | partial bleaching | bleached | lesions | discoloration | tissue loss | algal | broken |
|---|---|---|---|---|---|---|---|
| G1 | 2 | 3 | 2 | 0 | 1 | 0 | 0 |
| G2 | 14 | 2 | 5 | 3 | 0 | 0 | 1 |
| G3 | 9 | 1 | 2 | 4 | 2 | 2 | 1 |
| G4 | 3 | 0 | 2 | 2 | 2 | 1 | 0 |
| G5 | 18 | 4 | 3 | 1 | 2 | 2 | 1 |
| G6 | 10 | 1 | 1 | 0 | 1 | 2 | 1 |
| G7 | 12 | 1 | 0 | 2 | 3 | 3 | 0 |
| G8 | 6 | 1 | 4 | 0 | 1 | 1 | 1 |
| G9 | 9 | 3 | 3 | 0 | 1 | 3 | 1 |
| G10 | 12 | 1 | 0 | 0 | 2 | 8 | 2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| sum | **95** | **17** | **22** | **12** | **15** | **22** | **8** |
| avg | **9.5** | **1.7** | **2.2** | **1.2** | **1.5** | **2.2** | **0.8** |

Coral Damage Boat-Side:

| Transect | partial bleaching | Bleached | Lesions | Discoloration | Tissue Loss | Algal | Broken |
|---|---|---|---|---|---|---|---|
| B1 | 9 | 5 | 4 | 0 | 1 | 4 | 10 |
| B2 | 9 | 10 | 3 | 1 | 3 | 7 | 0 |
| B3 | 6 | 7 | 3 | 1 | 1 | 11 | 6 |
| B4 | 9 | 8 | 3 | 0 | 1 | 6 | 2 |
| B5 | 12 | 0 | 1 | 1 | 0 | 0 | 0 |
| B6 | 5 | 4 | 1 | 0 | 2 | 1 | 1 |
| B7 | 9 | 10 | 0 | 0 | 2 | 16 | 0 |
| B8 | 15 | 6 | 2 | 2 | 0 | 14 | 1 |
| B9 | 17 | 5 | 1 | 1 | 1 | 8 | 0 |
| B10 | 10 | 6 | 1 | 0 | 1 | 6 | 1 |
| Sum | **101** | **61** | **19** | **6** | **12** | **73** | **21** |
| Avg | **10.1** | **6.1** | **1.9** | **0.6** | **1.2** | **7.3** | **2.1** |

Damage Totals for Entire Reef:

| | partial bleaching | bleached | lesions | tissue loss | discoloration | algal | broken |
|---|---|---|---|---|---|---|---|
| G | 28 | 5 | 6 | 4 | 4 | 6 | 2 |
| B | 24 | 15 | 5 | 3 | 1 | 17 | 5 |

Fish Survey Guest Area:

| Transect | Small | Big | Individuals | Species | Indicator Species |
|---|---|---|---|---|---|
| G1 | 58 | 8 | 66 | 17 | 5 |
| G2 | 65 | 5 | 70 | 18 | 4 |
| G3 | 101 | 4 | 105 | 20 | 4 |
| G4 | 9 | 4 | 100 | 18 | 4 |
| G5 | 97 | 5 | 102 | 15 | 5 |
| G6 | 82 | 5 | 87 | 25 | 4 |
| G7 | 190 | 12 | 202 | 18 | 9 |
| G8 | 96 | 4 | 100 | 14 | 11 |
| G9 | 71 | 7 | 78 | 20 | 3 |
| G10 | 87 | 5 | 92 | 18 | 6 |
| **Avg** | **94.3** | **5.9** | **100.2** | **18.3** | **5.5** |

Fish Survey- Boat Area:

| | Small | Big | Individuals | Species | Indicator Species |
|---|---|---|---|---|---|
| B1 | 96 | 5 | 101 | 13 | 5 |
| B2 | 103 | 4 | 107 | 18 | 8 |
| B3 | 139 | 6 | 145 | 19 | 4 |
| B4 | 52 | 7 | 59 | 18 | 4 |
| B5 | 101 | 6 | 107 | 17 | 6 |
| B6 | 81 | 4 | 85 | 12 | 3 |
| B7 | 56 | 6 | 62 | 23 | 7 |
| B8 | 103 | 8 | 111 | 35 | 8 |
| B9 | 66 | 6 | 72 | 29 | 6 |
| B10 | 61 | 7 | 68 | 29 | 7 |
| **Avg** | **85.8** | **5.9** | **91.7** | **213** | **5.8** |

Urchins Guest Side:

| Transect | Urchins |
|---|---|
| G1 | 18 |
| G2 | 16 |
| G3 | 8 |
| G4 | 5 |
| G5 | 37 |
| G6 | 4 |
| G7 | 7 |
| G8 | 10 |
| G9 | 42 |
| G10 | 20 |
| AVG | 21 |

Urchins Boat Side

| Transect | Urchins |
|---|---|
| B1 | 20 |
| B2 | 99 |
| B3 | 52 |
| B4 | 32 |
| B5 | 73 |
| B6 | 15 |
| B7 | 88 |
| B8 | 19 |
| B9 | 11 |
| B10 | 5 |
| Avg | 41.4 |

## Statistical Data:

**Unhealthy**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:30 on 26-APR-2010

t= -2.14
sdev= 5.85
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.046
Group A: Number of items= 10
7.00 8.00 11.0 15.0 15.0 16.0 18.0 19.0 24.0 26.0

Mean = 15.9
95% confidence interval for Mean: 12.02 thru 19.78
Standard Deviation = 6.23
Hi = 26.0 Low = 7.00
Median = 15.5
Average Absolute Deviation from Median = 4.70
Group B: Number of items= 10
13.0 14.0 18.0 19.0 22.0 23.0 24.0 25.0 28.0 29.0

Mean = 21.5
95% confidence interval for Mean: 17.62 thru 25.38
Standard Deviation = 5.44
Hi = 29.0 Low = 13.0
Median = 22.5
Average Absolute Deviation from Median = 4.30
Data Reference: 50BE
Make a Box Plot

**Healthy**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:31 on 26-APR-2010

t=-0.830
sdev= 5.93
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.42
Group A: Number of items= 10
11.0 14.0 15.0 17.0 18.0 18.0 19.0 20.0 22.0 27.0

Mean = 18.1
95% confidence interval for Mean: 14.16 thru 22.04
Standard Deviation = 4.43
Hi = 27.0 Low = 11.0
Median = 18.0
Average Absolute Deviation from Median = 3.10
Group B: Number of items= 10
10.0 12.0 17.0 18.0 19.0 20.0 21.0 23.0 30.0 33.0

Mean = 20.3
95% confidence interval for Mean: 16.36 thru 24.24
Standard Deviation = 7.12
Hi = 33.0 Low = 10.0
Median = 19.5
Average Absolute Deviation from Median = 5.10
Data Reference: 50F8
Make a Box Plot
Format:

Y Scale Options:
Linear
Log
Options:
data swarm
mean with 1 error bars
boxplot

**Live**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:32 on 26-APR-2010

t= -2.04
sdev= 8.54
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.056
Group A: Number of items= 10
19.0 26.0 29.0 30.0 32.0 34.0 38.0 42.0 44.0 46.0

Mean = 34.0
95% confidence interval for Mean: 28.33 thru 39.67
Standard Deviation = 8.55
Hi = 46.0 Low = 19.0
Median = 33.0
Average Absolute Deviation from Median = 6.80
Group B: Number of items= 10
25.0 35.0 38.0 39.0 42.0 43.0 44.0 47.0 48.0 57.0

Mean = 41.8
95% confidence interval for Mean: 36.13 thru 47.47
Standard Deviation = 8.52
Hi = 57.0 Low = 25.0
Median = 42.5
Average Absolute Deviation from Median = 6.00

**Dead**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:35 on 26-APR-2010

t= -1.99
sdev= 4.17
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.063
Group A: Number of items= 10
0.00 1.00 1.00 4.00 5.00 5.00 6.00 6.00 7.00 12.0

Mean = 4.70
95% confidence interval for Mean: 1.932 thru 7.468
Standard Deviation = 3.53
Hi = 12.0 Low = 0.00
Median = 5.00
Average Absolute Deviation from Median = 2.50
Group B: Number of items= 10
3.00 3.00 4.00 5.00 6.00 10.0 11.0 13.0 14.0 15.0

Mean = 8.40
95% confidence interval for Mean: 5.632 thru 11.17

Standard Deviation = 4.72
Hi = 15.0 Low = 3.00
Median = 8.00
Average Absolute Deviation from Median = 4.20

**Broken**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:42 on 26-APR-2010

t= -1.22
sdev= 2.39
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.24
Group A: Number of items= 10
0.00 0.00 0.00 1.00 1.00 1.00 1.00 1.00 1.00 2.00

Mean = 0.800
95% confidence interval for Mean: -0.7854 thru 2.385
Standard Deviation = 0.632
Hi = 2.00 Low = 0.00
Median = 1.00
Average Absolute Deviation from Median = 0.400
Group B: Number of items= 10
0.00 0.00 0.00 0.00 1.00 1.00 1.00 2.00 6.00 10.0

Mean = 2.10
95% confidence interval for Mean: 0.5146 thru 3.685
Standard Deviation = 3.31
Hi = 10.0 Low = 0.00
Median = 1.00
Average Absolute Deviation from Median = 1.90
Data Reference: 529A

**Live cover**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:43 on 26-APR-2010

t= 1.00
sdev= 10.1
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.33
Group A: Number of items= 10
25.0 30.0 30.0 40.0 40.0 40.0 40.0 50.0 50.0 50.0

Mean = 39.5
95% confidence interval for Mean: 32.81 thru 46.19
Standard Deviation = 8.96
Hi = 50.0 Low = 25.0
Median = 40.0
Average Absolute Deviation from Median = 6.50
Group B: Number of items= 10
10.0 20.0 35.0 40.0 40.0 40.0 40.0 40.0 40.0 45.0

Mean = 35.0
95% confidence interval for Mean: 28.31 thru 41.69
Standard Deviation = 11.1

Hi = 45.0 Low = 10.0
Median = 40.0
Average Absolute Deviation from Median = 6.00
Data Reference: 52DB

**Dead cover**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:44 on 26-APR-2010

t= -4.73
sdev= 4.49
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.0002
Group A: Number of items= 10
10.0 10.0 15.0 15.0 20.0 20.0 20.0 20.0 20.0 20.0

Mean = 17.0
95% confidence interval for Mean: 14.02 thru 19.98
Standard Deviation = 4.22
Hi = 20.0 Low = 10.0
Median = 20.0
Average Absolute Deviation from Median = 3.00
Group B: Number of items= 10
20.0 20.0 25.0 25.0 25.0 25.0 30.0 30.0 30.0 35.0

Mean = 26.5
95% confidence interval for Mean: 23.52 thru 29.48
Standard Deviation = 4.74
Hi = 35.0 Low = 20.0
Median = 25.0
Average Absolute Deviation from Median = 3.50
Data Reference: 52F7

**Rubble cover**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:45 on 26-APR-2010

t= -5.04
sdev= 3.77
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is less than .0001The probability of this result, assuming the null hypothesis, is less than .0001
Group A: Number of items= 10
2.00 3.00 3.00 3.00 5.00 5.00 5.00 8.00 8.00 10.0

Mean = 5.20
95% confidence interval for Mean: 2.696 thru 7.704
Standard Deviation = 2.66
Hi = 10.0 Low = 2.00
Median = 5.00
Average Absolute Deviation from Median = 2.00
Group B: Number of items= 10
10.0 10.0 10.0 10.0 12.0 15.0 15.0 15.0 15.0 25.0

Mean = 13.7
95% confidence interval for Mean: 11.20 thru 16.20
Standard Deviation = 4.62

Hi = 25.0 Low = 10.0
Median = 13.5
Average Absolute Deviation from Median = 3.30
Data Reference: 5324

**Seaweed cover**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:45 on 26-APR-2010

t= 4.85
sdev= 10.1
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.0001
Group A: Number of items= 10
10.0 10.0 15.0 15.0 20.0 25.0 30.0 30.0 40.0 55.0

Mean = 25.0
95% confidence interval for Mean: 18.26 thru 31.74
Standard Deviation = 14.3
Hi = 55.0 Low = 10.0
Median = 22.5
Average Absolute Deviation from Median = 11.0
Group B: Number of items= 10
3.00 3.00 3.00 3.00 3.00 3.00 3.00 3.00 3.00 3.00

Mean = 3.00
95% confidence interval for Mean: -3.735 thru 9.735
Standard Deviation = 0.00
Hi = 3.00 Low = 3.00
Median = 3.00
Average Absolute Deviation from Median = 0.00

**Bleaching**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:48 on 26-APR-2010

t=-0.309
sdev= 4.34
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.76
Group A: Number of items= 10
2.00 3.00 6.00 9.00 9.00 10.0 12.0 12.0 14.0 18.0

Mean = 9.50
95% confidence interval for Mean: 6.615 thru 12.38
Standard Deviation = 4.90
Hi = 18.0 Low = 2.00
Median = 9.50
Average Absolute Deviation from Median = 3.70
Group B: Number of items= 10
5.00 6.00 9.00 9.00 9.00 9.00 10.0 12.0 15.0 17.0

Mean = 10.1
95% confidence interval for Mean: 7.215 thru 12.98
Standard Deviation = 3.70
Hi = 17.0 Low = 5.00
Median = 9.00

Average Absolute Deviation from Median = 2.50

**Bleached**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:49 on 26-APR-2010

t= -4.33
sdev= 2.27
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.0004
Group A: Number of items= 10
0.00 1.00 1.00 1.00 1.00 1.00 2.00 3.00 3.00 4.00

Mean = 1.70
95% confidence interval for Mean: 0.1898 thru 3.210
Standard Deviation = 1.25
Hi = 4.00 Low = 0.00
Median = 1.00
Average Absolute Deviation from Median = 0.900
Group B: Number of items= 10
0.00 4.00 5.00 5.00 6.00 6.00 7.00 8.00 10.0 10.0

Mean = 6.10
95% confidence interval for Mean: 4.590 thru 7.610
Standard Deviation = 2.96
Hi = 10.0 Low = 0.00
Median = 6.00
Average Absolute Deviation from Median = 2.10

**Lesions**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:50 on 26-APR-2010

t= 0.459
sdev= 1.46
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.65
Group A: Number of items= 10
0.00 0.00 1.00 2.00 2.00 2.00 3.00 3.00 4.00 5.00

Mean = 2.20
95% confidence interval for Mean: 1.228 thru 3.172
Standard Deviation = 1.62
Hi = 5.00 Low = 0.00
Median = 2.00
Average Absolute Deviation from Median = 1.20
Group B: Number of items= 10
0.00 1.00 1.00 1.00 1.00 2.00 3.00 3.00 3.00 4.00

Mean = 1.90
95% confidence interval for Mean: 0.9283 thru 2.872
Standard Deviation = 1.29
Hi = 4.00 Low = 0.00
Median = 1.50
Average Absolute Deviation from Median = 1.10
Data Reference: 5469

**Discoloration**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:50 on 26-APR-2010

t= 1.16
sdev= 1.15
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.26
Group A: Number of items= 10
0.00 0.00 0.00 0.00 0.00 1.00 2.00 2.00 3.00 4.00

Mean = 1.20
95% confidence interval for Mean: 0.4328 thru 1.967
Standard Deviation = 1.48
Hi = 4.00 Low = 0.00
Median = 0.500
Average Absolute Deviation from Median = 1.20
Group B: Number of items= 10
0.00 0.00 0.00 0.00 0.00 1.00 1.00 1.00 1.00 2.00

Mean = 0.600
95% confidence interval for Mean: -0.1672 thru 1.367
Standard Deviation = 0.699
Hi = 2.00 Low = 0.00
Median = 0.500
Average Absolute Deviation from Median = 0.600

**Tissue loss**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:51 on 26-APR-2010

t= 0.758
sdev= 0.885
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.46
Group A: Number of items= 10
0.00 1.00 1.00 1.00 1.00 2.00 2.00 2.00 2.00 3.00

Mean = 1.50
95% confidence interval for Mean: 0.9120 thru 2.088
Standard Deviation = 0.850
Hi = 3.00 Low = 0.00
Median = 1.50
Average Absolute Deviation from Median = 0.700
Group B: Number of items= 10
0.00 0.00 1.00 1.00 1.00 1.00 1.00 2.00 2.00 3.00

Mean = 1.20
95% confidence interval for Mean: 0.6120 thru 1.788
Standard Deviation = 0.919
Hi = 3.00 Low = 0.00
Median = 1.00
Average Absolute Deviation from Median = 0.600
Data Reference: 54BE

**Algal**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:52 on 26-APR-2010

t= -2.84
sdev= 4.01
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.011
Group A: Number of items= 10
0.00 0.00 1.00 1.00 2.00 2.00 2.00 3.00 3.00 8.00

Mean = 2.20
95% confidence interval for Mean: -0.4654 thru 4.865
Standard Deviation = 2.30
Hi = 8.00 Low = 0.00
Median = 2.00
Average Absolute Deviation from Median = 1.40
Group B: Number of items= 10
0.00 1.00 4.00 6.00 6.00 7.00 8.00 11.0 14.0 16.0

Mean = 7.30
95% confidence interval for Mean: 4.635 thru 9.965
Standard Deviation = 5.19
Hi = 16.0 Low = 0.00
Median = 6.50
Average Absolute Deviation from Median = 3.90
Data Reference: 54DF

**Total fish**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:53 on 26-APR-2010

t= 0.571
sdev= 33.3
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.57
Group A: Number of items= 10
66.0 70.0 78.0 87.0 92.0 100. 100. 102. 105. 202.

Mean = 100.
95% confidence interval for Mean: 78.10 thru 122.3
Standard Deviation = 38.3
Hi = 202. Low = 66.0
Median = 96.0
Average Absolute Deviation from Median = 21.6
Group B: Number of items= 10
59.0 62.0 68.0 72.0 85.0 101. 107. 107. 111. 145.

Mean = 91.7
95% confidence interval for Mean: 69.60 thru 113.8
Standard Deviation = 27.3
Hi = 145. Low = 59.0
Median = 93.0
Average Absolute Deviation from Median = 22.5
Data Reference: 54F2

**Species**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:54 on 26-APR-2010

t= -1.17
sdev= 5.74
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.26
Group A: Number of items= 10
14.0 15.0 17.0 18.0 18.0 18.0 18.0 20.0 20.0 25.0

Mean = 18.3
95% confidence interval for Mean: 14.49 thru 22.11
Standard Deviation = 3.02
Hi = 25.0 Low = 14.0
Median = 18.0
Average Absolute Deviation from Median = 1.90
Group B: Number of items= 10
12.0 13.0 17.0 18.0 18.0 19.0 23.0 29.0 29.0 35.0

Mean = 21.3
95% confidence interval for Mean: 17.49 thru 25.11
Standard Deviation = 7.53
Hi = 35.0 Low = 12.0
Median = 18.5
Average Absolute Deviation from Median = 5.70
Data Reference: 5510

**Indicator Species**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:54 on 26-APR-2010

t=-0.307
sdev= 2.19
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.76
Group A: Number of items= 10
3.00 4.00 4.00 4.00 4.00 5.00 5.00 6.00 9.00 11.0

Mean = 5.50
95% confidence interval for Mean: 4.047 thru 6.953
Standard Deviation = 2.55
Hi = 11.0 Low = 3.00
Median = 4.50
Average Absolute Deviation from Median = 1.70
Group B: Number of items= 10
3.00 4.00 4.00 5.00 6.00 6.00 7.00 7.00 8.00 8.00

Mean = 5.80
95% confidence interval for Mean: 4.347 thru 7.253
Standard Deviation = 1.75
Hi = 8.00 Low = 3.00
Median = 6.00
Average Absolute Deviation from Median = 1.40
Data Reference: 5538

**Urchins**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:55 on 26-APR-2010

t= -1.71
sdev= 26.6
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.10
Group A: Number of items= 10
5.00 7.00 8.00 10.0 16.0 18.0 20.0 37.0 42.0 47.0

Mean = 21.0
95% confidence interval for Mean: 3.322 thru 38.68
Standard Deviation = 15.5
Hi = 47.0 Low = 5.00
Median = 17.0
Average Absolute Deviation from Median = 11.8
Group B: Number of items= 10
5.00 11.0 15.0 19.0 20.0 32.0 52.0 73.0 88.0 99.0

Mean = 41.4
95% confidence interval for Mean: 23.72 thru 59.08
Standard Deviation = 34.3
Hi = 99.0 Low = 5.00
Median = 26.0
Average Absolute Deviation from Median = 27.4
Data Reference: 555B

**Small**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:56 on 26-APR-2010

t= 0.586
sdev= 32.5
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 0.57
Group A: Number of items= 10
58.0 65.0 71.0 82.0 87.0 96.0 96.0 97.0 101. 190.

Mean = 94.3
95% confidence interval for Mean: 72.74 thru 115.9
Standard Deviation = 36.7
Hi = 190. Low = 58.0
Median = 91.5
Average Absolute Deviation from Median = 21.7
Group B: Number of items= 10
52.0 56.0 61.0 66.0 81.0 96.0 101. 103. 103. 139.

Mean = 85.8
95% confidence interval for Mean: 64.24 thru 107.4
Standard Deviation = 27.5
Hi = 139. Low = 52.0
Median = 88.5
Average Absolute Deviation from Median = 22.6
Data Reference: 5586

**Big**
Student's t-Test: Results

The results of an unpaired t-test performed at 07:57 on 26-APR-2010

t= 0.00
sdev= 2.00
degrees of freedom = 18 The probability of this result, assuming the null hypothesis, is 1.00
Group A: Number of items= 10
4.00 4.00 4.00 5.00 5.00 5.00 5.00 7.00 8.00 12.0

Mean = 5.90
95% confidence interval for Mean: 4.573 thru 7.227
Standard Deviation = 2.51
Hi = 12.0 Low = 4.00
Median = 5.00
Average Absolute Deviation from Median = 1.50
Group B: Number of items= 10
4.00 4.00 5.00 6.00 6.00 6.00 6.00 7.00 7.00 8.00

Mean = 5.90
95% confidence interval for Mean: 4.573 thru 7.227
Standard Deviation = 1.29
Hi = 8.00 Low = 4.00
Median = 6.00
Average Absolute Deviation from Median = 0.900

## Informal Interviews:

***List of Interviewees and Topics Discussed:***

**Mike Procopakis,** *Manager, Mnemba Island Lodge*
Topics Discussed: General Island background, hotel logistics, conservation measures

**Eli Lang,** *Dive Instructor, Mnemba Island*
Topics Discussed: Reef Conditions, species abundance

**Robin Kamiya,** *Dive Instructor, Mnemba Island*
Topics Discussed: Reef Conditions, species abundance

**Makame,** *Boatman for over fourteen years, Mnemba Island*
Topics Discussed: Local Fisherman, conservation measures, education of locals, MIMCA

**MShamba,** *Staff member for over twenty-five years, Mnemba Island*

Topics Discussed: Island background, reef degradation over time

**One Ocean Dive Center,** *Stone Town, Unguja*
Topics Discussed: Mnemba Island Background, dive regulations, tourist treatment of coral, reef degradation