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**Title**

Benthic infaunal communities around two artificial reefs in Mamala Bay, Oahu, Hawaii.

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**Abstract**

Non-fishery use of artificial reefs has been given attention in recent years. The primary concern associated with non-fishery artificial reefs is their effects to the surrounding ecosystems. This study examined the infaunal communities around two non-fishery artificial reefs (the sunken vessels YO257 and Sea Tiger) in Mamala Bay, Hawaii. Infaunal community structures at these artificial reefs were relatively similar to one at a nearly natural patch reef. A large amount of basalt gravel around YO257 associated with

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its deployment operation possibly had an effect on the surrounding community by increasing pore space. Polychaete assemblages were compared with existing data throughout the bay, and this revealed that the variation in sediment grain sizes and depths seemed to play some role in structuring the polychaete communities. Nevertheless, the infaunal communities around the artificial reefs were typical and within the range of natural variation in Mamala Bay, supporting their beneficial uses in ecotourism.

## **Keywords**

Artificial reef; Benthic ecology; Polychaete; Multivariate analysis; Mamala Bay; Hawaii

## **1. Introduction**

Non-fishery use of an artificial reef (e.g. ecotourism and environmental mitigation) has been given great attention in recent years (Abelson, 2006; Ambrose, 1994; Brock, 1994; Falace et al., 2006; Fox et al., 2005; Reed et al., 2006). This is partly because, unlike the traditional use in fisheries and aquaculture, non-fishery artificial reefs are unlikely to cause a population decline of reef-associated organisms through aggregation (Bohnsack, 1989; Powers et al., 2003). The primary concern associated with non-fishery artificial reefs is their effects to the surrounding ecosystems. Artificial reefs constructed by haphazardly dumping scrap materials show not only poor enhancement of organisms but also instability and degradation of the materials over a relatively short time period (Brock and Norris, 1989). Materials such as steel, automobile tires and coal ash are of concern because leaching of chemical elements may cause pollution (Collins and Jensen, 1996). Deployment of artificial reefs modifies the bottom current and affects sediment grain size

1 distribution. These physical alterations, in combination with increased predations rates in  
2 the deployment areas, cause changes in the surrounding biological communities (e.g.  
3 species diversity and distribution patterns of sessile and infaunal organisms) (Ambrose and  
4 Anderson, 1990; Baynes and Szmant, 1989; Davis et al., 1982). Growth of epifauna on  
5 artificial structures, entrapment of drift algae and detritus in sediments, and activities and  
6 mortality of reef-associated organisms may lead to organic enrichment of sediments.

7 Two artificial reefs, YO257 and Sea Tiger, were constructed using large vessels as  
8 sites for ecotourism (submarine tours and SCUBA diving) in Mamala Bay, Oahu, Hawaii.  
9 Artificial reefs in the Hawaiian tropical water form a fouling invertebrate community  
10 consisting of corals, rock oysters, tube worms, tunicates and sponges (Bailey-Brock, 1989;  
11 Fitzhardinge and Bailey-Brock, 1989) and increase fish abundance and species richness  
12 (Brock, 1994; Brock and Kam, 1994). Invertebrate and fish communities around the two  
13 artificial reefs consist of these fouling invertebrates and fish and exhibit higher abundances  
14 of marine organisms in comparison to areas away from the reefs (personal observation).  
15 The non-fishery use of YO257 was also shown to provide much greater economic return  
16 than used for commercial fishery purposes (Brock, 1994). The Hawaiian economy largely  
17 depends on tourism, and therefore, it is important to evaluate effects of the artificial reefs  
18 on surrounding ecosystems to insure their sustainable use in ecotourism.

19 This study examined benthic infaunal communities around the two artificial reefs  
20 and evaluated their possible ecological effects for the first time since their deployment in  
21 Mamala Bay. The infaunal community data were compared with one from a nearby natural  
22 patch reef, and focus was then narrowed to polychaetes. Polychaete assemblages in  
23 Hawaiian waters have been intensively studied in relation to environmental monitoring

(Bailey-Brock et al., 2001; Bailey-Brock et al., 2002; Lee et al., 2006; Swartz et al, 2004). They comprise the most diverse and species rich group in sediment samples from Mamala Bay, with a variety of trophic, motility and reproductive modes that provide insight to the ecological conditions that prevail in the habitat (Lee et al., 2006). Polychaete community structures were compared with one from a natural reef and existing data from Mamala Bay. Benthic community structures can be influenced by various environmental factors (Fabi et al., 2002; Moura et al., 2007), and therefore, be highly variable within the bay. The comparison with existing data was (1) to examine if environmental variables (depth and grain size composition of sediments/sands) affect community structural patterns, and (2) to evaluate polychaete assemblages around the two artificial reefs by comparing them with those representing various natural habitats throughout Mamala Bay. This paper presents the case that the two artificial reefs in Mamala Bay provide beneficial use in ecotourism without causing detrimental impacts to the surrounding environments.

## **2. Materials and methods**

### **2.1 Study sites**

The study was carried out at two artificial reefs and a natural reef in Mamala Bay, off the south shore of Oahu, Hawaii (Fig. 1). The Sea Tiger artificial reef (21°16'47"N, 157°51'35"W) was created in 1999 by sinking a 51 m fishing vessel approximately 1.5 km offshore of Ala Moana Beach at a depth of 38 m. The artificial reef was deployed, after weeks of preparation, as the beginning effort of Voyager Submarines' Lopaka Reef Foundation that was formed to protect and re-establish natural coral reefs. The vessel lies perpendicular to the shore with the bow facing outward to the south. Patchy growth of the

seagrass, *Halophila decipiens*, was observed on the sand around the port and starboard sides of the vessel covering about 50% of the area at the time of sampling. This seagrass growth was assumed to be a relatively new, post-deployment settlement, as it had not been previously reported by local divers. Hull epifauna includes rock oysters, tube worms, bryozoans, tunicates and sponges. This artificial reef was regularly visited by the Voyager Submarine until its last operation in June 2001.

The YO257 artificial reef (21°15'38"N, 157°50'15"W) was created in 1989 by sinking a 53 m yard oiler approximately 2 km offshore of Waikiki Beach at a depth of 35 m. The yard oiler was cleared of toxic materials prior to the sinking, and large holes were cut through the hull to enhance shelter space, circulation and light penetration. It lies parallel to the shore with the bow facing to the west. The hull was filled with a large quantity of gravel to aid in the deployment operation and to stabilize the vessel on the sea floor. Some of the gravel spilled out and is found right around the vessel. Hull epifauna includes bryozoans (also on the gravel) and three species of coral on decks and superstructure. The interior of the hull is covered with sponges and dense growth of the alien anthozoan, *Carijoa riisei*. *C. riisei* has covered the steel plates in the last 17 years. This artificial reef has been used for tourism by Atlantis Submarine and dive charters. Both sunken vessels are used by local fisherman for non-commercial fishing, and YO257 was monitored for spear, net and hook and line fishing for a comparative economic study of commercial fishing and ecotourism use of this site (Brock, 1994).

The 100' hole (21°15'16"N, 157°50'2"W) is a natural patch reef located approximately 1.5 km offshore of Waikiki Beach at a depth of 32 m. It consists of a cluster of volcanic rocks forming ledges, caves and one large open-ended cavern and is a popular

dive site for SCUBA divers because of the coral cover and access for spear fishing. Epifauna growing on the reef includes corals, tube worms, tunicates and sponges, being similar to those on the artificial reefs. This raised patch reef is approximately 30 m in length, 10 m wide, 3 m in height and about 70 m in circumference. This natural reef was chosen for the comparative purpose in this study because of its proximity to the two artificial reefs, relatively similar environmental characteristics (e.g. depth and current intensity) to those of the artificial reefs, and its fairly large size as a patch reef in Mamala Bay, although it is still smaller than the artificial reefs.

The main current direction in Mamala Bay is parallel to the shore flowing from east to west, although reversals occur synchronizing with tides (Hamilton et al., 1995). This causes different water flow characteristics at the two artificial reef sites. The vessel at the Sea Tiger artificial reef lies perpendicular to the currents, and the yard oiler at the YO257 artificial reef lies parallel to the currents. The YO257 artificial reef and the 100' hole natural reef typically have stronger currents compared to the Sea Tiger artificial reef because of their proximity to Diamond Head, a headland that affects the current patterns along this coast (Hamilton et al., 1995). Mean predicted currents for a 12 month period at a depth of 35 m at the three study sites are approximately  $2 \text{ cm sec}^{-1}$  at Sea Tiger,  $6 \text{ cm sec}^{-1}$  at YO257 and  $7 \text{ cm sec}^{-1}$  at 100' hole (Blumberg and Connolly, 1995). Water quality in Mamala Bay has been tested intensively to examine effects of runoff and wastewater outfalls and shown that the discharge areas were not statistically different from reference areas (U.S. EPA, 2004). The study sites are, therefore, unlikely to be under the influence of land discharges.



## 2.2 Infauna sampling

Divers collected replicate cores of sediment (7.6 cm in diameter, 6 cm in depth) at the port and starboard sides of Sea Tiger in November 2005, at the port and starboard sides of YO257 in February 2005 and at 100' hole in April 2005. Transect lines were placed along the wrecks, a meter away from the hull, and six replicate cores were randomly taken along the transect lines at the four sampling locations; Sea Tiger port, Sea Tiger starboard, YO257 port and YO257 starboard. Similarly, a transect line was laid around 100' hole and six replicate cores were taken. Half of the replicates were taken inside the seagrass *H. decipiens* patches, and the other half outside the patches, at Sea Tiger. Sediments were preserved in 10% buffered formalin for a minimum of 48 hours. Organisms in sand were removed by elutriation with 500 µm mesh sieves (Sanders et al., 1965) and placed in 70% ethanol. Endolithic organisms were removed from carbonate rubbles using the acid dissolution technique (Brock and Brock, 1977). All infaunal organisms were identified to the lowest taxon possible.

## 2.3 Infauna data analyses

Infaunal organisms were categorized into major taxonomic groups at phylum to class level. Mean abundances and standard errors of the means (SE) of the taxonomic groups were calculated and dominant taxa at each site were identified. Abundances of these dominant groups were statistically compared among study sites using non-parametric Kruskal-Wallis test, avoiding assumptions of normal distribution and equality of variances, followed by multiple pairwise testing with the family significance level  $\alpha = 0.05$ . The statistical comparison initially treated samples from the starboard and the port sides of

artificial reefs separately. This initial comparison did not show any significant within-site variability, and therefore, samples from the starboard and port sides were lumped together considering each study site (Sea Tiger, YO257 and 100' hole) as one treatment.

Polychaetes were all identified to the species level according to Day (1967a; 1967b) and Bailey-Brock (1987). Polychaete species richness and Shannon-Wiener diversity index ( $\log e$ ) were computed for each sample. These indices were statistically compared by one-way ANOVA followed by Tukey multiple comparisons with family error rate  $\alpha = 0.05$ .

Differences in polychaete species composition among the study sites were examined by multivariate analyses using the statistical software PRIMER 5.2.9 (PRIMER-E 2002). Bray-Curtis similarity coefficients between samples were computed using non-standardized, fourth root transformed polychaete species abundance data. A 2-dimensional non-metric multi-dimensional scaling (MDS) was constructed using the Bray-Curtis similarity coefficients. An analysis of similarity (ANOSIM; Clarke and Warwick, 2001) was performed to examine if the pattern observed in the MDS showed a statistical difference in polychaete species composition among study sites.

The PRIMER similarity percentage routine (SIMPER; Clarke and Warwick, 2001) was used to compute the average Bray-Curtis similarities within each study site and the average Bray-Curtis dissimilarities between study sites. The similarities and dissimilarities were broken down into contributions from each polychaete species. Similarity and dissimilarity contributions of each polychaete species were averaged among replicates at each study site. A polychaete species with a high average similarity contribution ( $\bar{S}_i$ ) and a low standard deviation ( $SD(S_i)$ ) at a site indicates that the species is found at a high,

consistent abundance throughout the site, and therefore it typifies the site. Similarly, a polychaete species with a high average dissimilarity contribution ( $\bar{\delta}_i$ ) and a low standard deviation ( $SD(\delta_i)$ ) between two sites suggests that the species is a reliable discriminator between the two sites.

## 2.4 Polychaete species composition analyses

The polychaete species compositions were compared with existing data from the biannual monitoring in Mamala Bay conducted by the City and County of Honolulu (Swartz et al., 2004). The 40 stations for the biannual monitoring are numbered between 31 and 70 and spread throughout the bay (Fig. 1). The biannual monitoring also contains environmental variable data for each station, such as grain size distribution and depth. The infauna sampling core size and elutriation methods used are the same as those employed in this study, and therefore, the data were directly comparable. The data from the biannual monitoring and this study were combined, and Bray-Curtis similarity coefficients were calculated using non-standardized, fourth root transformed data. Cluster analysis was first performed to find groupings of the samples, and a similarity dendrogram was constructed using group-average linking. Station 61 of the biannual monitoring did not contain any polychaetes, and therefore had a similarity of 0% to all sites, so it was excluded from further analyses. Polychaete species that typify each group or discriminate groups were identified by performing SIMPER.

Associations between environmental variables and the biotic grouping observed in the similarity dendrogram were examined using the PRIMER matching of biotic to

environmental patterns (BIOENV; Clarke and Warwick, 2001). Environmental variables used in this analysis were grain size distribution and depth. Dissimilarities in environmental variables between samples were calculated using normalized Euclidean distances. Dissimilarities in polychaete species composition were based on the Bray-Curtis similarity coefficient; [Bray-Curtis dissimilarity] = 1 – [Bray-Curtis similarity]. The match between patterns of dissimilarities in environmental and biotic variables was measured using the Spearman coefficient ( $\rho_s$ ) rank correlation method (Clarke and Warwick, 2001), and environmental variables that group sites in a manner consistent with the polychaete species composition pattern were identified. These environmental variables were separately plotted by superimposing the values as different sizes of circles on MDS of polychaete abundances.

## 2.5 Granulometry

Divers collected sediment cores (6.5 cm in diameter, 6 cm in depth) at the port and starboard sides of Sea Tiger in October 2004, at the port and starboard sides of YO257 in October 2005 and at 100' hole in November 2004. Randomization of the samplings was performed in the same way employed in the collection of infauna samples. Five replicates were taken along the transect lines at the five sampling locations; Sea Tiger port, Sea Tiger starboard, YO257 port, YO257 starboard, and 100' hole. Sample processing was carried out using a wet sieve gravimetric procedure (McCarthy, 1996), and sediment fractions were removed to a nested sieve series (2.0 mm, 1.0 mm, 500  $\mu$ m, 250  $\mu$ m, 125  $\mu$ m and 63  $\mu$ m) by gently poring water through the sieves. The finest silt fraction (11  $\mu$ m) was removed by

filtering a set volume of the collected slurry. All fractions were oven dried at 80°C for a minimum of 24 hours before weighing.

Grain sizes were presented as phi ( $\Phi$ ) sizes, where  $\Phi = -\log_2$  [mean diameter in mm]. Each sample was characterized by seven grain size fractions; rubble ( $\leq -1\Phi$ ), sands ( $0\Phi, 1\Phi, 2\Phi, 3\Phi, 4\Phi$ ) and silt. The percent rubble fraction was calculated by dividing the rubble fraction by the sum of all seven fractions for each sample. The percent rubble fraction and the remaining six fractions were profiled as separate graphs with 95% confidence interval for each study site. Statistical analysis of the percent rubble fraction data was performed using one-way analysis of variance (ANOVA) followed by Tukey multiple comparisons with family error rate  $\alpha = 0.05$ . The data was log transformed prior to the analysis to meet the ANOVA assumptions of normality and equality of variances.

### 3. Results

#### 3.1 Infauna analyses

An average of 119 invertebrates (SE = 33.2) were found in the six sediment samples from the port side of the Sea Tiger artificial reef, 143 invertebrates (SE = 25.4) from the starboard side, 49 invertebrates (SE = 5.7) from the port side of the YO257 artificial reef, 45 invertebrates (SE = 6.8) from the starboard side, and 115 invertebrates (SE = 33.7) from the 100' hole natural reef (Table 1). The four taxa, polychaeta, nematoda, crustacea and oligochaeta, explained more than 85% of all infaunal organisms at the Sea Tiger artificial reef, more than 75% at the YO257 artificial reef, and in excess of 90% at the 100' hole natural reef (Table 1, Fig. 2). These four taxa were identified as major components of infaunal communities at the three study sites. The non-parametric Kruskal-Wallis tests

showed that abundances of the total infauna ( $p = 0.001$ ), nematodes ( $p < 0.0005$ ), oligochaetes ( $p = 0.002$ ) and polychaetes ( $p < 0.0005$ ) were significantly different among study sites. The following pairwise testing showed that YO257 had significantly lower abundances of total infauna, nematodes and polychaetes than the other two sites. Oligochaete abundances were also significantly lower at YO257 than at Sea Tiger. Despite the low infauna abundance at YO257, abundances of crustaceans were not significantly different among the three study sites ( $p = 0.859$ ). This means a relatively high percent abundance of crustaceans at YO257.

Polychaetes were, overall, the most abundant taxonomic group at all three sites with an exception at the 100' hole natural reef (Fig. 2). This exception at the 100' hole was due to one replicate with an extremely high nematode abundance (235 individuals). Excluding this replicate lowered the mean nematode abundance at the site to 11.8 (SE = 2.1), making polychaetes the most abundant taxonomic group. Polychaete species richness ( $S$ ) and Shannon-Wiener diversity index ( $H'$ ) were computed (Table 2), and the results of ANOVA showed that  $S$  ( $p < 0.0005$ ) and  $H'$  ( $p = 0.035$ ) were significantly different among the three study sites. The following Tukey multiple comparisons showed that  $S$  was significantly lower at the YO257 artificial reef than at the other two sites, and  $H'$  was significantly lower at the YO257 artificial reef compared to the Sea Tiger artificial reef.

Multi-dimensional scaling of polychaetes data showed a grouping of polychaete species composition at the Sea Tiger artificial reef, but not at the YO257 artificial reef and the 100' hole natural reef (Fig. 3). The result of ANOSIM confirmed this pattern (global test,  $p = 0.001$ ) with pairwise tests showing that Sea Tiger had a significantly different polychaete species assemblage compared to those at YO257 ( $p = 0.001$ ) and 100' hole ( $p =$

0.002). Polychaete species assemblage at YO257 and 100' hole did not differ significantly ( $p = 0.501$ ). When polychaete species compositions at starboard and port sides of the two artificial reefs were analyzed separately, there were no significant differences in polychaete species composition within each artificial reef site (the starboard and the port sides of YO257 and Sea Tiger with  $p = 0.470$  and  $p = 0.768$  respectively). Polychaete species composition at Sea Tiger was affected by the presence of *H. decipiens* ( $p = 0.015$ ). A comparison between polychaete assemblages at Sea Tiger without *H. decipiens* and at YO257 did not show significant differences in species composition ( $p = 0.461$ ), while other pairwise comparisons showed significant differences in polychaete assemblages between Sea Tiger and the other two sites regardless of the presence/absence of *H. decipiens*.

The result of SIMPER showed that the average within-site similarity was lowest at the YO257 artificial reef (27.44%), while the Sea Tiger artificial reef and the 100' hole natural reef both had the average similarity around 45% (Table 3). *Pionosyllis heterocirrata* (Family Syllidae) showed high contributions to within-site similarities at all three study sites (Table 3). *Myriochele oculata* (Family Oweniidae) and *Euchone* sp. (Family Sabellidae) showed high contributions at Sea Tiger (Table 3) and were identified as contributors to the dissimilarities in polychaete species compositions between Sea Tiger and the other two sites (Table 4). *Euchone* sp. was the most dominant polychaete representing approximately 35% of all polychaetes found inside the seagrass *Halophila decipiens* patches at Sea Tiger, while it comprised less than 5% of all polychaetes in the replicates taken outside the seagrass patches. The YO257 artificial reef had relatively low

values of  $\bar{S}_i/SD(S_i)$  for all top three contributors compared to the other two study sites (Table 3).

The similarity dendrogram constructed using polychaete species data from this study and existing data from Mamala Bay (Swartz et al., 2004) showed a similar result (Fig. 4). The polychaete species compositions at the three study sites were separated into two main groups and 3 smaller groups; Group ST mostly consisting of samples from the Sea Tiger artificial reef, Group H-Y consisting of samples from the 100' hole natural reef and the YO257 artificial reefs, and groups Y-1, Y-2 and Y-3 mainly consisting of samples from the YO257 artificial reef. Other samples were separated into seven groups at 30% similarity level; Group A through Group G. Top three polychaete species that contributed to within-group similarities of Group H-Y and Group ST mostly matched the three species that typified 100' hole and Sea Tiger respectively. Top two species that typified YO257 showed high contribution to within-group similarity of Group Y-3. *P. heterocirrata* showed high contribution to within-group similarities of all groups except Group Y-1 and Group Y-2.

The result of BIOENV showed patterns of dissimilarities in environmental and biotic variables had the highest correlation when depths and percentage of sand fractions ( $1\Phi$ ,  $2\Phi$  and  $3\Phi$ ) were considered ( $\rho_s = 0.450$ ). Depths showed the highest correlation with the biotic pattern ( $\rho_s = 0.356$ ) as a single environmental variable, and then, percentages of fine sand  $3\Phi$  (mean diameter of  $125 \mu\text{m}$ ;  $\rho_s = 0.275$ ). MDS of polychaete abundance with superimposed circles representing values of these environmental variables visually showed relationships between polychaete species compositions and the two environmental



variables, depth and percentage of  $3\Phi$  fraction (Fig. 5). Although association between depths and percentages of fine sand was somewhat suspected from the plots (higher percentage of fine sand at shallower depth), these two environmental variables did not show a strong correlation ( $R^2 = 0.024$ ).

### 3.2 Granulometry

The mean percent rubble fraction was highest at the YO257 artificial reef, then the 100' hole natural reef and the Sea Tiger artificial reef (Fig. 6). The result of ANOVA suggested that mean percent rubble fractions were statistically different among study sites ( $p < 0.0005$ ), and the following Tukey multiple comparisons showed that the port (seaward) side of YO257 had a significantly higher percentage of rubble fraction compared to any other sites. The starboard (shoreward) side of YO257 also had a significantly higher percentage of rubble fraction than the starboard side of Sea Tiger. The rubble fraction from YO257 contained a large amount of gravel. There was no significant difference in the percentages of rubble at Sea Tiger and 100' hole. The analysis of the remaining fractions excluding rubble showed that 100' hole contained, on average, approximately 80% of sediments with grain size below  $1\Phi$  (larger than 0.5 mm), while Sea Tiger and YO257 had approximately 50% (Fig. 7). These results revealed grain size composition of relatively coarse sediments at 100' hole, medium to fine sediments at Sea Tiger, and medium to fine sediments with a large amount of gravel at YO257.

## 4. Discussion

Infauna communities around the two artificial reefs, Sea Tiger and YO257, and the natural reef, 100' hole, were mainly dominated by polychaetes. Other dominant taxonomic groups found at the three sites were nematodes, oligochaetes, and crustaceans. Although the YO257 artificial reef had a lower abundance of infaunal organisms, the taxonomic compositions at the three study sites did not differ greatly. Nematodes were equally abundant at the 100' hole natural reef and the Sea Tiger artificial reef, but less abundant YO257. Abundances of nematodes generally have a positive association with levels of organics in their habitat (Raffaelli and Mason, 1981; Sandulli et al., 2004), but they are also associated with fine sediments that facilitate burrowing (Wenner, 1988; McCarthy et al., 1998). Similar abundances of nematodes at 100' hole and Sea Tiger suggest that the deployment of Sea Tiger had no more effect, in terms of organic levels, on the surrounding environment than a natural patch reef would. The low abundance of nematodes at YO257 may be due to the large amount of gravel in the sediments (Fig. 6).

Polychaete abundance and species richness were significantly lower at the YO257 artificial reef than the other two study sites, while crustacean percent abundance was relatively higher. A previous study comparing a carbonate rubble habitat with adjacent soft sediments in Mamala Bay showed that the rubble habitat supported higher densities, taxonomic richness and benthic biomass of polychaetes and crustaceans (McCarthy et al., 1998). YO257 had a higher percent rubble fraction in the sediments compared with the other two sites, but lower polychaete abundance and species richness at this artificial reef contradicted the finding by McCarthy et al. (1998). This may be because the rubble fractions at YO257 mostly contained basalt gravel that was used in the deployment operation, and therefore, they were not calcium carbonate fragments of corals. Coral

1 rubbles increase pore space and present higher structural complexity and habitat for borers,  
 2 and therefore they support a variety of epifaunal organisms as well as diverse endolithic  
 3 cryptofauna (McCarthy et al., 1998). While the basalt gravel at the YO257 artificial reef  
 4 did not contain any endolithic boring organisms, such as polychaetes, it still provided a  
 5 suitable habitat for epifaunal crustaceans, resulting in their relatively high percent  
 6 abundance at the site.

7 Consideration of polychaete species composition through multivariate analysis  
 8 suggested that the Sea Tiger artificial reef and the 100' hole natural reef had different  
 9 polychaete communities. MDS of polychaete abundance (Fig. 3) and ANOSIM showed a  
 10 separation of polychaete species composition at Sea Tiger from those at the other two sites.  
 11 Although the presence of the seagrass *H. decipiens* affected the polychaete species  
 12 composition at Sea Tiger, SIMPER showed that this site still had a relatively high within-  
 13 site similarity in the species composition. The similarity dendrogram (Fig. 4) also  
 14 separated samples from Sea Tiger (Group ST) from those from 100' hole and YO257  
 15 (Group H-Y). The high similarity and strong grouping of polychaete assemblage at Sea  
 16 Tiger was mostly due to the presence of *Myriocela oculata* in consistently high abundance.

17 *Euchone* sp. also showed a high contribution to the within-site similarity at the Sea  
 18 Tiger artificial reef, but the lower value of  $\bar{S}_i/SD(S_i)$  indicated a high variability in their  
 19 abundance. This is because *Euchone* sp. was highly abundant inside the *Halophila*  
 20 *decipiens* patches, but absent or sparse outside the patches. Seagrass vegetation plays an  
 21 important role in marine soft bottom ecosystems by increasing habitat complexity and  
 22 affects distribution of infaunal polychaetes (Brito et al., 2005; Omena and Creed, 2004).

Influence of *H. decipiens* on the polychaete assemblage at Sea Tiger was also evidenced when ANOSIM was performed treating samples inside and outside the seagrass patches separately. Comparisons between polychaete assemblages at Sea Tiger and YO257 resulted in a significant difference when Sea Tiger samples were all combined, but not when only those taken outside the seagrass patches were used. Nevertheless, the similarity dendrogram (Fig. 4) did not show a separation between the samples inside and outside of the patches at Sea Tiger owing the persistent presence of *M. oculata*.

Co-existence of *M. oculata* and *Euchone* sp. at the Sea Tiger artificial reef (especially inside the seagrass patches) is somewhat contradictory. *Myriochele oculata* is a tubicolous, surface-feeding detritivore and has been characterized as a possible early indicator of organic enrichment in Hawaii (Davis, 1987). It was one of the most characteristic polychaetes in sands underneath a fish culture operation in Mamala Bay and likely to be tolerant to attrition from anoxia (Lee et al., 2006). *Euchone* sp. is a small tubicolous suspension feeder that is abundant away from the influence of sewage outfalls and the fish cages in Mamala Bay, and is a negative indicator of organic enrichment (Bailey-Brock et al., 2001; Bailey-Brock et al., 2002; Lee et al., 2006). These species, therefore, inversely respond to organic enrichment, and the co-existence suggests that factors other than organic levels may control their abundances at the site.

Polychaete species that showed high contribution to within-site similarities and between-sites dissimilarities have been commonly found in Mamala Bay (Swartz et al., 2004). *Pionosyllis heterocirrata* was the most dominant polychaete species at the three study sites as well as almost all stations of the biannual monitoring (Fig. 4). This species is robust and active, and it is possibly the most commonly encountered species in biogenic

sands around the island of Oahu (Bailey-Brock et al., 2001; Bailey-Brock et al., 2002).  
Absence of *P. heterocirrata* in a few samples from the YO257 artificial reef contributed to  
relatively low within-site similarity in polychaete composition at the site.

The similarity dendrogram (Fig. 4) suggested that Mamala Bay exhibited diverse  
polychaete communities, and the result of BIOENV showed that environmental variables  
(depth and grain size) could affect patterns in polychaete species composition. This  
suggests a difficulty to study effects of artificial reefs by comparing infaunal data from the  
artificial reefs and a natural reef because different locations have different environmental  
parameters. While such comparisons have been suggested as an alternative way in case  
pre-deployment data did not exist (Carr and Hixon, 1997), effects of artificial reefs are  
better examined with a comparison between pre- and post-deployment data (Wilding and  
Sayer, 2002). Comparisons between pre- and post-deployment data were not possible for  
this study due to a lack of pre-deployment data specific to the two artificial reef sites.

Deployments of artificial reefs have the potential to biologically and/or physically  
change surrounding natural sand bottom communities (Davis et al., 1982, Ambrose &  
Anderson, 1990). Biological and physical factors and how these factors affect the  
surrounding benthic community are likely to differ at each artificial reef. Fabi et al. (2002)  
examined biological and physical factors and concluded that the composition and  
abundance of an infaunal community appeared to be more affected by physical factors,  
such as bottom current and variations in the sediment grain size distribution, than biological  
factors, such as predation. On the other hand, Bortone et al. (1998) suggested the potential  
of artificial reef fish assemblages to alter trophic structures of nearby fauna through  
increased predation and emphasized importance of the biological factor in management of

artificial reefs. Exact physical and biological changes caused by deployment of the two artificial reefs in Mamala Bay cannot be elucidated without pre-deployment data. Nevertheless, further studies should consider biological and physical factors to determine what biological and/or physical factors may structure the infaunal communities around the two artificial reefs in Mamala Bay. Changes in the physical and biological parameters and infaunal community structure along a gradient away from these reefs should be examined, because such studies may lead to an inference of whether the deployment of the two artificial reefs in Mamala Bay actually altered those parameters of the surrounding environments.

## 5. Conclusion

This research showed the infaunal communities around the two artificial reefs were predominantly represented by polychaetes, nematodes, crustaceans and oligochaetes. The YO257 artificial reef in general had a less abundant total infauna, fewer nematodes and polychaetes compared to the Sea Tiger artificial reef and the 100' hole natural reef possibly due to the gravel spilled during deployment. Similarity and dissimilarity of polychaete species composition were affected by the variation in sediment grain sizes and depths, and polychaete assemblages were more variable at YO257 in comparison to those at Sea Tiger or 100' hole. Nevertheless, comparisons of polychaete data with those from various natural habitats suggested that polychaete assemblages around the two artificial were typical and within the range of natural variation in Mamala Bay. These findings strongly suggest that the beneficial uses of the two artificial reefs would not have negative impact on the surrounding environment beyond the level of natural variation.

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# Tables

Table 1: The mean abundances of total infauna and dominant taxonomic groups in six replicate samples at each sampling site. Each cell shows the mean abundance and the standard error of the mean in parentheses.

	Sea Tiger Port	Sea Tiger Starboard	YO257 Port	YO257 Starboard	100' Hole
Total infauna	119.3 (33.2)	143.2 (25.4)	48.5 (5.7)	45.0 (6.8)	114.5 (33.7)
Polychaeta	62.3 (20.2)	67.5 (13.6)	21.7 (5.0)	13.3 (2.0)	45.5 (11.0)
Crustacea	7.7 (1.9)	12.7 (2.5)	9.2 (4.1)	11.3 (2.7)	8.3 (1.8)
Nematoda	24.0 (6.9)	33.2 (8.4)	3.5 (0.8)	3.2 (1.1)	49.0 (37.2)
Oligochaeta	9.5 (1.5)	19.3 (1.9)	6.0 (1.4)	6.3 (2.8)	4.3 (1.3)

Table 2: The mean polychaete species richness (S) and Shannon-Wiener diversity index (H') in six replicate samples at each sampling site. The standard error of the mean is shown in parentheses.

	Sea Tiger Port	Sea Tiger Starboard	YO257 Port	YO257 Starboard	100' Hole
S	15.33 (1.52)	16.67 (1.60)	8.17 (1.40)	8.33 (1.05)	13.33 (1.02)
H'	2.128 (0.10)	2.152 (0.07)	1.627 (0.13)	1.885 (0.14)	1.887 (0.22)

Table 3: The top three polychaete species that typify each study site based on SIMPER on Bray-Curtis similarity (non-standardized and forth root transformed data). The top row shows the average polychaete species similarity within each site. The bottom row shows lists of polychaete family with high contribution to the similarity within each site. The percent contribution ( $\bar{S}_i$ ) and the ratio of the average similarity to the standard deviation of similarities ( $\bar{S}_i/SD(S_i)$ ) for each species are shown in parentheses.

	YO257	Sea Tiger	100' hole
Average similarity	27.44%	46.68%	44.36%
Polychaete species ( $\bar{S}_i, \bar{S}_i/SD(S_i)$ )	<i>Pionosyllis heterocirrata</i> (25.99%, 1.00)  <i>Prionospio cirrifera</i> (21.62%, 1.05)  <i>Micropodarke</i> sp. (9.76%, 0.52)	<i>Pionosyllis heterocirrata</i> (19.59%, 5.74)  <i>Myriochele oculata</i> (13.71%, 2.06)  <i>Euchone</i> sp. (9.13%, 1.30)	<i>Pionosyllis heterocirrata</i> (23.06%, 5.01)  <i>Micropodarke</i> sp. (17.12 %, 10.55)  <i>Pisione</i> sp. (16.72%, 4.31)

Table 4: Top two polychaete species that highly contribute to dissimilarities in polychaete composition between study sites. The species were identified based on SIMPER on Bray-Curtis dissimilarity (standardized and forth root transformed data). Each cell shows the average polychaete species dissimilarities between study sites and the lists of polychaete species with high contribution to the dissimilarities. The percent contribution ( $\bar{\delta}_i$ ) and the ratio of the average dissimilarity to the standard deviation of dissimilarities ( $\bar{\delta}_i/SD(\delta_i)$ ) for each species are shown in parentheses.

	YO257	Sea Tiger	100' hole
YO257		<p>70.87%</p> <p><i>Euchone</i> sp. (6.69%, 1.75)</p> <p><i>Myriochele oculata</i> (5.72%, 1.60)</p>	<p>68.58%</p> <p><i>Pionosyllis heterocirrata</i> (5.82%, 1.13)</p> <p><i>Pisione</i> sp. (5.28%, 1.46)</p>
Sea Tiger	<p>Average dissimilarity</p> <p>Polychaete species (<math>\bar{\delta}_i, \bar{\delta}_i/SD(\delta_i)</math>)</p>		<p>65.64%</p> <p><i>Euchone</i> sp. (5.95%, 1.70)</p> <p><i>Myriochele oculata</i> (4.84%, 1.53)</p>

## Figures

Fig. 1. A map of the study area showing the Sea Tiger artificial reef, YO257 artificial reef, and 100' hole natural reef, as well as 40 sampling sites, station 31 through station 70, from the biannual monitoring (Swartz et al. 2004) conducted by the City and County of Honolulu. The GPS coordinates of the biannual monitoring stations were provided by the City and County of Honolulu Oceanographic team.

Fig. 2. The mean abundances of major taxonomic groups at each study site. The group “others” includes Mollusca, Echinodermata, Nemertea, Chaetognatha, Chordata, Kinorhyncha, Phoronida, Platyhelminthes, Priapulida, and Sipuncula. The error bars show the standard errors of the mean.

Fig. 3. MDS of polychaete abundance data from the three study sites using Bray-Curtis similarities calculated on fourth root transformed polychaete species abundance data. The five sampling sites are indicated by different symbols (stress = 0.21). At the Sea Tiger artificial reef, the replicates 1, 2 and 3 were taken outside the seagrass *Halophila decipiens* patches, and the replicates 4, 5 and 6 inside the patches.

Fig. 4. Similarity dendrogram for hierarchical clustering of the 70 sites, using group-average linking of Bray-Curtis similarities calculated on fourth root transformed data. The numbers 31 through 70 are the 40 samples from the biannual monitoring in Mamala Bay. “STP” is the port side of Sea Tiger, “STS” the starboard side of Sea Tiger, “YOP” the port side of YO257, “YOS” the starboard side of YO257, and “HOLE” the 100' hole natural reef. The top three polychaete species that typify each group are shown on the bottom. The percent contribution ( $S_i$ ) and the ratio of the average similarity to the standard deviation of similarities ( $\bar{S}_i/SD(S_i)$ ) for each species are shown in parentheses.

Fig. 5. MDS of polychaete abundance data from the 69 sites using Bray-Curtis similarities calculated on fourth root transformed polychaete species abundance data with superimposed circles representing (a) depths and (b) percentages of 3 $\Phi$  fraction (mean diameter of 125  $\mu$ m). Larger circles represent (a) deeper depths and (b) higher percentages of 3 $\Phi$  fraction. Labels are consistent with the grouping shown in Figure 6.

Fig. 6. Mean percentage of the rubble fraction by weight at each study site. The bars are showing 95% confidence interval.

Fig. 7. Mean cumulative percentages (retained) of all fractions by weight excluding rubbles at each study site. The bars are showing 95% confidence interval.



Fig.1

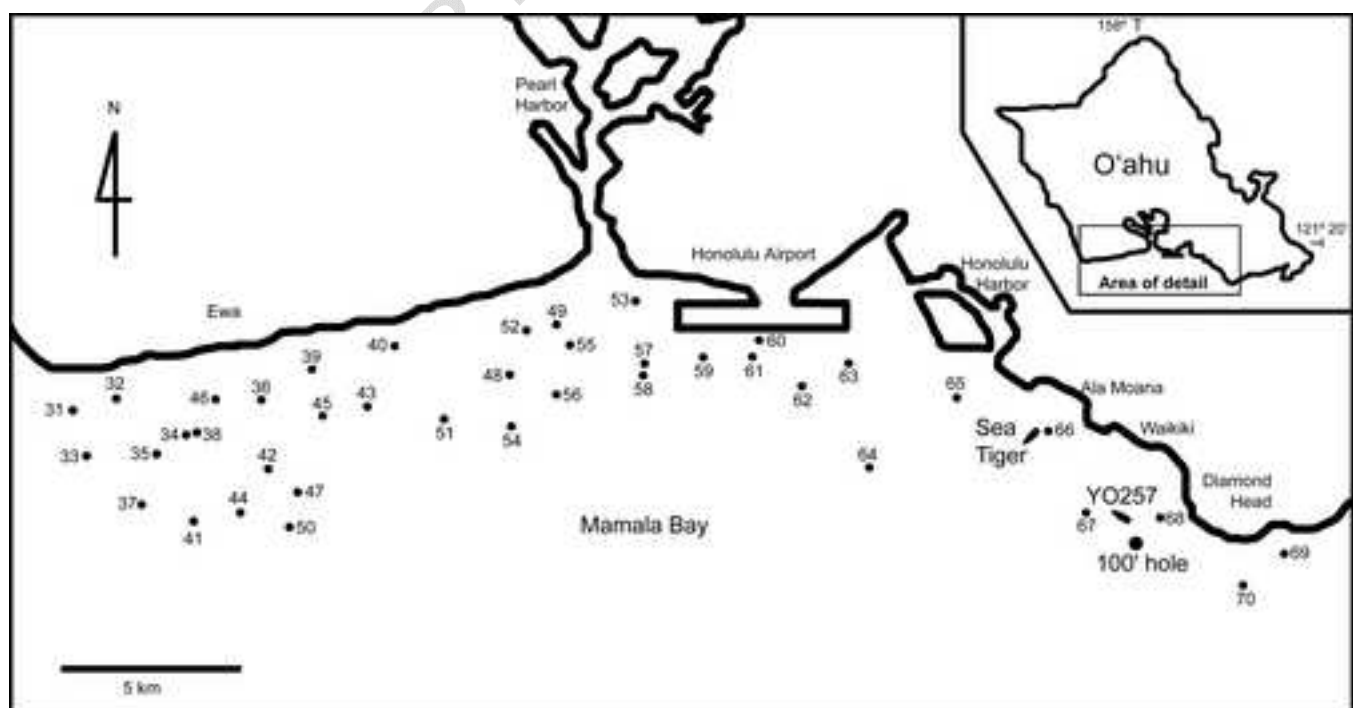


Fig.2

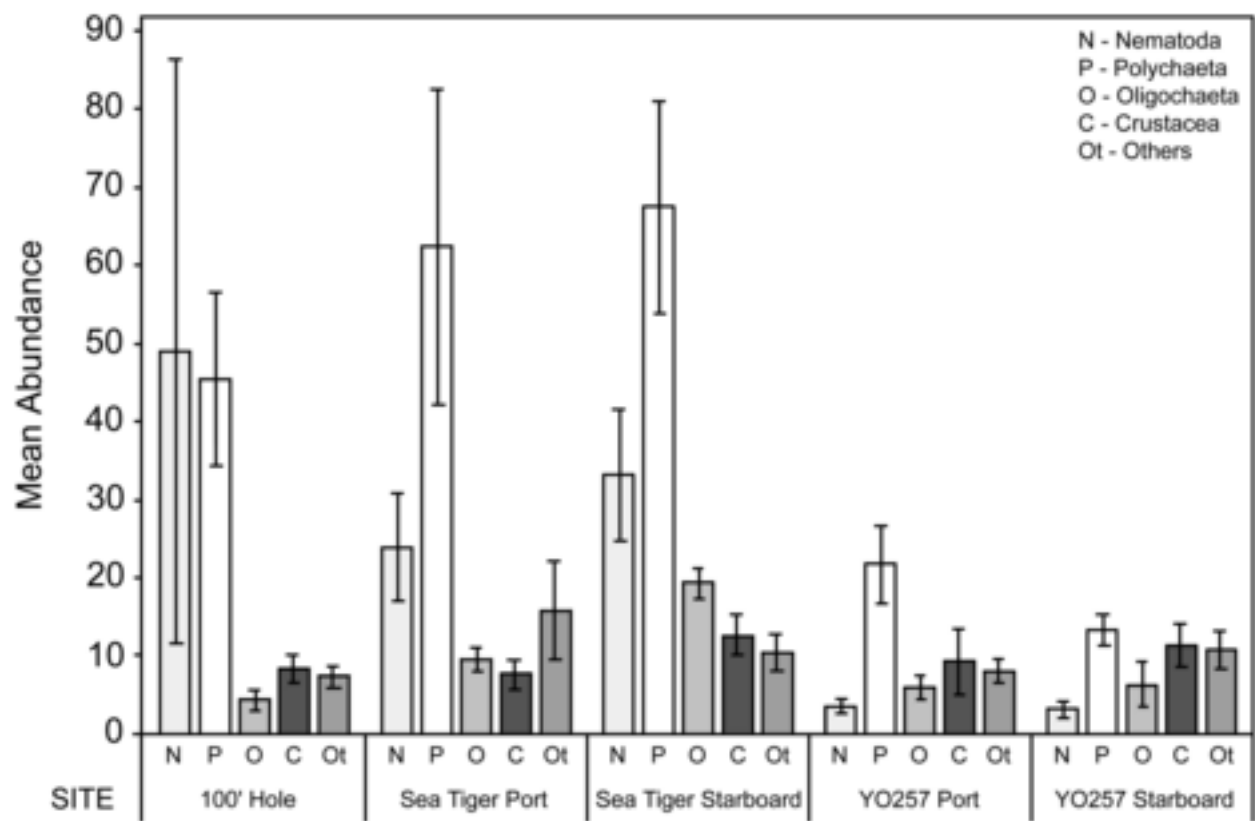
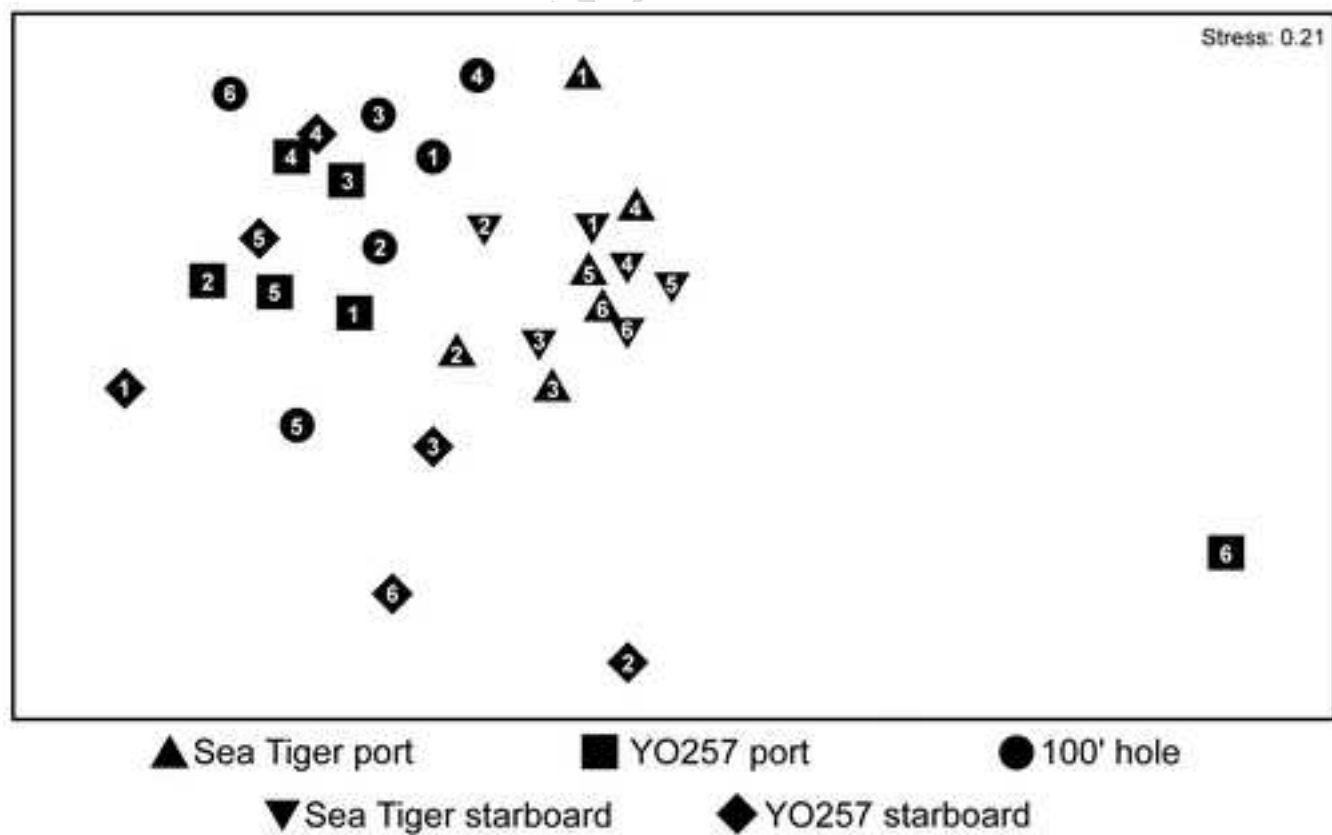


Fig.3



ACCEPTED MANUSCRIPT

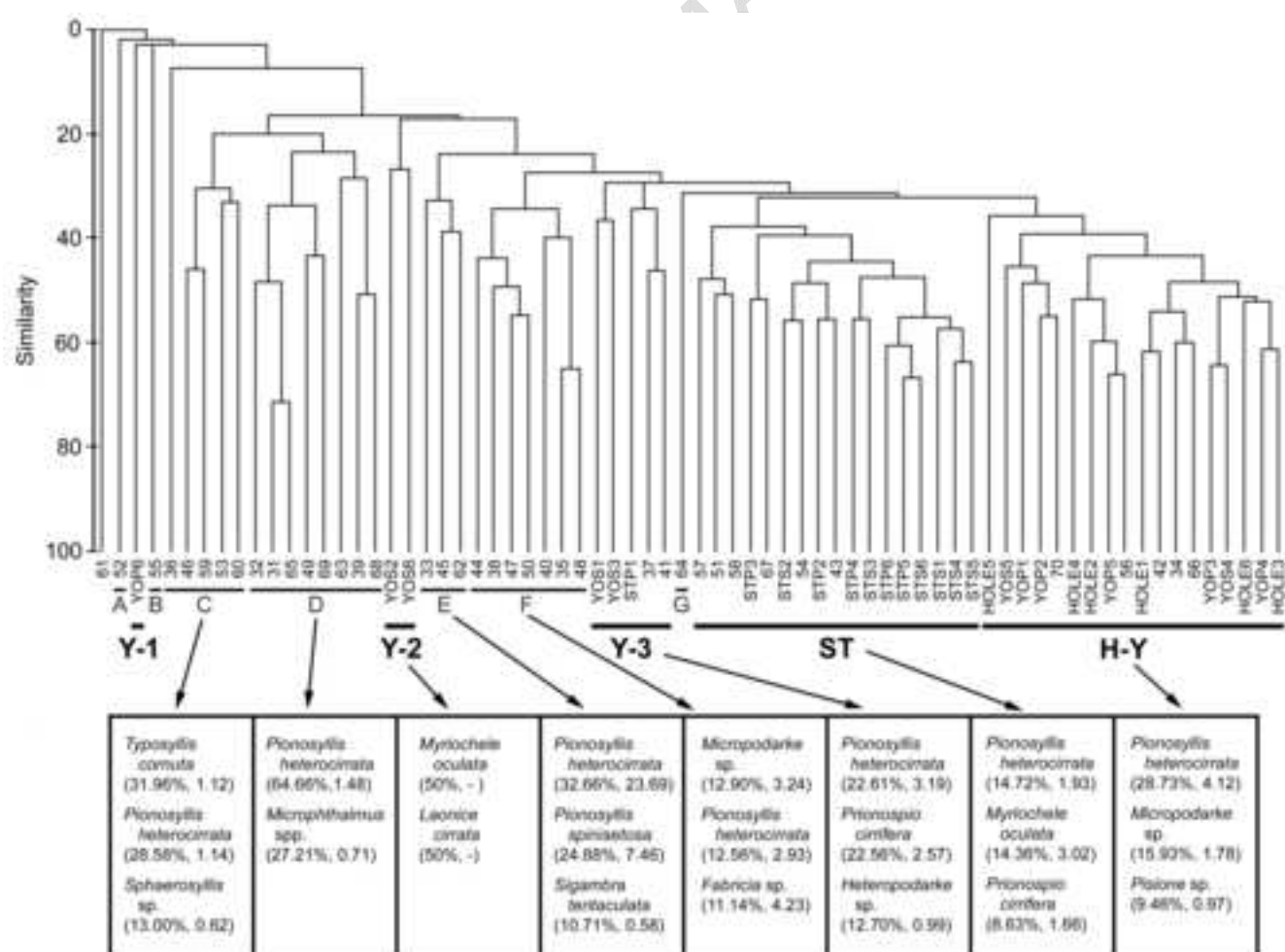


Fig.5

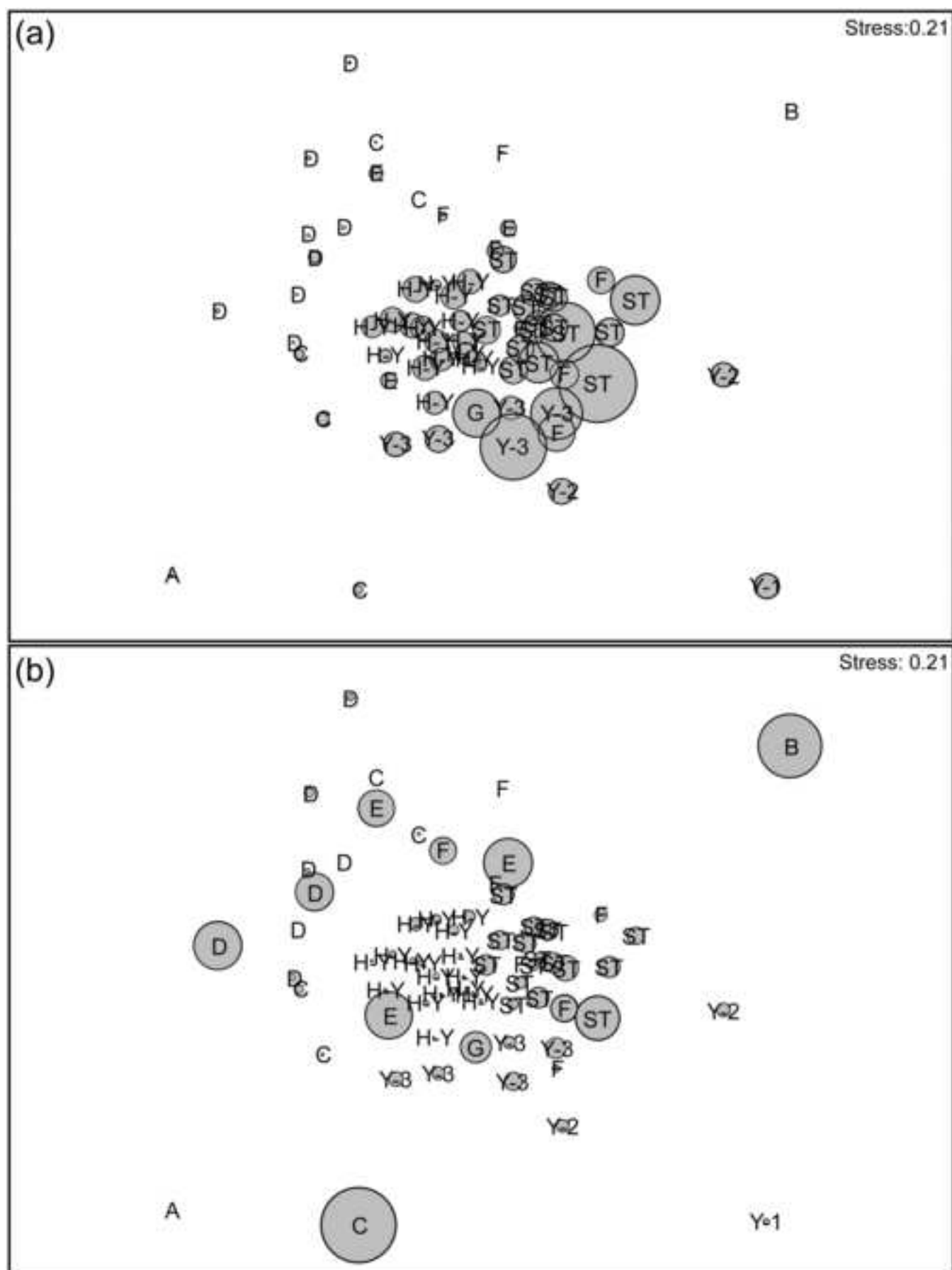


Fig.6

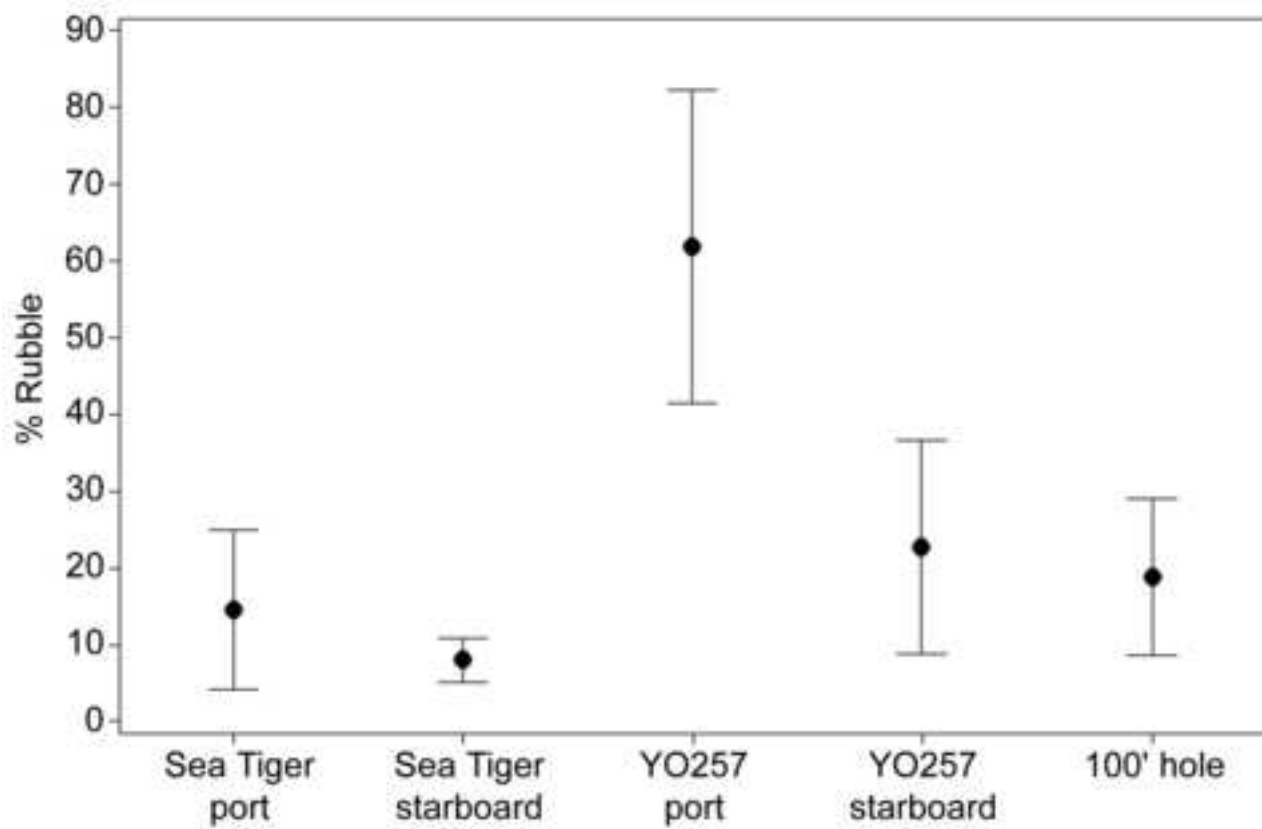


Fig.7

