MARINE BIOLOGICAL SURVEY OF INNER APRA HARBOR, GUAM

by

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Review Draft

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Finally, we are especially grateful for the guidance provided by Dr. Mark Moese of Earth Tech, Inc. for acting as our liaison and project coordinator. His guidance and patience made the project possible.

INTRODUCTION

Inner Apra Harbor is a natural embayment formed by tectonic activity along the Cabras Fault, separating the volcanic Tenjo Block in central Guam from the limestone Orote Block immediately to the west (see Tracey et al., 1964 for structural details). Rotation of the Orote Block resulted in subsidence of the eastern portion of the block adjacent to the Cabras Fault line. Accompanying rotation, the sea flooded into the slumped areas, forming Apra Harbor, a deep-water lagoon bounded on the north by Cabras Island and the long, curving Glass Breakwater. Two rivers—the Apalacha and Atantano—drain the volcanic mountain land to the east of Apra Harbor and empty into the inner harbor (Randall and Holloman, 1974).

Although naturally formed, Inner Apra Harbor has been extensively modified by dredging, construction, and landfills by the U.S. Navy since 1945 (Paulay et al., 2001a). The inner harbor was dredged, changing the southernmost part of the original lagoon from a reef-choked, silty embayment into a harbor with a nearly uniform depth and mud bottom. Fill projects created the Dry Dock Peninsula, Polaris Point, and manmade shorelines along the northeastern and southeastern boundaries of the harbor. These and other developments in the outer harbor (e.g., construction of Glass Breakwater) reduced water exchange between the harbor and the Philippine Sea, creating a gradient of increasing turbidity, abundance of plankton and benthic suspension feeders, and finer sediments from the entrance to the outer harbor to the inner harbor environment. The only portion of the inner harbor remaining unchanged is the mangrove area at the mouth of the Atantano River.

Randall and Holloman (1974) reported living *Pocillopora* and *Porites* corals on the wharf and dock structures in the inner harbor. Paulay et al. (2001a) found that artificial surfaces in the inner harbor supported diverse fouling communities, including both indigenous and introduced species. They noted the presence of *Porites convexa*, known in Guam from only a few locations. They also remarked about the abundance of the hammer oyster *Malleus decurtatus* on wharf faces in Inner Apra Harbor.

Relocation of elements of the Marine Expeditionary Force (MEF) from Okinawa to Guam by the Marine Corps will require renovation of existing port facilities to accommodate MEF embarkation, as well as construction of various new operations facilities in support of the MEF mission. Furthermore, new training areas and associated facilities are proposed for selected areas on Guam. These developments require extensive surveys that locate, identify, and assesses the natural resources of Guam.

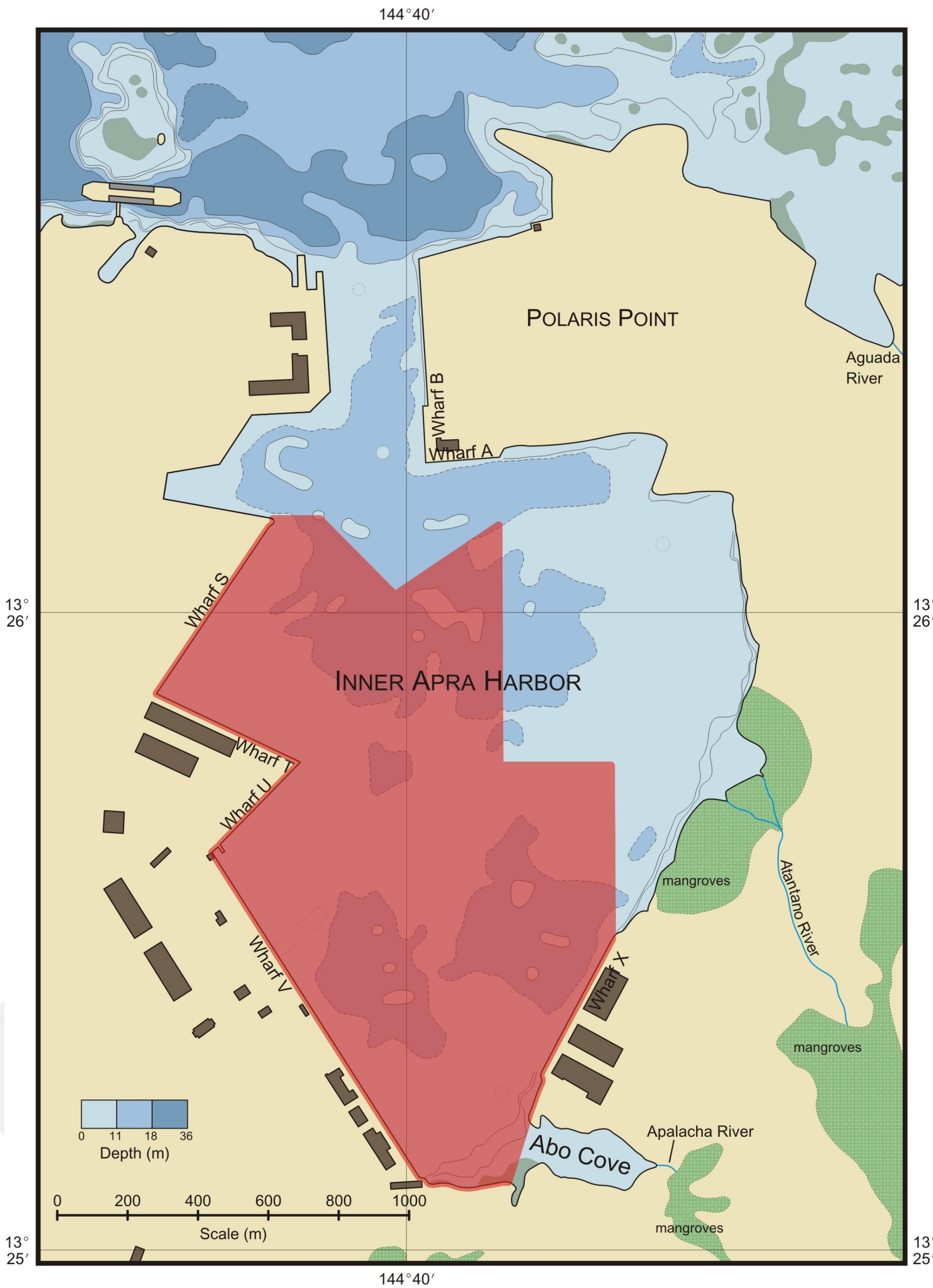

Figure 1. Map of Inner Apra Harbor showing geographic locations and the general survey area (shaded orange).

Scope of Work

The University of Guam Marine Laboratory was contracted to perform a study of marine communities in the southwestern half of Inner Apra Harbor (Figure 1) . The specific objectives of the study were:

- Quantitative assessments of corals
- Quantitative assessment of select macroinvertebrates
- Fish census
- Assessment of essential fish habitat
- Assessment of endangered species (both federally listed, proposed for listing, and candidate species and those similarly listed or otherwise recognized by Guam) to include abundance and preferred habitat, if any
- Survey areas will be subjectively evaluated using the four criteria for Habitat Areas of Particular Concern (HAPC): 1. the ecological function provided by the habitat is significant; 2. the habitat is sensitive to human-induced environmental degradation; 3. development activities are, or will be, stressing the habitat type; and 4. the habitat is rare

Data from the survey are expected to serve as a guide for decisions affecting land and coastal use for proposed construction and renovation of facilities and training sites on Department of Defense lands in Guam.

METHODS

Sampling Site Selection

The general ecological condition of an approximately 145 ha area (Figure 2) was assessed by a modified manta tow method. Two observers were towed behind a boat piloted along the 6,188-m boundary of the study area. Visibility was limited to less than 5 m because of high turbidity of the water. The locations and general surface coverage of corals were noted by the observers. Based upon these observations, three sites (Abo Cove, Transect 1, and Transect 2) were selected for benthic surveys, and five sites (Wharves S, T, U, V, and X) were selected for surveys of vertical wharf faces (Figure 2). A 100-m transect line was established along the 2-m isobath at Abo Cove. For Transects 1 and 2, in open areas of the harbor floor away from wharves or the shoreline, a GPS-tracking unit in a waterproof housing was towed by a diver swimming along the harbor floor. Lengths of the tracks were calculated with SigmaScan Pro 5.0 (SPSS, Inc., 1999). At Wharves S, V, and X, 100-m transects were established. At Wharves T and U, 50-m transects were established, because access to larger wharf areas was not granted. GPS coordinates were recorded for the ends of all transects.

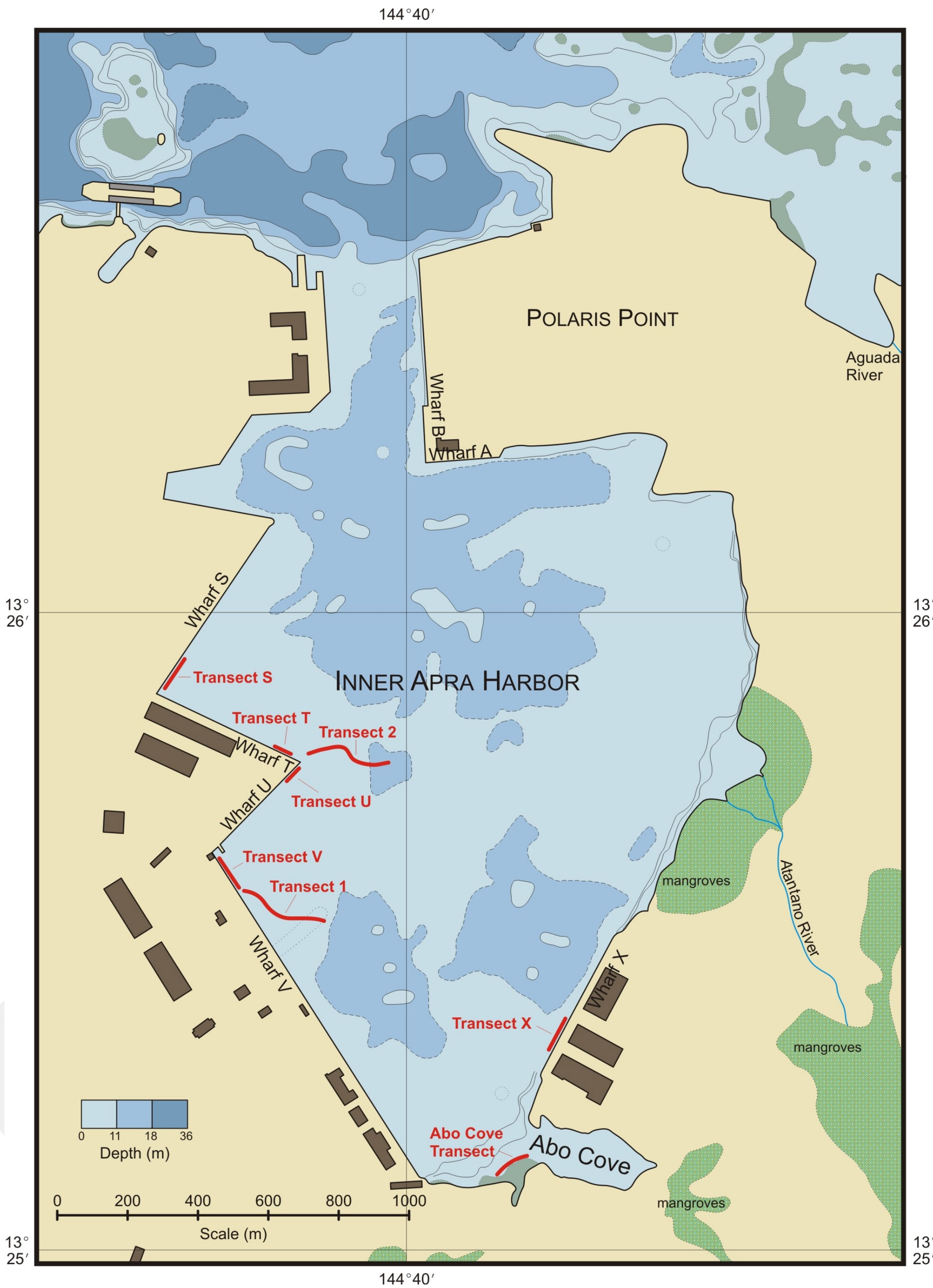

Figure 2. Map of Inner Apra Harbor showing locations of transects surveyed in this study.

Benthic Cover

Benthic quadrats were surveyed along transects established for coral, invertebrate, and fish surveys. Fifty-meter transects were installed at a fixed depth (3–5 m) at six sites throughout the inner harbor (Figure 2). Per transect, the percentage cover of algae, corals, and sponges in five 0.25-m^2 quadrats was quantified in situ, and the data were entered into a relational database (MS Access). The limited visibility in the inner harbor precluded documentation of benthic flora and fauna with photoquadrat records, but macro photographs of the representative species were taken. Voucher specimens of algae were collected to establish a reference collection of algae from Inner Apra Harbor. Explorative data analysis was performed through analysis of variance and non-metric multidimensional scaling. In situ cover estimates of turf algae were also troubled by poor visibility and, therefore, removed from the data set prior to analysis.

Corals

Coral communities were assessed quantitatively along the transects by an observer by the point-quarter method of Cottam et al. (1953). Points were assigned 3–10 m apart on each transect. Each point served as a focus of four equal-sized quadrants arrayed around the point. Within each quadrant, the coral closest to the central point was located. This coral's identity, distance from the point, length, and width were recorded. If no corals lay within 1 m of the point, that quadrant was recorded as having no corals. From the recorded data, community and species-specific population density of colonies, percent coverage, and frequency of occurrence were then computed with the following equations from Cottam et al. (1953):

Total Density Of All Colonies = Unit Area / (Average Point-To-Colony Distance)^2
Relative Density Of A Species = 100 * Number Of Colonies Of The Species / Number Of All Colonies
Absolute Density Of A Species = Percent Density * Total Density / 100
Total Percent Coverage Of All Species = Total Density * Average Coverage Of All Species
Relative Coverage Of A Species = Species Density * Average Coverage of the Species

Population data for each species were also calculated, including the number of colonies, average colony size, standard deviation of colony size, and minimum and maximum colony size. To record the less common species not recorded by the quantitative survey, a list of species was also assembled by swimming along the entire transects and recording all species seen within 2 m of the line. Species names followed Veron (2000).

Macroinvertebrates

All conspicuous solitary epibenthic macroinvertebrates occurring within 1 m of either side of the transect lines at Abo Cove and Wharves S, T, U, V, and X were identified and enumerated by an observer swimming along the transect line. For Transects 1 and 2, species of conspicuous epibenthic macroinvertebrates were recorded within 1 m of an imaginary line in front of an observer swimming over the harbor floor, as described above. For this study, conspicuous is defined as being larger than 50 mm in size and as being clearly visible to an observer without need of overturning rocks or digging into the substrate. Cryptic, microscopic, nocturnal, and highly motile species that avoid humans (e.g., crabs and shrimps) were not included within the scope of this study. Species diversity and abundance were recorded in 10-m intervals along the transect line. Therefore, for statistical purposes, each belt transect consisted of five to ten 20-m^2 replicate plots, except where noted.

Similarities in structure of macroinvertebrate assemblages for all transects were calculated by the Bray-Curtis similarity method, and the resulting matrix subjected to cluster analysis (group average method, fourth root-transformed data) and multidimensional scaling (MDS) analysis (fourth root-transformed data bootstrapped with n = 100 iterations) to investigate relationships between transects. Cluster and MDS analyses were performed with PRIMER v5 (Clarke and Gorley, 2001). Species of macroinvertebrates observed in the study area, but not encountered along the transect line, were also recorded but not included in the similarity analyses.

Fishes

Fishes were surveyed visually along transect lines. Observations were constrained by poor visibility and all species had to be counted on a single pass along the transect line. At Abo Cove, the line was deployed along the bottom as the diver observed and counted fishes. Along wharf faces, three transects were run (where possible), respective of depth, just below the surface (subsurface), at mid-depth (the principal transect line), and at the bottom of the wharf wall. All fishes observed 0.5m above or below the line, were counted on subsurface and mid-depth transects; at the bottom, all fishes observed 1 m to the seaward side (away from the wharf face) of the line were counted. At two stations located in open areas of the harbor away from wharves or the shoreline, GPS-tracking was used to census fishes. Here, one diver utilized a GPS unit set on timed-tracking mode and towed above him in a waterproof housing, recorded all benthic species observed within 1 m either side of an imaginary line directly in front of the diver (Colin and Donaldson, in review). Observations were recorded a during the course of the swim just above the bottom. Pelagic species could not be observed because of poor visibility. These methods provided estimates of density (no. individuals/m^2) for each species.

Fishes were identified to species. Identifications followed Myers (1999) and Myers and Donaldson (2003), except where more recent taxonomic studies were relevant. Reference photographs and video were taken with an underwater digital camera or underwater digital video camera, but image quality tended to be extremely poor because of turbid conditions.

For estimates of species diversity, standard measures of species richness, species diversity, and similarity were calculated and compared between stations with PRIMER vers. 5.2.2; DIVERSE PROCEDURE). Multidimensional scaling (PRIMER vers. 5.2.2; MDS procedure) was used to examine similarities between stations based upon Bray-Curtis coefficients calculated for each. This test indicates relative distances between samples based upon their similarities in assemblage structure. Points found close together represent samples that were very similar in species composition while those far away represented different assemblage structures (Clarke and Gorley, 2001). Analysis of Similarities (PRIMER, ver. 5.2.2;

ANOSIM procedure) was used to test the null hypothesis that there were no differences in assemblage structure between groups of samples at stations.

Essential Fish Habitat

Extremely poor visibility on transects at all stations limited the ability to collect data on essential fish habitat. Underwater photographs taken along the transect line to estimate benthic structure used by different species were essentially useless. Similarly, measures of rugosity (benthic structural complexity), limited to the edge of a shallow reef at Abo Cove, were made under near-zero visibility and were fraught with error. Therefore, it was possible only to make qualitative descriptions of habitats used by fishes.

RESULTS AND DISCUSSION

GPS coordinates for the locations of transects are reported in Table 2 and illustrated in Figure 1. No GPS data were captured for the distal ends of transects at Victor and X-ray wharves.

Table 1. GPS coordinates of transects surveyed in Inner Apra Harbor for this study.

			Start		Finish	
Study Site	Date	Length (m) (M)	Latitude (°N)	Longitude (°E)	Latitude (°N)	Longitude (°E)
Abo Cove	2008/05/29	100	13.41927	144.66937	13.41865	144.6692
Sierra Wharf	2008/05/29	100	13.25922	144.39646	13.25881	144.39616
Tango Wharf	2008/05/23	50	13.42973	144.66336	nd[1]	nd
Victor Wharf	2008/05/29	100	13.62535	144.66269	13.42627	144.66206
Uniform Wharf	2008/05/22	50	13.25687	144.39766	13.25706	144.39783
X-ray Wharf	2008/05/21	100	13.42399	144.67168	nd	nd
Transect 1	2008/05/29	260	13.42617	144.66239	13.42531	144.66441
Transect 2	2008/05/29	250	13.42946	144.66391	13.42916	144.66638

[1]No data recorded.

Benthic Cover

Table 2 shows the sampling effort of benthic surveys. The number of surveyed transects is a function of site accessibility, which was often limited by port operations and the size of the wharfs. Continued efforts to increase the number of transects at Uniform and Tango wharves were prevented as the team was denied access to the inner harbor on several occasions.

Table 2. Dates and sampling effort of benthic surveys.

Site	Date	# Transects	# Quadrats
Abo Cove	5-May-08	3	14
Sierra Wharf	21-May-08	2	10
X-ray Wharf	21-May-08	2	10
Uniform Wharf	22-May-08	1	5
Tango Wharf	23-May-08	1	5
Victor Wharf	23-May-08	2	10

Table 3 lists the 70 benthic taxa that were recorded and quantified during this study. The total number of taxa recorded is low compared to benthic surveys in other parts of the harbor. The average species richness of the quadrats is also low compared to similar studies in other parts of Guam. Figures 3 and 4 show a large difference in the total number of species and species richness between quadrats from Abo Cove and the wharf transects. The most authentic “natural” site (Abo Cove) is significantly less taxon-rich than the wharf sites (Tables 4 and 5). Turbidity and sediment deposition are most likely the most important causal factors for this difference. *Caulerpa verticillata* is a green alga that copes well with increased levels of sedimentation and reduced salinities. Exceptionally large specimens of this alga were found in Abo Cove, probably a result of relatively low herbivore pressure. The distribution of the seagrass species *Halophila japonica* also seems to be restricted to Abo Cove in the inner harbor.

Table 3. Taxonomic list of biotic categories observed in the benthic surveys.

Higher classification	Taxon
Chlorophyta - Ulvophyceae - Bryopsidales - Caulerpaceae	*Caulerpa serrulata*
Chlorophyta - Ulvophyceae - Bryopsidales - Caulerpaceae	*Caulerpa verticillata*
Chlorophyta - Ulvophyceae - Bryopsidales - Udoteaceae	*Halimeda gracilis*
Chlorophyta - Ulvophyceae - Bryopsidales - Udoteaceae	*Halimeda opuntia*
Chlorophyta - Ulvophyceae - Bryopsidales - Udoteaceae	*Rhipilia sinuosa*
Chordata - Ascidiacea - Phlebobranchia - Ascidiidae	*Phallusia julinea*
Chordata - Ascidiacea - Phlebobranchia - Ascidiidae	*Phallusia nigra*
Chordata - Ascidiacea - Phlebobranchia - Diazonidae	*Rhopalaea circula*
Chordata - Ascidiacea - Phlebobranchia - Diazonidae	*Rhopalaea* sp. 2–gold spot
Cnidaria - Anthozoa - Corallimorpharia - Actinodiscidae	*Discosoma* sp.

Higher classification	Taxon
Cnidaria - Anthozoa - Scleractinia - Acroporidae	*Astreopora* sp.
Cnidaria - Anthozoa - Scleractinia - Agariciidae	*Leptoseris mycetoseroides*
Cnidaria - Anthozoa - Scleractinia - Astrocoeniidae	*Stylocoeniella armata*
Cnidaria - Anthozoa - Scleractinia - Dendrophylliidae	*Tubastrea* sp.
Cnidaria - Anthozoa - Scleractinia - Faviidae	*Goniastrea retiformis*
Cnidaria - Anthozoa - Scleractinia - Faviidae	*Leptastrea bottae*
Cnidaria - Anthozoa - Scleractinia - Faviidae	*Leptastrea purpurea*
Cnidaria - Anthozoa - Scleractinia - Oculinidae	*Galaxea fascicularis*
Cnidaria - Anthozoa - Scleractinia - Pocilloporidae	*Pocillopora damicornis*
Cnidaria - Anthozoa - Scleractinia - Poritidae	*Alveopora* sp.
Cnidaria - Anthozoa - Scleractinia - Poritidae	*Porites densa*
Cnidaria - Anthozoa - Scleractinia - Poritidae	*Porites horizontalata*
Cnidaria - Anthozoa - Scleractinia - Poritidae	*Porites lichen*
Cnidaria - Anthozoa - Scleractinia - Poritidae	*Porites lobata*
Cnidaria - Anthozoa - Scleractinia - Poritidae	*Porites lutea*
Cnidaria - Anthozoa - Scleractinia - Poritidae	*Porites rus*
Cnidaria - Anthozoa - Scleractinia - Poritidae	*Porites solida*
Cnidaria - Anthozoa - Scleractinia - Siderastreidae	*Psammocora superficialis*
Ectoprocta - Gymnolaemata - Cheilostomata - Bugulidae	*Celleporaria sibogae*
Ectoprocta - Gymnolaemata - Cyclostomata - Lichenoporidae	*Lichenopora* sp.
Magnoliophyta - Liliopsida - Alismatales - Hydrocharitaceae	*Halophila japonica*
Mollusca - Bivalvia - Pterioida - Malleidae	*Malleus decurtatus*
Mollusca - Bivalvia - Veneroida - Chamidae	*Chama lazarus*
Ochrophyta - Phaeophyceae - Dictyotales - Dictyotaceae	*Dictyota adnata*
Ochrophyta - Phaeophyceae - Dictyotales - Dictyotaceae	*Dictyota bartayresiana*
Ochrophyta - Phaeophyceae - Dictyotales - Dictyotaceae	*Dictyota friabilis*
Ochrophyta - Phaeophyceae - Dictyotales - Dictyotaceae	*Lobophora variegata*
Ochrophyta - Phaeophyceae - Dictyotales - Dictyotaceae	*Padina boryana*
Porifera - Demospongiae - Dendroceratida - Darwinellidae	*Aplysilla* sp.
Porifera - Demospongiae - Dendroceratida - Dysideidae	*Dysidea* cf. *avara*
Porifera - Demospongiae - Dictyoceratida - Spongiidae	*Aplysina* sp. (yellow)
Porifera - Demospongiae - Dictyoceratida - Thorectidae	*Hyrtios* sp.
Porifera - Demospongiae - Hadromerida - Spirastrellidae	*Spheciospongia vagabunda*
Porifera - Demospongiae - Halichondrida - Halichondriidae	*Halichondria* sp.
Porifera - Demospongiae - Poecilosclerida - Anchinoidae	*Phorbas* sp.
Porifera - Demospongiae - Poecilosclerida - Desmacellidae	*Biemna fistulosa*
Porifera - Demospongiae - Poecilosclerida - Desmacellidae	*Neofibularia hartmani*
Porifera - Demospongiae - Poecilosclerida - Desmacididae	*Iotrochota protea*
Porifera - Demospongiae - Poecilosclerida - Guitarridae	*Tetrapocillon* sp.
Porifera - Demospongiae - Poecilosclerida - Microcionidae	*Clathria eurypa*
Porifera - Demospongiae - Poecilosclerida - Microcionidae	*Clathria mima*
Porifera - Demospongiae - Poecilosclerida - Microcionidae	*Clathria* sp. 1
Porifera - Demospongiae - Poecilosclerida - Microcionidae	*Echinochalina* sp.
Porifera - Demospongiae - Poecilosclerida - Mycalidae	*Ulosa spongia*
Porifera - Demospongiae - Poecilosclerida - Phoriospongiidae	*Psammoclemma* sp.
Porifera - Demospongiae - Poecilosclerida - Raspailiidae	*Ceratopsion* sp. 1
Prokaryota - Bacteria - Negibacteria - Cyanobacteria	*Calothrix scopulorum*
Prokaryota - Bacteria - Negibacteria - Cyanobacteria	*Lyngbya penicilliformis*

Higher classification	Taxon
Prokaryota - Bacteria - Negibacteria - Cyanobacteria	*Phormidium* cf. *dimorphum*
Prokaryota - Bacteria - Negibacteria - Cyanobacteria	*Symploca hydnoides*
Rhodophyta - Florideophyceae - Ceramiales - Rhodomelaceae	*Lophocladia* sp.
Rhodophyta - Florideophyceae - Corallinales - Corallinaceae	*Hydrolithon onkodes*
Rhodophyta - Florideophyceae - Corallinales - Corallinaceae	*Lithophyllum kotschyanum*
Rhodophyta - Florideophyceae - Corallinales - Corallinaceae	*Lithophyllum pygmaeum*
Rhodophyta - Florideophyceae - Corallinales - Corallinaceae	*Mesophyllum funafutiense*
Rhodophyta - Florideophyceae - Corallinales - Corallinaceae	*Pneophyllum conicum*
Rhodophyta - Florideophyceae - Halymeniales - Peyssonneliaceae	*Peyssonnelia boergesenii*
Rhodophyta - Florideophyceae - Halymeniales - Peyssonneliaceae	*Peyssonnelia inamoena*
Rhodophyta - Florideophyceae - Halymeniales - Peyssonneliaceae	*Peyssonnelia rubra*
Turf algae	Turf algae

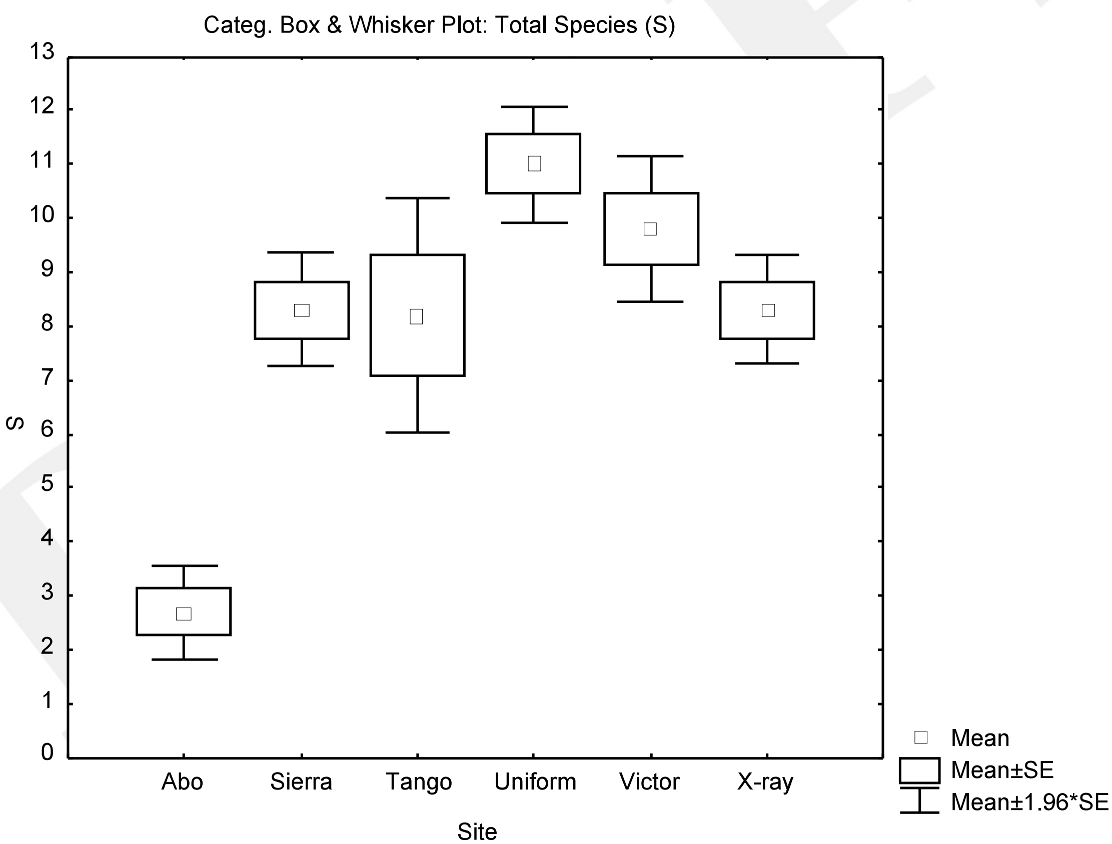

Figure 3. Total species (*S*) of quadrats per site. Abbreviations: Abo, Abo Cove; Sierra, Sierra Wharf; Tango, Tango Wharf; Uniform, Uniform Wharf; Victor, Victor Wharf; X-ray, X-ray Wharf.

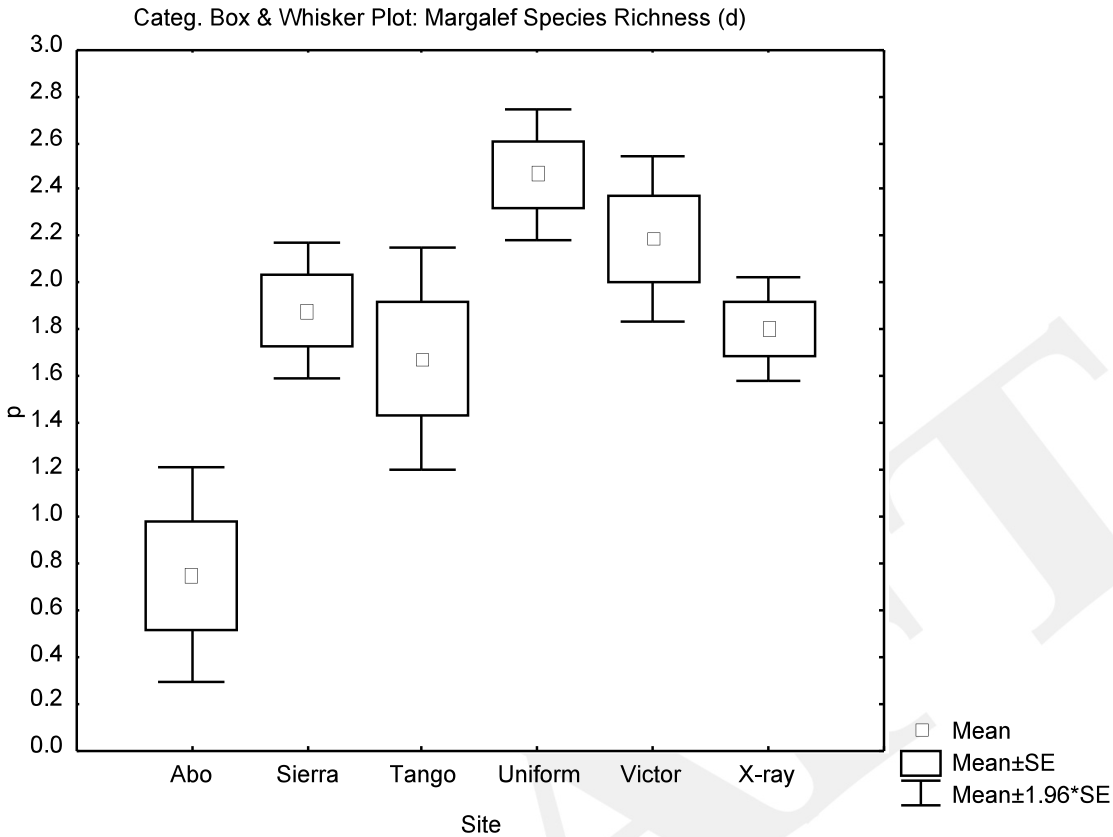

Figure 4. Margalef species richness (*d*) of quadrats per site. Abbreviations as in Figure 3.

Table 4. One-way Analysis of Variance (ANOVA) of *S* with Tukey HSD for unequal sample size as a post-hoc test. Differences significant at P < 0.05 are italicized. Abbreviations as in Figure 3.

	Abo	Sierra	Tango	Uniform	Victor	X-ray
Abo		*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Sierra	*0.00*		1.00	0.19	0.44	1.00
Tango	*0.00*	1.00		0.16	0.73	1.00
Uniform	*0.00*	0.19	0.16		0.90	0.19
Victor	*0.00*	0.44	0.73	0.90		0.44
X-ray	*0.00*	1.00	1.00	0.19	0.44	

Table 5. One-way ANOVA of *d* with Tukey HSD for unequal sample size as a post-hoc test. Differences significant at P < 0.05 are italicized. Abbreviations as in Figure 3.

	Abo	Sierra	Tango	Uniform	Victor	X-ray
Abo		*0.00*	0.13	*0.00*	*0.00*	*0.00*
Sierra	*0.00*		0.99	0.59	0.83	1.00
Tango	0.13	0.99		0.27	0.72	1.00
Uniform	*0.00*	0.59	0.27		0.97	0.46
Victor	*0.00*	0.83	0.72	0.97		0.66
X-ray	*0.00*	1.00	1.00	0.46	0.66	

Turbidity is high throughout the inner harbor, but the vertical orientation of hard substrates (and probably ship activity) at the wharves results in a lower amount of sediment deposition, favoring the growth of epilithic biota adapted to low light conditions. Although very different from Abo Cove, the benthic assemblages of the wharves contain interesting taxa as well. Some of the taxa recorded here do not appear in the most recent taxonomic treatises for Guam. For example, the very abundant *Celleporaria sibogae* and the rather uncommon *Lichenopora* sp. are most likely new bryozoan records for Guam, as this group has been virtually unstudied in the region (Paulay, 2003). Diversity measures mimic the differences in species richness between the inner harbor sites (Figure 5; Table 6). Sponges contribute most to the benthic diversity of the wharves. A number of these probably also constitute new records for Guam, and others are infrequently encountered elsewhere around the island as they are typically confined to deep water, caves, or other cryptic habitats.

Table 6. One-way ANOVA of *H′* with Tukey HSD for unequal sample size as a post-hoc test. Differences significant at P < 0.05 are italicized. Abbreviations as in Figure 3.

	Abo	Sierra	Tango	Uniform	Victor	X-ray
Abo		*0.01*	0.13	*0.00*	*0.00*	*0.00*
Sierra	*0.01*		1.00	0.64	0.14	0.73
Tango	0.13	1.00		0.69	0.53	0.94
Uniform	*0.00*	0.64	0.69		1.00	0.99
Victor	*0.00*	0.14	0.53	1.00		0.87
X-ray	*0.00*	0.73	0.94	0.99	0.87	

As found for taxonomic richness and diversity, the benthic assemblages of Abo Cove differ significantly from the wharf sites in having a low overall biotic cover (Figure 6; Table 7). As discussed before, this is a direct result of the Abo Cove site being a mostly horizontally oriented sedimentation flat. In contrast, the biotic assemblages of the wharfs are best developed on the shallow vertical surfaces. It is important to note, however, that corals are the main constituent of the biotic assemblages at Abo Cove, while the wharfs are predominantly covered by crustose algae and sponges (Figure 7).

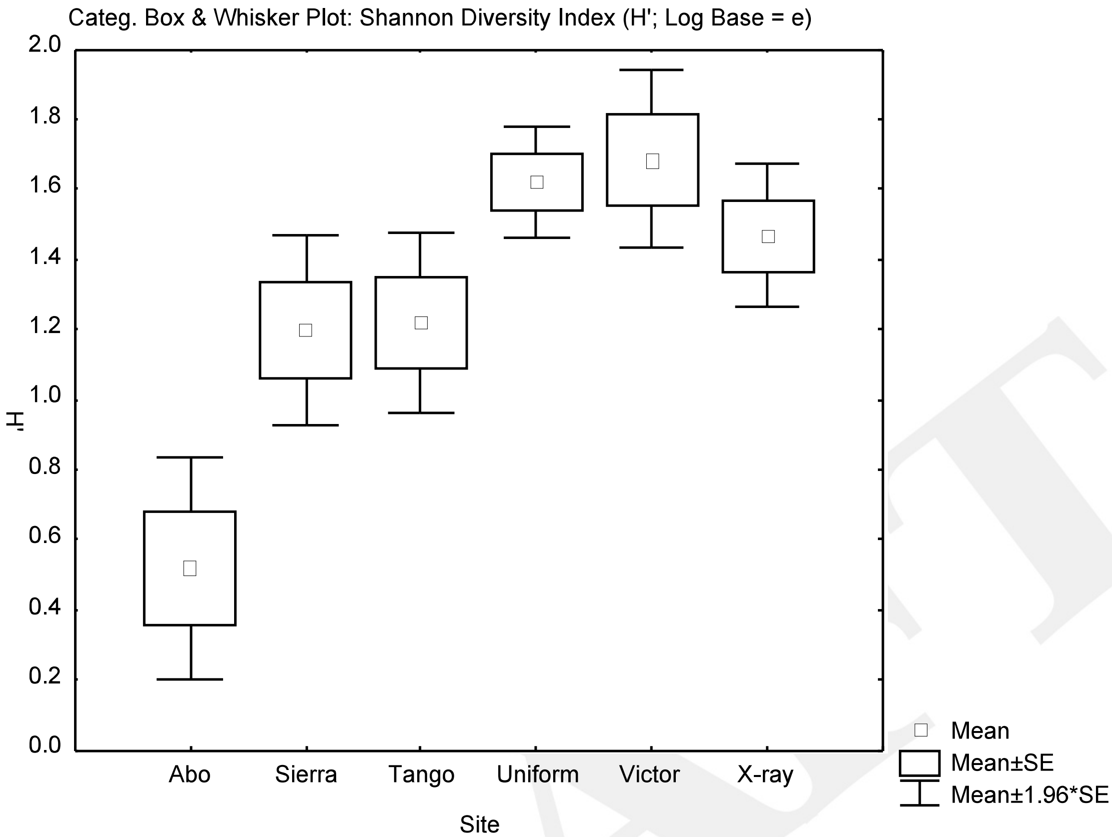

Figure 5. Shannon index (*H′*) of quadrats per site. Abbreviations as in Figure 3.

Table 7. One-way ANOVA of biotic cover with Tukey HSD for unequal sample size as a post-hoc test. Differences significant at $P < 0.05$ are italicized. Abbreviations as in Figure 3.

	Abo	Sierra	Tango	Uniform	Victor	X-ray
Abo		*0.00*	*0.02*	0.21	*0.01*	*0.01*
Sierra	*0.00*		0.98	1.00	1.00	1.00
Tango	*0.02*	0.98		0.87	0.92	0.92
Uniform	0.21	1.00	0.87		1.00	1.00
Victor	*0.01*	1.00	0.92	1.00		1.00
X-ray	*0.01*	1.00	0.92	1.00	1.00	

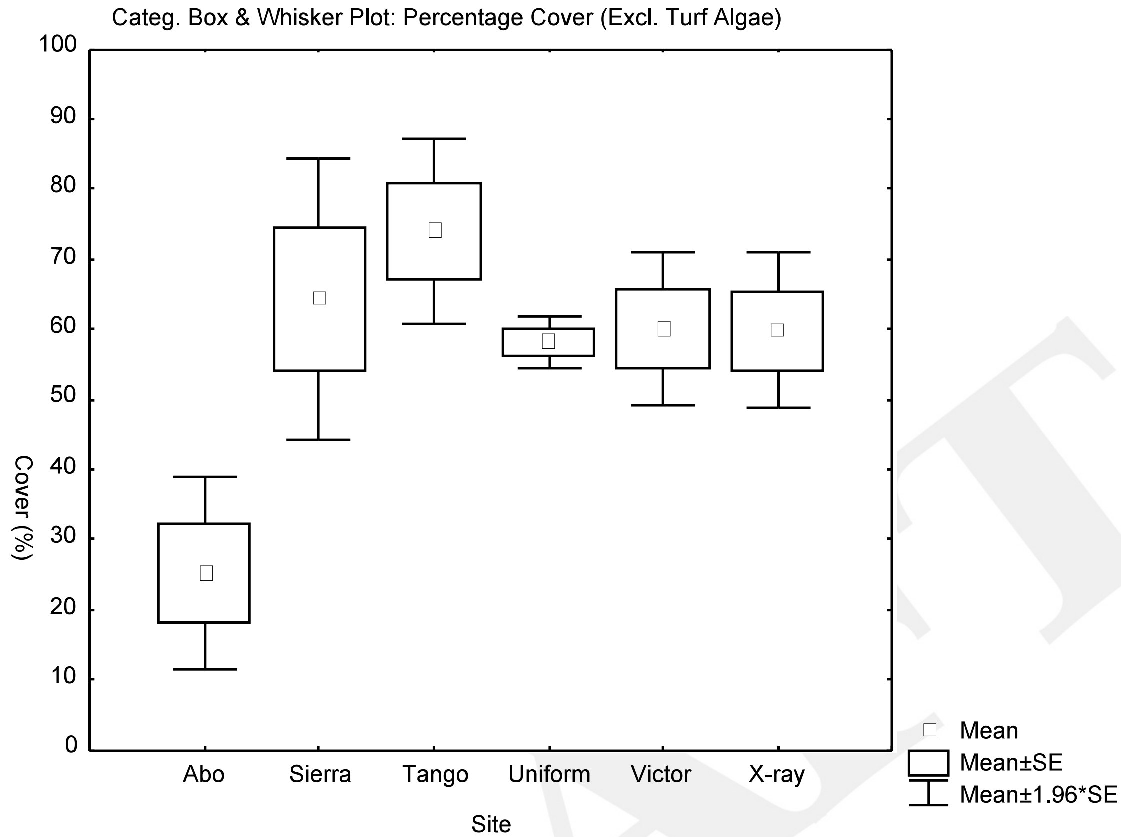

Figure 6. Biotic cover (excluding turf algae) of quadrats per site. Abbreviations as in Figure 3.

Non-metric multidimensional scaling (NMDS) was performed on the square root-transformed benthic data. The two-dimensional NMDS plot is an excellent representation of the biotic affinities between sites (low stress) and highlights the differences between Abo Cove and the Wharf sites in accordance with the above findings. Similarity is highest among the three southwestern wharves (Tango, Uniform, and Victor). Further multivariate analyses should reveal the main differences between the other sites and the most important indicator taxa in the data set.

Corals

Size-frequency distributions of the 13 species of scleractinian corals encountered on six transects in Inner Apra Harbor are presented in Table 8. An additional 13 species of scleractinian corals were observed on substrates adjacent to the transects (Table 3). Two species of non-scleractinian anthozoans were also recorded. Therefore, a cumulative total of 28 species of corals and related organisms, representing 11 families and 13 genera, was observed at the study site. This count represents a minimum, because several corals could be identified only to genus in the field and, therefore, may consist of more than one species.

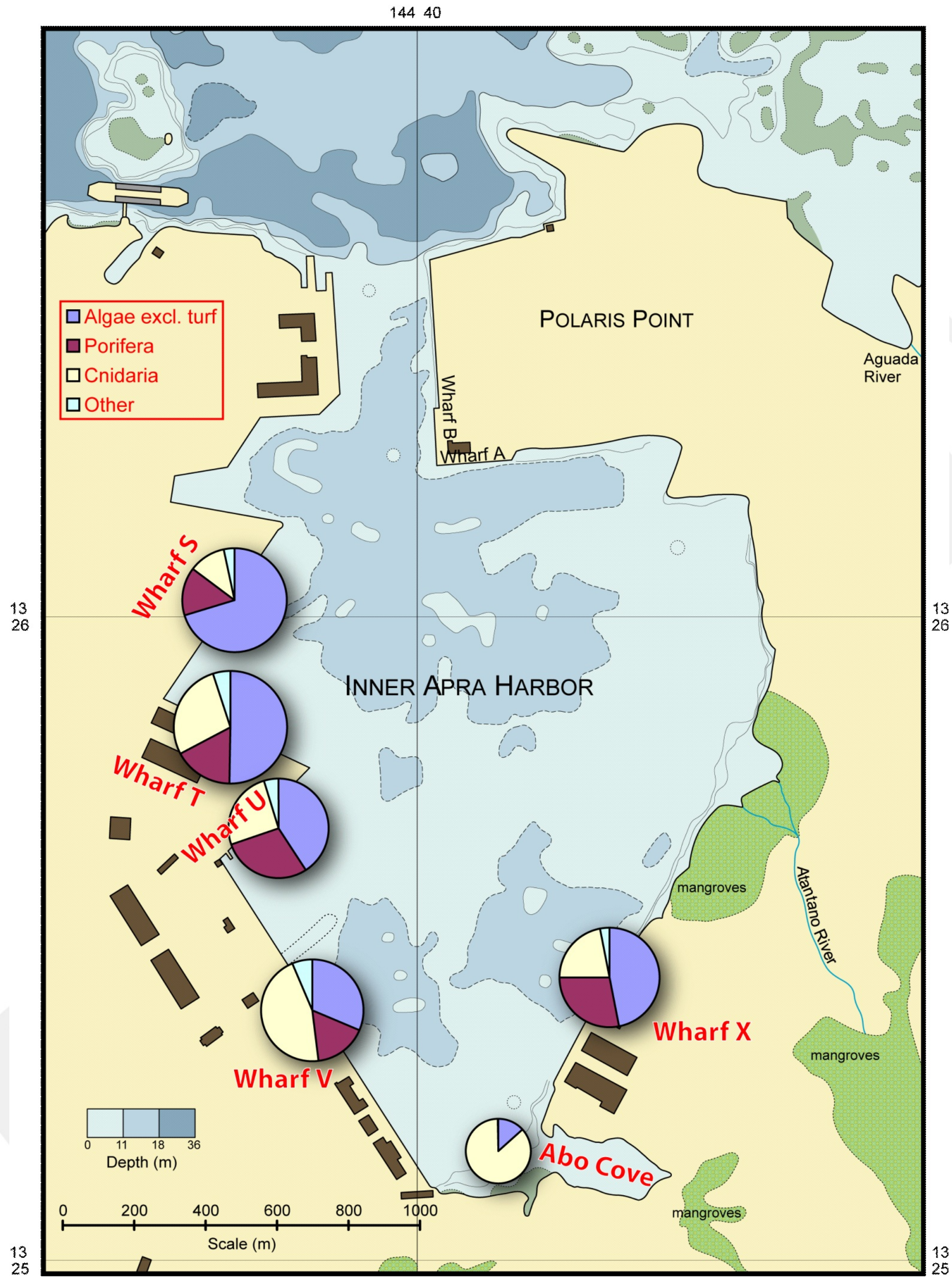

Figure 7. Pie charts displaying the percent cover of algae (Chlorophyta, Ochrophyta, Prokaryota, Rhodophyta), Porifera, Cnidaria, and other groups (Chordata, Magnoliophyta, Mollusca) for the different study sites. Size of the pie chart is proportional to the average total cover of benthic assemblages in the sampled quadrats. Biotic cover ranges from 25 % (Abo Cove) to 74 % (Tango Wharf).

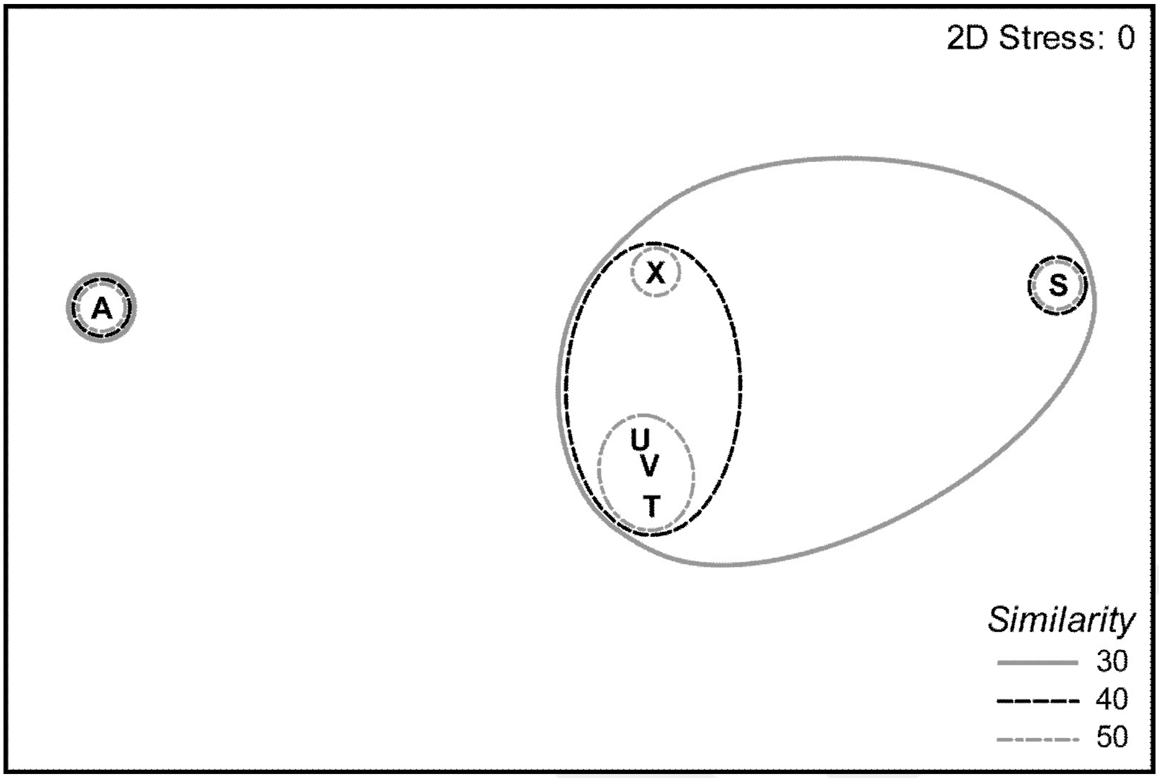

Figure 8. Non-metric multidimensional scaling (NMDS) plot of the six inner harbor sites. Bray-Curtis similarities obtained from a cluster analysis based on the benthic data (square root transformed) are overlaid. Abbreviations: A, Abo Cove; S, Sierra Wharf; T, Tango Wharf; U, Uniform Wharf; V, Victor Wharf; X, X-ray Wharf.

Species richness was highest at X-ray Wharf, where eight species occurred on the transect; only four species occurred on transects at Above Cove and Tango, Uniform, and Victor Wharves. *Porites lutea* and *Pocillopora damicornis* were the most common species, occurring on five of the six transects. Seven species occurred on only one transect, and three of these species were represented by single observations.

Quantitative analysis of the coral species encountered on transect is presented in Table 9. Poritid corals were predominant in coverage, averaging some 83% relative coverage on transects. Similarly, *Porites* spp. occurred at high frequencies on transects, although smaller species, such as *Pocillopora damicornis* and *Leptastrea purpurea*, exhibited high frequencies, as well.

The harbor floor consists of fine-grain sediments unsuitable for settlement by coral larvae. Consequently, few corals were encountered on Transects 1 and 2 on the harbor floor. Small colonies of *Porites lutea* were observed on scattered pieces of debris and old pilings that provided the only hard substrate available for settlement of larvae. With the exception of what

Table 8. Size-frequency distributions of coral species recorded on transects in Inner Apra Harbor. N = number of colonies. Mean, SD (standard deviation), and Range refer to colony coverage in cm^2.

Location	Habitat	Species	N	Mean	SD	Range
Abo Cove	Reef	*Porites* sp.	10	1291.9	1703.2	74.02–5013.98
		Goniastrea retiformis	4	12.7	15.0	3.93–34.99
		Porites lutea	7	1472.2	2624.4	45.95–7242.94
		Porites murrayensis	2	27.7	10.8	20.01–35.34
Wharf S	Wharf face	*Porites rus*	8	19.7	10.7	7.42–39.25
		Lobophyllia hataii	1	9.9	–	9.88
		Stylocoeniella armata	3	25.8	18.1	7.15–43.28
		Leptastrea purpurea	3	8.7	2.6	5.72–10.60
		Pocillopora damicornis	1	0.3	–	0.31
Wharf T	Wharf face	*Leptastrea purpurea*	5	11.7	11.3	0.55–29.10
		Porites lutea	10	99.3	191.2	2.64–631.43
		Pocillopora damicornis	3	25.0	29.1	1.65–57.59
		Porites sp.	2	4.1	0.0	4.10–4.10
Wharf U	Wharf face	*Porites lutea*	12	134.9	282.7	1.53–978.21
		Pocillopora damicornis	10	46.3	43.1	1.98–129.59
		Leptastrea purpurea	15	8.7	9.4	0.20–37.70
		Porites rus	2	1165.7	855.0	561.10–1770.29
Wharf V	Wharf face	*Leptastrea purpurea*	10	2.8	2.4	0.33–8.91
		Pocillopora damicornis	14	46.4	66.0	0.44–253.68
		Porites lutea	12	256.3	434.0	4.67–1555.09
		Stylocoeniella guntheri	3	236.2	406.9	0.55–706.07
Wharf X	Wharf face	*Porites lutea*	11	25.7	26.9	1.96–74.30
		Porites rus	7	640.3	866.3	3.77–2172.16
		Leptastrea purpurea	15	5.3	6.5	0.20–25.40
		Porites sp.	1	1.04	–	3.77
		Montipora sp.	2	12.9	5.1	9.30–16.49
		Porites australiensis	1	4.9	–	4.90
		Pocillopora damicornis	2	32.6	28.3	12.53–52.59
		Pavona explanulata	1	1.0	–	1.04

appeared to be the remains of an old pier extending perpendicular from Victor Wharf (Transect 1, Figure 1), the amount of debris was greater near the wharves. No corals were observed on the harbor floor at distances of 20 m or more.

The fourth root-transformed relative coral coverage data were analyzed by non-metric multidimensional scaling (NMDS). The two-dimensional NMDS plot (Figure 9) shows the biotic affinities between the sites (low stress) and reveals differences not only between Abo Cove and the wharf sites, but between Sierra Wharf and the four remaining wharves. Uniform and X-ray

Table 9. Population density, frequency, and coverage of coral species recorded on transects in Inner Apra Harbor.

Location	Habitat	Species	N	Relative Density	Absolute Density	Frequency	Coverage	Relative Coverage
Abo Cove	Reef	*Porites* sp.	10	0.43	0.06	0.60	80.98	81.58
		Goniastrea retiformis	4	0.17	0.03	0.20	0.32	0.32
		Porites lutea	7	0.30	0.04	0.30	17.62	17.75
		Porites murrayensis	2	0.09	0.01	0.10	0.35	0.35
Wharf S	Wharf face	*Porites rus*	8	0.50	0.04	0.60	1.01	61.78
		Lobophyllia hataii	1	0.06	0.01	0.20	0.05	3.33
		Stylocoeniella armata	3	0.19	0.02	0.40	0.42	26.02
		Leptastrea purpurea	3	0.19	0.02	0.40	0.14	8.77
		Pocillopora damicornis	1	0.06	0.01	0.20	0.00	0.10
Wharf T	Wharf face	*Leptastrea purpurea*	5	0.25	0.03	0.80	0.39	5.11
		Porites lutea	10	0.50	0.07	0.80	6.63	86.85
		Pocillopora damicornis	3	0.15	0.02	0.40	0.56	7.37
		Porites sp.	2	0.10	0.01	0.20	0.06	0.72
Wharf U	Wharf face	*Porites lutea*	12	0.31	0.30	0.800	39.80	35.63
		Pocillopora damicornis	10	0.26	0.25	0.600	11.39	10.20
		Leptastrea purpurea	15	0.38	0.37	1.000	3.20	02.87
		Porites rus	2	0.05	0.05	0.100	57.32	51.31
Wharf V	Wharf face	*Leptastrea purpurea*	10	0.26	0.10	0.50	0.29	00.62
		Pocillopora damicornis	14	0.36	0.15	0.80	6.78	14.55
		Porites lutea	12	0.31	0.13	0.50	32.13	68.93
		Stylocoeniella guntheri	3	0.08	0.03	0.10	7.40	15.88
Wharf X	Wharf face	*Porites lutea*	11	0.28	0.05	0.50	1.15	05.66
		Porites rus	7	0.18	0.03	0.50	18.34	89.92
		Leptastrea purpurea	15	0.38	0.06	0.70	0.49	02.40
		Porites sp.	1	0.03	0.00	0.10	0.02	0.08
		Montipora sp.	2	0.05	0.01	0.10	0.11	0.52
		Porites australiensis	1	0.03	0.00	0.10	0.02	0.10
		Pocillopora damicornis	2	0.05	0.01	0.20	0.27	1.31
		Pavona explanulata	1	0.03	0.00	0.10	0.00	0.02

Wharves cluster together, as do Tango and Victor Wharfs. Coral communities on the four southern wharves are more similar to each other than to either Sierra Wharf or Abo Cove.

Macroinvertebrates

The distribution and abundance of conspicuous solitary epibenthic macroinvertebrates occurring on 8 transects in Inner Apra Harbor are reported in Table 10

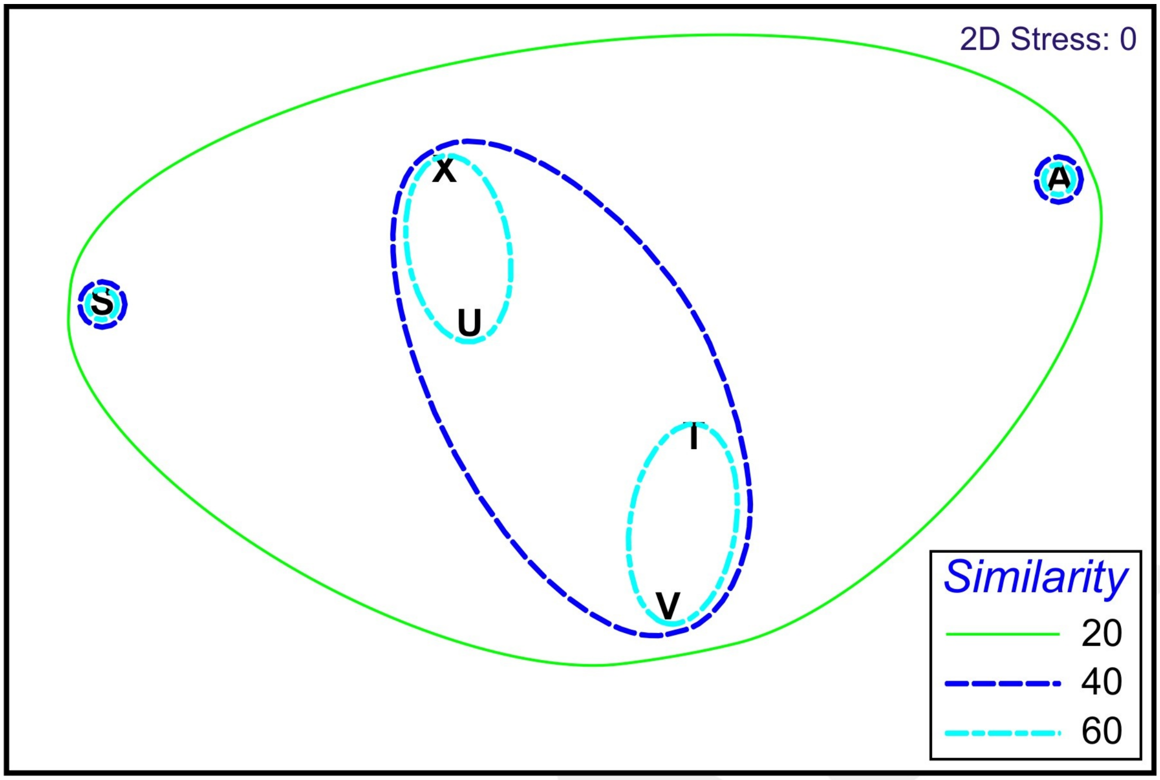

Figure 9. Non-metric multidimensional scaling (NMDS) plot of the six inner harbor transect sites. Bray-Curtis similarities obtained from a cluster analysis based on the coral data (fourth root-transformed) are overlaid. Abbreviations: A, Abo Cove; S, Sierra Wharf; T, Tango Wharf; U, Uniform Wharf; V, Victor Wharf; X, X-ray Wharf.

(colonial invertebrates are included in Table 3). Twenty species of solitary macroinvertebrates in four phyla were encountered on the transects, and 10 additional species were observed in areas adjacent to the transects (Table 11). Three of the species on transects occurred as single observations, and one species, *Phallusia nigra*, is reported as nonindigenous (Paulay et al., 2001a; Lambert, 2002, 2003). The greatest α diversity (i.e., 16 species, or 80% of the α diversity on transects) was found on the vertical face at Victor Wharf (Transect V), and the least (i.e., 8 species) on the coral reef at Abo Cove (Transect A). Bivalve molluscs and ascidians dominated the macroinvertebrate fauna in terms of both diversity and density. Remarkably, 100% of the macroinvertebrate species encountered on transects were suspension feeders. Of the total 30 species of solitary macroinvertebrates listed in Table 11, all but three are suspension feeders—the three being detritus feeders. The predominance of suspension feeders in lagoonal environments, such as the inner harbor, may be a result of nutrient enrichment by terrestrial run-off and the extended residence time of waters in the lagoon.

Table 10. Mean densities of conspicuous epibenthic invertebrates observed on transects in Inner Apra Harbor, Guam. Densities are reported as mean ± standard deviation in twenty 10-m^{-1} quadrats sampled along a 100-m transect, except at Wharf T and Wharf U, where ten 10-m^{-1} quadrats were sampled along a 50-m transect.

	Abo Cove	Wharf S	Wharf T	Wharf U	Wharf V	Wharf X
Cirripathes sp.					0.05 ± 0.22	
Spirobranchus giganteus	0.05 ± 0.22		0.90 ± 0.74	1.20 ± 1.69	0.35 ± 0.67	0.10 ± 0.31
Sabellastarte sanctijosephi	0.05 ± 0.22					
Arca ventricosa					0.05 ± 0.22	
Barbatia spp.	0.30 ± 0.47		0.40 ± 1.26			0.35 ± 0.93
Chama lazarus		7.25 ± 4.30	9.70 ± 2.54	7.90 ± 4.36	11.50 ± 11.37	6.20 ± 3.32
Chama spp.	0.05 ± 0.22	0.35 ± 0.67		0.50 ± 0.85		0.75 ± 1.25
Malleus decurtatus	3.15 ± 2.43	0.20 ± 0.52	4.10 ± 1.73	31.90 ± 27.65	93.40 ± 91.23	54.60 ± 39.55
Spondylus multimuricatus		1.65 ± 2.46	3.10 ± 2.08	2.30 ± 1.49	3.75 ± 3.01	3.05 ± 1.76
Spondylus squamosus		0.65 ± 0.93	0.40 ± 0.52	1.70 ± 1.25	2.15 ± 2.18	5.90 ± 4.76
Spondylus spp.			28.10 ± 9.10	19.90 ± 5.92	10.95 ± 10.65	20.00 ± 9.21
ostreid spp.		0.20 ± 0.70		0.30 ± 0.48	0.65 ± 0.99	0.50 ± 1.15
Septifer bilocularis			0.30 ± 0.95			0.25 ± 0.72
Ascidia ornata	0.20 ± 0.52			0.10 ± 0.32	0.15 ± 0.37	
Ascidia sp. 1[a,b]					0.40 ± 0.60	
Phallusia julinea		0.05± 0.22	0.40 ± 0.70	2.70 ± 2.45	5.45 ± 5.58	
Phallusia nigra				0.20 ± 0.42	0.50 ± 0.83	
Polycarpa spp.	0.55 ± 0.69	0.20 ± 0.52	1.10 ± 1.10	2.20 ± 1.87	1.40 ± 1.43	0.50 ± 0.76
Rhopalaea circula	0.05 ± 0.22	2.45 ± 1.99	63.30 ± 18.09	8.20 ± 5.69	11.60 ± 8.09	4.50 ± 4.51
Rhopalaea sp. 2–gold spot[a,c]			31.90 ± 11.44		1.35 ± 1.69	

[a]These identifications follow the morphospecies designated by Paulay et al. (2001b).
[b]*Ascidia* sp. A of Lambert (2003).
[c]*Rhopalaea* sp. A (n.sp.?) of Lambert (2003).

Table 11. Species of conspicuous epibenthic invertebrates observed on or adjacent to transects in Inner Apra Harbor, Guam. Observations of live specimens are denoted by filled circles (●), and records based on dead specimens are denoted by open circles (○).

	Harbor Floor 1	Harbor Floor 2	Abo Cove	Wharf S	Wharf T	Wharf U	Wharf V	Wharf X
Mastigias papua							●	●
Scyphozoa sp.–transparent				●		●	●	
Cirripathes sp.							●	
Zoanthus sp.							●	
Spirobranchus giganteus	●		●		●	●	●	●
Sabellastarte sanctijosephi			●					
Bittium zebrum	●							
Creseis acicula				●	●	●	●	●
Arca ventricosa							●	
Barbatia spp.	●		●		●	●		●
Chama lazarus				●	●	●	●	●
Chama spp.			●	●				●
Malleus decurtatus	●		●	●	●	●	●	●
Spondylus multimuricatus				●	●	●	●	●
Spondylus squamosus	●			●	●	●	●	●
Spondylus varius						○		
Spondylus spp.	●				●	●		●
Hyotissa hyotis						○		
Saccostrea cf. *cucullata*	●	●						
ostreid spp.				●			●	●
Septifer bilocularis					●	●		●
Mespilia globulus						●		
Parasalenia gratiosa						●		
Ascidia ornata			●			●	●	
Ascidia sp. 1[a]							●	
Phallusia julinea				●	●	●	●	
Phallusia nigra						●	●	
Polycarpa spp.			●	●	●	●	●	●
Rhopalaea circula			●	●	●	●	●	●
Rhopalaea sp. 2–gold spot[a]					●	●	●	

[a]These identifications follow the morphospecies designated by Paulay et al. (2001b).

Densities of solitary macroinvertebrates ranged from less than 1 individual of a species to more than 90 individuals/10 m^2, with bivalve molluscs and ascidians being predominant. The hammer oyster *Malleus decurtatus* occurred in the greatest densities (up to 9.3 oysters/m^2 at Victor Wharf), with thorny oysters, *Spondylus* spp., and jewel box clams, *Chama* spp., also abundant. Among ascidians, *Rhopalaea circula* reached a density of 6.3 individuals/m^2 at Tango Wharf. The greatest total density was observed Victor Wharf (Transect V), where there were 143.7 macroinvertebrates/10 m^2; the lowest total density was 4.4 macroinvertebrates/10 m^2 at Abo Cove (Transect V). As noted above for benthic coverage, this pattern may be explained by the greater availability of hard substrate for post-larval settlement on the vertical faces of the wharves, as compared to the sediment-laden horizontal substrate on the reef at Abo Cove.

The harbor floor is largely depauperate of epibenthic macroinvertebrates. The substrate of the harbor consists predominately of a sticky, fine silt/mud sediment that is easily resuspended. As a result, the transect line sank from sight into the soft sediments. Further, any contact or near contact with the bottom by divers resuspended sediments and reduced visibility markedly. Therefore, we were not able to quantify macroinvertebrates on the harbor floor. However, seven epibenthic species were observed during two swimming transects (Transects 1 and 2). Observed species were associated with debris that provided hard substrate, with the exception of the detritivorous snail *Bittium zebrum*. Generally, the volume of debris, and therefore the number of macroinvertebrates, diminished with distance from the wharves. Although few epibenthic macroinvertebrates were observed on the harbor floor, large numbers of burrow openings were present, indicating an abundance infaunal organisms.

Comparison of macroinvertebrate community structure across transects by cluster analysis indicates considerable contrast for horizontal and vertical substrates (Figure 10). The macroinvertebrate community on vertical faces of the wharves form a single, large clade that is distinctly different than the community inhabiting the horizontal substrate at Abo Cove. As noted for benthic cover, similarity is high for Uniform and Victor Wharves. However, for solitary macroinvertebrates, X-ray Wharf is more similar to these communities than to the community at Tango Wharf.

Non-metric multidimensional scaling (NMDS) on the fourth root-transformed data further demonstrate the dissimilarity of macroinvertebrate assemblages on horizontal and vertical substrates (Figure 11). The Abo Cove macroinvertebrate community is distinctly different from the communities on the wharf faces, which clustered together. A stress level of 0.01 indicates a high level of significance in the relationships represented by this analysis.

Possibly the most abundant solitary invertebrates were neither epibenthic nor conspicuous. The pelagic thecosomate gastropod *Creseis acicula* was abundant in surface waters adjacent to all the wharves that we surveyed. Commonly known as sea butterflies or pteropods, these free-swimming gastropods feed upon plankton, exhibiting diurnal migrations in pursuit of their prey. Although small (<1 cm) and almost transparent, the snails are important in marine food webs (Seibel and Diersson, 2003). Their sensitivity to temperature and acidity have led scientists to express concern over the possible effects of global climate change and ocean acidification upon the survival of these organisms and the consequent impacts on marine food webs (Seibel and Diersson, 2003; Orr et al., 2005; Fabry et al., 2008).

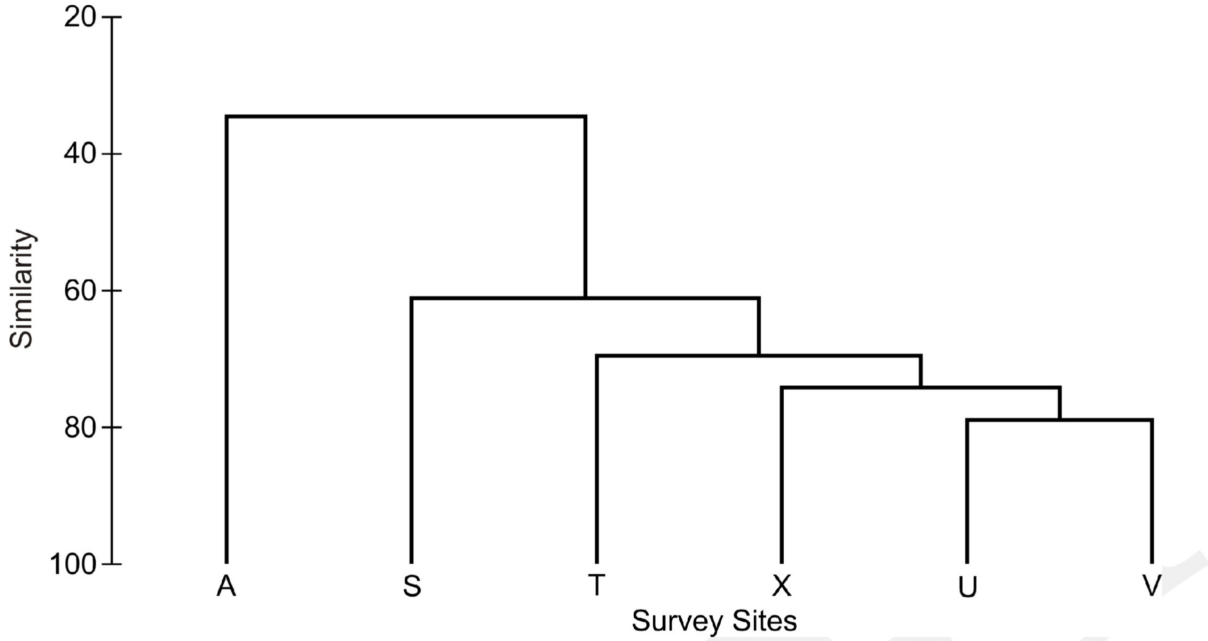

Figure 10. Cluster analysis (group averaging) of macroinvertebrate assemblage relationships between transects at Inner Apra Harbor study sites. Values of similarity (0 to 100%) were calculated in pair-wise comparisons with the Bray-Curtis similarity index and then assembled in a matrix prior to cluster analysis. Abbreviations: A, Abo Cove; S, Sierra Wharf; T, Tango Wharf; U, Uniform Wharf; V, Victor Wharf; X, X-ray Wharf.

We have no basis for statistical comparison of our data on macroinvertebrate populations in Inner Apra Harbor. The most recent survey (Paulay et al., 2001a) of the macroinvertebrate communities in the inner harbor focused primarily upon only three taxa (i.e., sponges, echinoderms, and ascidians), and their study was qualitative in structure.

Fishes

A checklist of species and their relative abundance (as percent) at each station is given in Table 12. Sixty-two species of fishes were observed on transects surveyed within the Apra Inner Harbor. While this number indicates an impoverished fish fauna (there are approximately 1,000 species of reef and nearshore fishes known from the Mariana Islands; Myers and Donaldson, 2003; unpublished data), the fauna seems representative of protected, turbid lagoons or bays of Guam (unpublished data). Further, at least three species appear to be invasive or new records for Guam and the Mariana Islands. One, *Neopomacentrus violescens* (Pomacentridae-damselfishes), has been reported previously (Myers, 1999; Myers and Donaldson, 2003). The other two, *Amblygliphididon ternatensis* (Pomacentridae) and *Rhamdia cypselurus* (Apogonidae-cardinalfishes) have not been reported previously from the Mariana Islands. Both occur elsewhere in the western Indo-Pacific region in natural habitats somewhat similar to those found in Inner Apra Harbor (Myers, 1999). Either both of these species have escaped detection

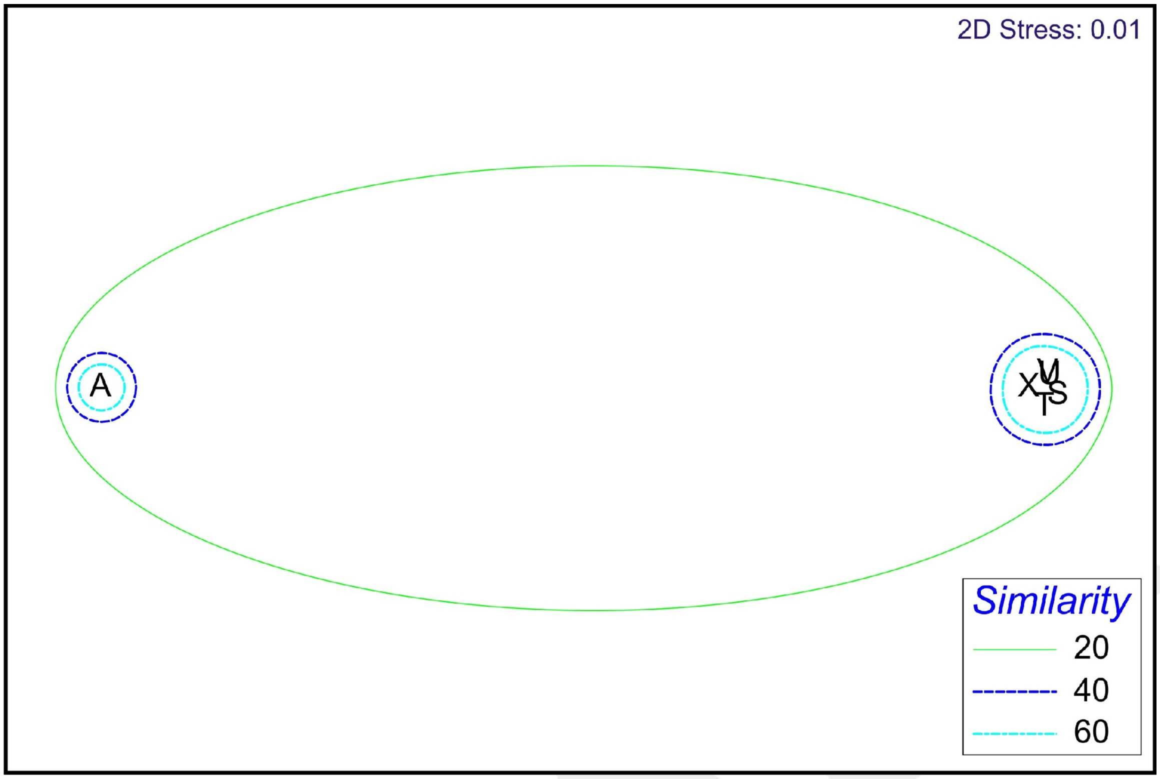

Figure 11. Non-metric multidimensional scaling (NMDS) plot of macroinvertebrate assemblages at the six inner harbor transect sites. Bray-Curtis similarities obtained from a cluster analysis based on the coral data (fourth root-transformed) are overlaid. Abbreviations: A, Abo Cove; S, Sierra Wharf; T, Tango Wharf; U, Uniform Wharf; V, Victor Wharf; X, X-ray Wharf.

previously, owing to the very turbid conditions found in the inner harbor, or they have been introduced, likely as larvae in bilge water of ships moored in the inner harbor, and have been seen for the first time during the present surveys,

Species richness (the number of species observed) between stations ranged from 2 (harbor floor, Transect 2) to 29 (UniformWharf–bottom, Transect U_B). Generally, species richness was greater on the bottom at stations, where debris provided shelter for various species. Some wharf walls (mid-depth transects), however, supported relatively high numbers of species, as well. Subsurface transects at all wharf stations tended to have the lowest number of species, with some exceptions, as did Abo Cove (Table 14). A measure of species diversity, Shannon's H' (Magurran, 1988), that adjusts species richness to consider also the influence of abundance, was highest along the mid-depth transect at Victor Wharf (Transect V_M), and then along the bottom transect at Uniform (Transect U_B). Species diversity was also relatively high on mid-depth transects at X-ray (Transect X_M) and Uniform (Transect U_M) Wharves, but also on subsurface transects at Tango (Transect T_S) and X-ray (Transect X_S) wharves. Corals, soft corals, and molluscs (mainly oysters) were present at these stations and appeared to be protected

Table 12. Relative abundance (%) of fishes observed on transects in Inner Apra Harbor. Survey sites are designated as follows: A = Abo Cove, S_M = Sierra Wharf mid-depth, S_S = Sierra Wharf subsurface, T_M = Tango Wharf mid-depth, T_S = Tango Wharf subsurface, T_B = Tango Wharf bottom, U_M = Uniform Wharf mid-depth, U_S = Uniform Wharf subsurface, U_B = Uniform Wharf bottom, V_M = Victor Wharf mid-depth, V_S = Victor Wharf subsurface, V_B = Victor Wharf bottom, X_M = X-Ray Wharf mid-depth, X_S = X-Ray Wharf subsurface, X_B = X-Ray Wharf bottom, O_1 = harbor floor 1, O_2 = harbor floor 2.

	Survey Sites																
Taxon	A	S_M	S_S	T_M	T_S	T_B	U_M	U_S	U_B	V_M	V_S	V_B	X_M	X_S	X_B	O_1	O_2
Family Clupeidae (herrings)																	
Spratelloides delicatulus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family Mugilidae (mullets)																	
Moolgarda seheli	5.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family Holocentridae (squirrelfishes)																	
Neoniphon opercularis	0	0	0	0	0.6	0	0	0	0.2	0	0	0	0	0	0	0	0
Sargocentron spiniferum	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0
Family Serranidae (groupers)																	
Epinephelus maculatus	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0
Family Apogonidae (cardinalfishes)																	
Apogon lateralis	0	97.5	64.4	28.2	0	5.8	0	0	44.6	0	0	75.4	58.9	0	89.2	0	0
Apogon leptacanthus	5.3	1	2.9	0	6	0	0	0	5	0	0	1	6	0	9	0	0
Archamia biguttata	0	0	0	0	1.2	0	0	0	2	0	0	0	0	0	0	0	0
Archamia fucata	0	0	0	0	0	5.8	0	0	0	0	0	14.1	0	0	0	0	0
Cheilodipterus quinquelineatus	68.2	0	0	0	1.2	0	0	3.1	0.2	5	0.6	3.6	0	0	0	0	0
Foa brachygramma?	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0
Rhabdamia cypselurus?	0	0	2.3	57.6	68.3	0	0	0	20	0	0	0	1.8	0	0	0	0
Sphaeramia orbicularis	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0
Family Carangidae (trevallys)																	
Caranx ignobilis	0	0	0	0.9	0	0	0	0	0	0	0	0.1	1.8	0	0	0	0
Caranx melampygus	0	0	0	0.3	0	0	0	0	0.2	0	0	0.1	0	0	0	0	0
Scomberoides lysan	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Gnathanodon speciosus	0	0	0	0	0	0	0	0	0	0	0.6	0.1	0	0	0	0	0
Family Lutjanidae (snappers)																	
Lutjanus ehrenbergi?	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0
Lutjanus fulvus	5.3	0.1	0	0	0	11.6	0	0	0	0	0	0.3	0	0	0	0	0

Table 12. Continued.

Taxon	A	S_M	S_S	T_M	T_S	T_B	U_M	U_S	U_B	V_M	V_S	V_B	X_M	X_S	X_B	O_1	O_2
	Survey Sites																
Family Lethrinidae (emperors)																	
Lethrinus harak	0	0	0	0	0	0	1.6	0	0	0	0	0.1	0	0	0	0	0
Family Haemulidae (sweetlips)																	
Plectorhinchus albovittatus	0	0	0	0	0	0	0	0	0.2	0	0	0.1	0	0	0	0	0
Family Chaetodontidae (butterflyfishes)																	
Chaetodon auriga	0	0	0	0	0	0	0	0	0.4	0	0	0.1	0.6	1	0	0	0
Chaetodon bennetti	0	0.1	0	0	0	0	1.6	0	0.6	6	7	0.1	0	0	0	0	0
Chaetodon ephippium	0	0	0	0.6	0	5.8	0	0	1.2	0	0	0.2	3	0	0	0	0
Chaetodon lunula	0	0	0	0	0.6	0	0	0	0	1	0.6	0	0.6	0	0	0	0
Chaetodon lunulatus	0	0	0	0	1.2	0	0	0	0	0	0	0	1.8	0	0	0	0
Chaetodon unimaculatus	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Chaetodon ulietensis	0	0	0	0.3	0.6	0	4.8	0	0.6	0	0	1	0	0	0	0	0
Heniochus chrysostomus	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0
Family Pomacentridae (damselfishes)																	
Amblyglyphididon ternatensis	0	0	16.9	0	2.4	0	29	81.7	0	18	78.6	0	0	0	0	0	0
Abudefduf sexfasciatus	0	0	0	0	0	0	0	0	0	0	1.2	0	2.4	0	0	0	0
Chromis viridis	0	0.2	11.7	0.3	0	0	0	0	0	19.4	0	0	0	0	0	0	0
Chrysiptera traceyi	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neopomacentrus violascens	0	0	0	0	4.8	0	0	6.1	10	0	0	0	0	1	0	0	0
Pomacentrus blue spot	0	0	0	0	0	0	0	9.1	0	0	0	0	10.1	0	0	0	0
Pomacentrus amboinensis	0	0	0	0.6	6.8	0	1.6	0	0.6	9.7	9.7	0	0	1	0	0	0
Pomacentrus pavo	0	0	0.3	0	11.1	0	3.2	0	0	7.2	5.7	0	1.2	1	0	0	0
Family Labridae (wrasses)																	
Cheilinus fasciatus	0	0	0	0	0	5.8	1.6	0	0	0	0	0	0	0	0	0	0
Cheilinus trilobatus	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
Family Blenniidae (blennies)																	
Ecsenius bicolor	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Meiacanthus atrodorsalis	0	0	0	0	0	0	1.6	0	0	0	0	0	0	0	0	0	0
Petroscirtes mitratus	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0
Blue dorsal spot tube blenny	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Table 12. Continued.

	Survey Sites																
Taxon	A	S_M	S_S	T_M	T_S	T_B	U_M	U_S	U_B	V_M	V_S	V_B	X_M	X_S	X_B	O_1	O_2
Family Gobiidae (gobies)																	
Amblygobius nocturnus	0	0	0	0	0	11.6	0	0	2.4	0	0	5	0	0	0	0	0
Amblygobius phaelena	0	0	1.5	0.3	0.6	0	1.6	0	0.2	0	1.2	0.2	0.6	0	0	0	0
Asterropteryx semipunctatus	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0
Cryptocentrus strigilliceps	5.3	0	0	0	0	0	0	0	0	0	0	0	0	0	1.8	0	0
Cristatogobius sp. A	0	0	0	0	0	11.6	0	0	0.4	0	0	6	0	0	0	0	0
Ctenogobiops feroculus	5.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62.5	90
Gnatholepis cauerensis	5.3	0	0	0	0	5.8	0	0	4.2	0	0	0	0	0	0	0	0
Oplopomus oplopomus	0	0	0	0	0	0	0	0	0.2	0	0	0.2	0	0	0	12.5	0
Oxyurichthys papuensis	0	0	0	0	0	0	0	0	2.6	0	0	0.2	0	0	0	25	10
Paragobiodon lacunicolus	0	0	0	0	0	0	1.6	0	0	0	0	0	0	0	0	0	0
Priolepis cincta	0	0	0	0	0.6	0	0	0	0	3	0.6	0	0	0	0	0	0
Family Zanclidae (Moorish Idol)																	
Zanclus cornutus	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Family Siganidae (rabbitfishes)																	
Siganus argenteus	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0
Family Acanthuridae (surgeonfishes)																	
Acanthurus blochii	0	0	0	0.3	0	36.2	19.4	0	0	11.3	0	2.8	11.2	0	0	0	0
Acanthurus xanthopterus	0	0	0	2.5	0	0	32.4	0	0	15.4	0	0	0	1	0	0	0
Zebrasoma veliferum	0	0	0	0	0	0	0	0	0.6	0	0.6	0.1	1.8	0	0	0	0
Family Balistidae (triggerfishes)																	
Balistoides viridescens	0	0	0	0.3	0	0	0	0	0.6	0	0	0.1	0	0	0	0	0
Rhinecanthus aculeatus	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0
Family Tetraodontidae (pufferfishes)																	
Canthigaster solandri	0	0	0	0.3	0	0	0	0	0.2	0	0.6	0	1.2	0	0	0	0
Total individuals	**19**	**1025**	**343**	**346**	**162**	**17**	**62**	**33**	**528**	**97**	**157**	**632**	**179**	**17**	**56**	**16**	**10**

by ship fenders that effectively prevented ship hulls from damaging these microhabitats, thus making them available to fishes for shelter.

Densities of fish species (no. individuals/m^2) at each station are given in Table 13. Small, structure-associated cardinalfishes had the greatest density among stations. *Apogon lateralis* (Apogonidae) densities where high at Sierra Wharf (20/m^2 at mid-depth and 4.4/m^2 at subsurface depth), Victor Wharf (4.5/m^2 at the bottom), Uniform Wharf (2.5/m^2 at the bottom), and X-ray Wharf (2.06/m^2 at mid-depth). Another cardinalfish, the apparently invasive *Rhabdamia cypselerus*, had relatively high densities at Sierra Wharf (8/m^2 at subsurface depth) and Tango Wharf (4/m^2 at mid-depth and 2/m^2 at subsurface depth). Both species tended to occur in aggregations of several individuals. The invasive damselfish, *Amblyglyphididon ternatensis* (Pomacentridae), was relatively dense at Victor Wharf (2.24/m^2 at mid-depth) and Sierra Wharf (1.16 per m^2 subsurface depth). This species occurred in aggregations as well; many were juveniles. Densities of other species were low to very low and ranged from 0.0033/m^2 to1.0/m^2 (Table 13).

The similarity of species composition between stations and transect depths was examined with multiple dimension scaling analysis (Figure 12). The meager fish assemblages of the two harbor floor transects (Transect 1 and Transect 2) formed a distinct group. The fish assemblages on the Abo Cove and Tango Wharf-bottom transects formed a group, as well. The mid-depth and subsurface transects at Uniform and Victor wharves formed a distinct group, too, as did the subsurface transect at X-ray Wharf. Finally, the fish assemblages on the subsurface transects at Sierra and Tango wharves, the mid-depth transects at Sierra, Tango and X-ray wharves, and the bottom transects at Uniform, Victor, and X-ray wharves, all formed a distinct group. A stress level of 0.11 indicated a moderate confidence in the analysis results (Clarke and Gorley, 2001). Analysis of similarity (ANOSIM) between stations (locality and depth treated as a station) indicated that there were only weakly significant differences between them (Global R = 0.21). Thus, the fish faunas of each tended to share many of the same species typical of protected and turbid waters, while differences can be attributed to the presence of seemingly unusual species (i.e., butterflyfishes normally seen in clear or less-turbid reef systems) associated with structure on some transects or the simple absence of species, other than some burrowing gobies, on others (i.e., Transect 1 and Transect 2).

Essential Fish Habitat

Qualitative measures of habitat utilization by fishes were limited to observations of association between species and habitat and microhabitat types (Table 14). Major habitat types were reefs (Abo Cove), wharves (all stations except Abo Cove and the harbor floor transects), or harbor floor. Microhabitats included corals, debris (hanging and deposited on the bottom), rubble, rocks, soft corals, sand, shells, or the water column), and wharf faces and pilings. Corals, soft corals, and shells were usually found on the wharf faces, as well.

Overall, wharves provided considerable habitat for a diverse array of fishes compared to the reef at Abo Cove or the harbor floor offshore from the wharves (Table 14). Microhabitats associated with wharves included coral, debris, shell, and soft corals that were attached to a wharf, the wharf wall and associated structures (pilings, fenders, pipes, cables, etc.), debris, rubble, rock, and sand at the base of the wharf wall, and the water column directly adjacent to the wharf. Most species were associated with one or more of these microhabitats. Benthic

Table 13. Density of fishes (no./m²) on transects in Inner Apra Harbor. Survey sites are designated as follows: A = Abo Cove, S_M = Sierra Wharf mid-depth, S_S = Sierra Wharf subsurface, T_M = Tango Wharf mid-depth, T_S = Tango Wharf subsurface, T_B = Tango Wharf bottom, U_M = Uniform Wharf mid-depth, U_S = Uniform Wharf subsurface, U_B = Uniform Wharf bottom, V_M = Victor Wharf mid-depth, V_S = Victor Wharf subsurface, V_B = Victor Wharf bottom, X_M = X-Ray Wharf mid-depth, X_S = X-Ray Wharf subsurface, X_B = X-Ray Wharf bottom, 1 = Transect 1 (harbor floor), 2 = Transect 2 (harbor floor).

	Survey Sites																
Taxon	A	S_M	S_S	T_M	T_S	T_B	U_M	U_S	U_B	V_M	V_S	V_B	X_M	X_S	X_B	1	2
Family Clupeidae (herrings)																	
Spratelloides delicatulus	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family Mugilidae (mullets)																	
Moolgarda seheli	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Family Holocentridae (squirrelfishes)																	
Neoniphon opercularis	0	0	0	0	0.02	0	0	0	0.01	0	0	0	0	0	0	0	0
Sargocentron spiniferum	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0
Family Serranidae (groupers)																	
Epinephelus maculatus	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Family Apogonidae (cardinalfishes)																	
Apogon lateralis	0	20	4.4	2	0	0.01	0	0	2.5	0	0	4.5	2.06	0	0.5	0	0
Apogon leptacanthus	0.01	0.2	0.2	0	0.2	0	0	0	0.25	0	0	0.1	0.2	0	0.05	0	0
Archamia biguttata	0	0	0	0	0.04	0	0	0	0.1	0	0	0	0	0	0	0	0
Archamia fucata	0	0	0	0	0	1	0	0	0	0	0	0.89	0	0	0	0	0
Cheilodipterus quinquelineatus	0.13	0	0	0	0.04	0.01	0	0.02	0.01	0.1	0.02	0.23	0	0	0	0	0
Foa brachygramma?	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0
Rhabdamia cypselurus?	0	0	8	4	2	0	0	0	0.01	0	0	0	0.06	0	0	0	0
Sphaeramia orbicularis	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0
Family Carangidae (trevallys)																	
Caranx ignobilis	0	0	0	0.06	0	0	0	0	0	0	0	0.01	0.06	0	0	0	0
Caranx melampygus	0	0	0	0.02	0	0	0	0	0.05	0	0	0.01	0	0	0	0	0
Scomberoides lysan	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0
Gnathanodon speciosus	0	0	0	0	0	0	0	0	0	0	0.02	0.01	0	0	0	0	0
Family Lutjanidae (snappers)																	
Lutjanus ehrenbergi?	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0
Lutjanus fulvus	0.01	0.02	0	0	0	0.02	0	0	0	0	0	0.03	0	0	0	0	0
Family Lethrinidae (emperors)																	
Lethrinus harak	0	0	0	0	0	0	0.02	0	0	0	0	0.01	0	0	0	0	0
Family Haemulidae (sweetlips)																	
Plectorhinchus albovittatus	0	0	0	0	0	0	0	0	0.01	0	0	0.01	0	0	0	0	0
Family Chaetodontidae (butterflyfishes)																	
Chaetodon auriga	0	0	0	0	0	0	0	0	0.02	0	0	0.01	0.02	0.02	0	0	0
Chaetodon bennetti	0	0.02	0	0	0	0	0.02	0	0.03	0.12	0.22	0.01	0	0	0	0	0

Table 13. Continued.

Taxon	Survey Sites																
	A	S_M	S_S	T_M	T_S	T_B	U_M	U_S	U_B	V_M	V_S	V_B	X_M	X_S	X_B	1	2
Family Chaetodontidae (butterflyfishes)																	
Chaetodon ephippium	0	0	0	0.04	0	0.02	0	0	0.06	0	0	0.02	0.1	0	0	0	0
Chaetodon lunula	0	0	0	0	0.02	0	0	0	0	0.02	0.02	0	0.02	0	0	0	0
Chaetodon lunulatus	0	0	0	0	0.04	0	0	0	0	0	0	0	0.06	0	0	0	0
Chaetodon unimaculatus	0	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0
Chaetodon ulietensis	0	0	0	0.02	0.02	0	0.06	0	0.03	0	0	0.1	0	0	0	0	0
Heniochus chrysostomus	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0
Family Pomacentridae (damselfishes)																	
Amblyglyphididon ternatensis	0	0	1.16	0	0.08	0	0.36	0.54	0	0.36	2.24	0	0	0	0	0	0
Abudefduf sexfasciatus	0	0	0	0	0	0	0	0	0	0	0.04	0	0.08	0	0	0	0
Chromis viridis	0	0.04	0.8	0.02	0	0	0	0	0	0.4	0	0	0	0	0	0	0
Chrysiptera traceyi	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neopomacentrus violascens	0	0	0	0	0.16	0	0	0.04	0.5	0	0	0	0	0.02	0	0	0
Pomacentrus blue spot	0	0	0	0	0	0	0	0.06	0	0	0	0	0.36	0	0	0	0
Pomacentrus amboinensis	0	0	0	0.04	0.22	0	0.02	0	0.03	0.2	0.3	0	0	0.02	0	0	0
Pomacentrus pavo	0	0	0.02	0	0.36	0	0.04	0	0	0.14	0.18	0	0.04	0.02	0	0	0
Family Labridae (wrasses)																	
Cheilinus fasciatus	0	0	0	0	0	0.01	0.02	0	0	0	0	0	0	0	0	0	0
Cheilinus trilobatus	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
Family Blenniidae (blennies)																	
Ecsenius bicolor	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Meiacanthus atrodorsalis	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0
Petroscirtes mitratus	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0
Blue dorsal spot tube blenny	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0	0	0
Family Gobiidae (gobies)																	
Amblygobius nocturnus	0	0	0	0	0	0.02	0	0	0.12	0	0	0.05	0	0	0	0	0
Amblygobius phaelena	0	0	0.1	0.02	0.02	0	0.02	0	0.01	0	0.04	0.02	0.02	0	0	0	0
Asterropteryx semipunctatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
Cryptocentrus strigilliceps	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0
Cristatogobius sp. A	0	0	0	0	0	0.02	0	0	0.02	0	0	0.06	0	0	0	0	0
Ctenogobiops feroculus	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.03
Gnatholepis cauerensis	0.01	0	0	0	0	0.01	0	0	0.21	0	0	0	0	0	0	0	0
Oplopomus oplopomus	0	0	0	0	0	0	0	0	0.01	0	0	0.02	0	0	0	0.004	0
Oxyurichthys papuensis	0	0	0	0	0	0	0	0	0.13	0	0	0.02	0	0	0	0.008	0.0033
Paragobiodon lacunicolus	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0
Priolepis cincta	0	0	0	0	0.02	0	0	0	0	0.06	0.02	0	0	0	0	0	0

Table 13. Continued.

Taxon	Survey Sites																
	A	S_M	S_S	T_M	T_S	T_B	U_M	U_S	U_B	V_M	V_S	V_B	X_M	X_S	X_B	1	2
Family Zanclidae (Moorish Idol)																	
Zanclus cornutus	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0
Family Siganidae (rabbitfishes)																	
Siganus argenteus	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0
Family Acanthuridae (surgeonfishes)																	
Acanthurus blochii	0	0	0	0.02	0	0.05	0.24	0	0	0.22	0	0.18	0.4	0	0	0	0
Acanthurus xanthopterus	0	0	0	0.38	0	0	0.4	0	0	0.3	0	0	0	0.02	0	0	0
Zebrasoma veliferum	0	0	0	0	0	0	0	0	0.03	0	0.02	0.01	0.06	0	0	0	0
Family Balistidae (triggerfishes)																	
Balistoides viridescens	0	0	0	0.02	0	0	0	0	0.03	0	0	0.01	0	0	0	0	0
Rhinecanthus aculeatus	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0
Family Tetraodontidae (pufferfishes)																	
Canthigaster solandri	0	0	0	0.02	0	0	0	0	0.01	0	0.02	0	0.04	0	0	0	0

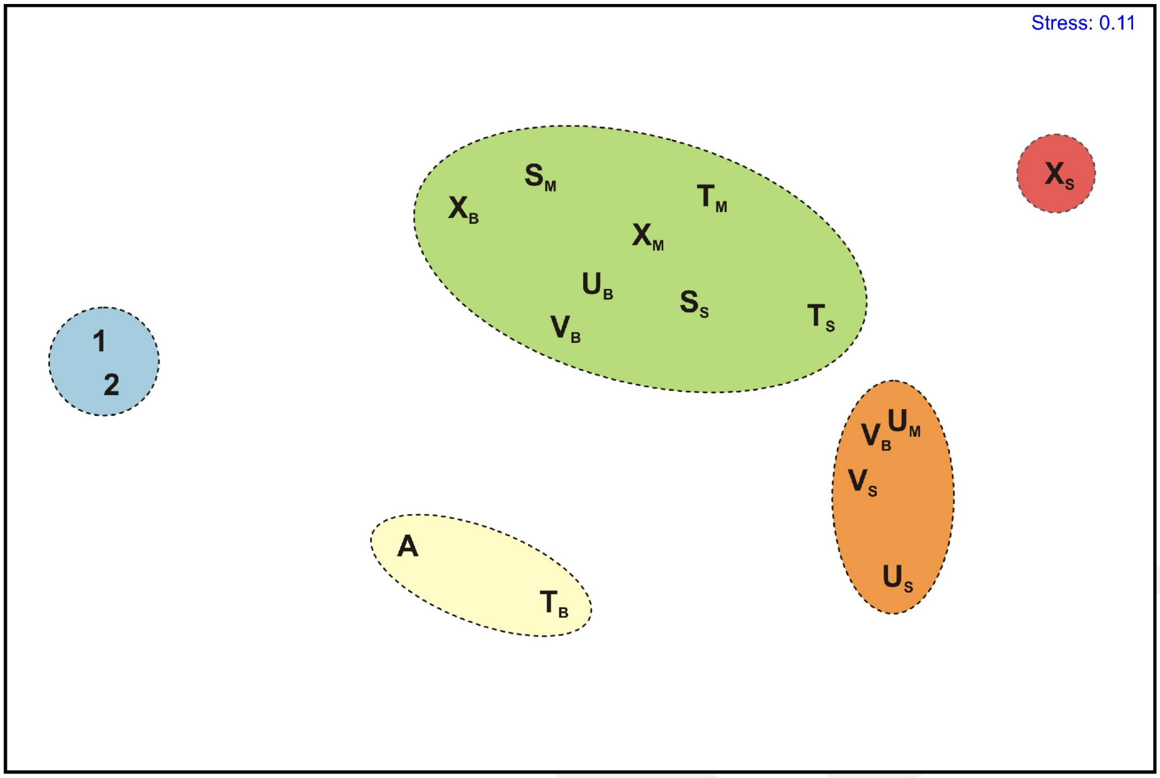

Figure 12. Multiple dimensional scaling (MDS) analysis of fish assemblages observed on transects in Inner Apra Harbor. Five distinct groups are recognized based upon similarities in fish faunal composition. Transect abbreviations are given in Table 12.

species such as cardinalfishes, damselfishes and gobies favored corals, debris, shells, sand, soft corals, and the wharf wall and pilings. Species that were active swimmers, such as butterflyfishes (Chaetodontidae), emperors (Lethrinidae), snappers (Lutjanidae), surgeonfishes (Acanthuridae), sweetlips (Haemulidae), trevallys and jacks (Carangidae), etc., were found in the water column directly adjacent to the wharves.

On the reef at Abo Cove, cardinalfishes were observed with corals or rock, gobies with sand, mullet (Mugilidae) with rubble or sand, and a snapper with sand (Table 14). Visibility was exceptionally poor at Abo Cove during the survey, and it is expected that other species listed for the wharf transects would be present as well, particularly at high tide. The harbor floor transects, also surveyed under conditions of poor visibility, had burrowing gobies associated with fine sand, only (Table 14).

Threatened and Endangered Species

High turbidity levels in Inner Apra Harbor limited visibility (<5 m)of highly motile species, especially vertebrate organisms. Despite this constraint, we observed a single green

Table 14. Habitat and microhabitat associations of fishes in the Inner Apra Harbor. Associations listed are based upon qualitative observations. Station codes are defined in Table F1. Habitat codes are: SB = soft bottom (harbor floor), R = coral reef, and W = wharf. Microhabitat codes are: C = coral, D = debris, Rb = rubble, Rk = rock, Sc = soft coral, Sd = sand, Sh = shell, Wc = water column, and Wp = wharf wall and pilings.

	Survey Sites																
Taxon	A	S_M	S_S	T_M	T_S	T_B	U_M	U_S	U_B	V_M	V_S	V_B	X_M	X_S	X_B	1	2
Family Clupeidae																	
Spratelloides delicatulus		W;Wc															
Family Mugilidae																	
Moolgarda seheli	R;Rb,Sd																
Family Holocentridae																	
Neoniphon opercularis					W;Wp				W;D								
Sargocentron spiniferum				W;Wp													
Family Serranidae																	
Epinephelus maculatus									W;D								
Family Apogonidae																	
Apogon lateralis		W;C,Wp	W;C,Wp	W;C,Wp		W;D			W;D			W;D	W;C		W;D		
Apogon leptacanthus	R;C,Rk	W;C,Sc	W;C,Wp		W;C,Wp				W;D			W;D	W;C		W;D		
Archamia biguttata					W;C,Wp				W;D								
Archamia fucata						W;D						W;D					
Cheilodipterus quinquelineatus	R;C,Rk				W;C,Wp			W;Wp	W;D	W;Wp	W;Wp	W;D					
Foa brachygramma?									W;D								
Rhabdamia cypselurus?			W;C,Wp	W;C,Wp	W;C,Wp				W;D				W;C				
Sphaeramia orbicularis														W;Wp			
Family Carangidae																	
Caranx ignobilis				W:Wc								W;Wc	W;Wc				
Caranx melampygus				W;Wc					W;Wc			W;Wc					
Scomberoides lysan				W;Wc													
Gnathanodon speciosus											W;Wc	W;Wc					
Family Lutjanidae																	
Lutjanus ehrenbergi?									W;Sd								
Lutjanus fulvus	R;Sd	W;Wc				W;Wc						W;Wc					
Family Lethrinidae																	
Lethrinus harak							W;Wc					W;Wc					
Family Haemulidae																	
Plectorhinchus albovittatus									W;D			W;Wc					
Family Chaetodontidae																	
Chaetodon auriga									W;D			W;Wc	W;Wp	W;Wp			
Chaetodon bennetti		W;Wc					W;Wc		W;D	W;Wc	W;Wc	W;Wc					
Chaetodon ephippium				W;Wc		W;Wc			W;D			W;Wc	W;Wp				
Chaetodon lunula					W;Wc					W;Wc	W;Wc		W;Wp				
Chaetodon lunulatus					W;Wc								W;Wp				
Chaetodon unimaculatus										W;Wc							
Chaetodon ulietensis				W;Wc	W;Wc		W;Wc		W;D			W;Wc					

Table 14. Continued.

Taxon	Survey Sites																
	A	S_M	S_S	T_M	T_S	T_B	U_M	U_S	U_B	V_M	V_S	V_B	X_M	X_S	X_B	1	2
Family Chaetodontidae																	
Heniochus chrysostomus									W;D								
Family Pomacentridae																	
Amblyglyphididon ternatensis			W;Wc		W;C,Sc		W;Wp	W;Wp		W;Wp	W;Wp						
Abudefduf sexfasciatus											W;Wp		W;Wp				
Chromis viridis		W;C,Wp	W;C,Wp	W;C,Wp						W;C,Wp							
Chrysiptera traceyi			W;Wp														
Neopomacentrus violascens					W;Wp			W;Wp	W;D					W;C,Wp			
Pomacentrus blue spot								W;Wp					W;Wp				
Pomacentrus amboinensis				W;Wp	W;Wp		W;Wp		W;D	W;Wp	W;Wp			W;Wp			
Pomacentrus pavo			W;D,Wp		W;C,Wp					W;Wp	W;Wp		W;Wp	W;Wp			
Family Labridae																	
Cheilinus fasciatus						W;Wc	W;Wc										
Cheilinus trilobatus												W;Wc					
Family Blenniidae																	
Ecsenius bicolor		W;Sh,Wp															
Meiacanthus atrodorsalis							W;Wp,Sh										
Petroscirtes mitratus				W;Sh,Wp													
Blue dorsal spot tube blenny														W;Wp			
Family Gobiidae																	
Amblygobius nocturnus						W;Wp			W;D,Sd			W;Sd					
Amblygobius phaelena			W;Wp	W;Wp	W;Wp		W;Wp		W;D,Sd		W;Wp	W;Sd	W;Wp				
Asterropteryx semipunctatus														W;Wp			
Cryptocentrus strigilliceps	R;Sd														W;Sd		
Cristatogobius sp. A						W;Sd			W;Sd			W;Sd					
Ctenogobiops feroculus	R;Sd															SB;Sd	SB;Sd
Gnatholepis cauerensis	R;Sd					W;Sd			W;Sd								
Oplopomus oplopomus									W;Sd			W;Sd				SB;Sd	
Oxyurichthys papuensis									W;Sd			W;Sd				SB;Sd	SB;Sd
Paragobiodon lacunicolus							W;C										
Priolepis cincta					W;Wp					W;Wp	W;Wp						
Family Zanclidae																	
Zanclus cornutus									W;Wc								
Family Siganidae																	
Siganus argenteus									W;Wc								
Family Acanthuridae																	
Acanthurus blochii				W;Wc		W;Wc	W;Wc			W;Wc		W;Wc	W;Wc				
Acanthurus xanthopterus				W'Wc			W;Wc			W;Wc				W;Wp			
Zebrasoma veliferum									W;Wc		W;Wc	W;Wc	W;Wc				

Table 14. Continued.

	Survey Sites																
Taxon	A	S_M	S_S	T_M	T_S	T_B	U_M	U_S	U_B	V_M	V_S	V_B	X_M	X_S	X_B	1	2
Family Balistidae																	
Balistoides viridescens				W;Wc					W;D,Wp			W;D,Wc					
Rhinecanthus aculeatus				W;Wp													
Family Tetraodontidae																	
Canthigaster solandri				W;Wp					W;D,Wp		W;D,Wc		W;Wp				

turtle from the boat in waters between Abo Cove and the southern end of Victor Wharf. *Chelonia mydas* is listed as a threatened species under the U.S. Endangered Species Act. The individual that we observed was small (0.5–1.0 m carapace length), and it dove immediately after a quick breath. Because of the fine-grained, muddy composition of the shoreline of Inner Apra Harbor, the beaches in the vicinity are not considered as potential nesting sites for endangered and threatened marine turtles known to occur in the seas around Guam. The nearest documented nesting beaches are near Gabgab Beach, in the outer harbor. Therefore, we presume the individual that we sighted was foraging.

Habitat Areas of Particular Concern (HAPC)

None of the three areas of Apra Harbor recognized by Paulay et al. (2001a) for their species richness and unique biota are encompassed by Inner Apra Harbor. These authors described the inner harbor as the most altered area with Apra Harbor, while remarking on the presence of uncommon species, such as *Porites convexa*, and the abundance of the hammer oyster *Malleus decurtatus* on wharf faces.

Inner Apra Harbor lies at the extreme end of the gradient of increasing turbidity, abundance of plankton and benthic suspension feeders, and finer sediments. The harbor continues to support thriving marine communities, despite the extensive dredging and filling operations that significantly altered the area after World War II. Data from this study indicate that Abo Cove is unique and deserves special attention in managing the natural resources of the inner harbor. As Paulay et al. (2001a) noted, Apra Harbor is unlike other major ports, where communities of marine organisms tend to be greatly degraded. Therefore, we advise decision-makers not to extrapolate data from the current study to other areas within Inner Apra Harbor that were not within the scope of this study, especially the inner Abo Cove embayment and the mangrove area at the mouth of the Atantano River.

SUMMARY

This study shows a clear difference between the most authentic inner harbor habitats at Abo Cove and the manmade wharfs. Because of its restricted spatial extent, the distinct benthic assemblages, and the relatively high coral cover, Abo Cove deserves special attention in managing the natural resources of the inner harbor. Ironically, the artificial and most anthropogenically impacted habitats of the wharfs might contribute most to the biotic richness and diversity of the inner harbor. The synoptic account of the benthic invertebrates is indicative of unique benthic fauna, especially so for the sponges. Hence, more extensive taxonomic surveys are warranted to assess the biological value of the inner harbor, as well as its potential as an area for potential establishment of invasive species.

The coral fauna of the study area consisted of 30 species, or about 10% of the coral fauna of Guam (see Randall, 2003). The predominant corals were massive *Porites* spp., one of which exceeded 1 m in diameter at Abo Cove. The coral assemblage in Inner Apra Harbor is characteristic of environments with high levels of sedimentation and turbidity, with the most common species, in order of tolerance to these conditions, being *Porites lutea*, *Pocillopora damicornis*, and *Leptastrea* *purpurea* (Amesbury et al., 1977). Coral species richness is highest on relatively sediment-free, hard substrates on vertical faces of wharves.

Macroinvertebrates communities in the inner harbor were only moderately diverse, with 30 species observed on or near transects. As for corals, availability of sediment-free hard substrate for sessile and sedentary macroinvertebrates is a limiting factor on horizontal surface. On the harbor floor, macroinvertebrates were limited to scattered debris that provided on the only hard substrate available. Macroinvertebrate assemblages in the inner harbor were dominated by suspension-feeding species, which comprised 100% of the species occurring on transects and 90% of all species observed. Except for a single species of marine snail, no macroinvertebrates were observed on the soft sediments of the harbor floor.

The species richness and diversity of the fish fauna within the Inner Harbor are relatively low compared to habitats elsewhere on Guam (Donaldson, unpublished data). However, the fauna is highly adapted and representative of protected and turbid habitats usually associated with mangroves, estuaries, and back reefs, with some exceptions. A considerable amount of habitat is provided by artificial shelter in the form of wharves, and the microhabitats found on or adjacent to those wharves was utilized by many species of fishes. Larval fishes of these species could have settled and recruited to these habitats and microhabitats, either through natural stochastic processes or by transport (i.e., bilge water), and became established at each of the stations. Many of the individuals of these species were juveniles or subadults. Alternatively, some species, particularly those that swim actively in the water column, may have colonized these habitats as adults after swimming to them from outside of the inner harbor.

Perhaps the only relatively unique species present at most or all stations are the bottom-dwelling, burrowing goby species that may be specific only to sand bottoms in back bay or estuarine areas. The extent of the distribution of these species is not well known, however, because of the generally poor visibility encountered in such areas (i.e., Inner Apra Harbor and Sasa Bay in western Guam, and the estuaries of the Pago, Ylig, and Talofofo Rivers in eastern Guam).

RECOMMENDATIONS

During the planning phase for construction and renovation of facilities and training sites surveyed in Inner Apra Harbor in this study, the following recommendations should be given consideration.

1. **Abo Cove and its associated coral reefs deserve special attention in managing the natural resources of the inner harbor.**
   Despite its restricted spatial extent, Abo Cove is unique within the inner harbor because of the coral reefs that have developed there. The reef is characterized by relatively high coral cover and the largest coral colonies in the area studied. Further, Abo Cove supports distinct benthic assemblages of sponges, corals, and macroinvertebrates (see Figures 8, 9, and 11). Therefore, renovation and construction activities requiring dredging and filling in and adjacent to Abo Cove should have the lowest priority. A minimum buffer zone of 400 feet should be maintained between Abo Cove and all dredge and fill activities in the inner harbor.

If Abo Cove is selected for development, a compensatory mitigation plan should be developed for review by the appropriate agencies and authorities. To the extent possible and appropriate, any mitigation project should be "on-site" and "in-kind" (PBS&J, 2008), with consideration given to relocation of the corals to a similar environment, like that in the outer portion of Sasa Bay in the outer harbor. Biological monitoring should be required for any project that is proposed for construction in the vicinity of Abo Cove.

2. **Floating turbidity curtains, extending from the surface to the lagoon floor, should be placed completely around all dredge and fill sites, and turbidity curtains should be routinely monitored and maintained to contain silt produced by construction.**
Dredge and fill operations produce large quantities of fine silt particles suspended in the water column. Turbidity and sedimentation are significant problems for coral reefs surrounding high islands or in coastal areas of continents. Sediments may have an energetic cost to the coral that must cleanse its surface, resulting in slower growth rates and in less energy available for reproduction (Tomascik and Sander, 1987; Wolanski et al., 2003). Sediments can also interfere with larval recruitment on coral reefs by interfering with the chemosensory ability of coral larvae seeking the appropriate chemical signals from preferred settlement substrates, such as coralline algae (Richmond, 1997). Turbidity curtains can be effective in confining suspended sediments when properly deployed and maintained. Removal of the turbidity barriers and the related components is vital once the project activities are complete. Failure to do so can cause the barrier to come loose from its anchors and entangle benthic and other marine organisms (PBS&J, 2008).

3. **All dredge and fill operations should be suspended during the period of the annual coral spawning event in Guam waters.**
Some 85% of reef-building corals are spawners, i.e., reproduction occurs after the release of gametes into the water, where fertilization takes place (Richmond, 1997). Multispecies mass-spawning events occur during limited periods each year. To maximize reproductive success, most spawning species release their gametes over a 5–8-day period that is related to the lunar cycle. Studies in Guam revealed that peak spawning occurs 7–10 days after the full moon in July (Richmond and Hunter, 1990). Because suspended sediments may interfere with egg-sperm interactions in the fertilization process (Richmond, 1997; Wolanski et al., 2003), dredge and fill operations can affect coral reproduction on reefs far down current of the actual construction activities.

Construction windows are a management tool to map out the times of year during which coastal construction may be limited due to the presence of threatened or endangered species or other sensitive marine life (PBS&J, 2008). Construction windows may consider wildlife activity such as coral spawning and coral bleaching. U.S. Army Corps of Engineers permits for maintenance dredging of the Naval Base require that dredging operations cease during annual coral spawning periods in Guam (M.E. Guarin, P.E., Construction Management Engineer, NAVFAC OICC Marianas, personal communication, April 27, 2004).

4. **Marine biological communities should be monitored during and after dredge and fill operations in Inner Apra Harbor.**
Monitoring studies on small, tropical islands have shown that precautions for environmental protection can limit the effects of dredge and fill operations on nearby marine communities.

Amesbury et al. (1982) identified few measurable effects related to construction of the airport runway extension at Weno Island, Chuuk [= Moen Island, Truk]. However, these authors reported that fluctuations in species richness, percent cover, and population density of several taxa occurred during the construction period. Where siltation was heaviest, the decline in coral coverage was significant, and no evidence of new coral recruitment was found one year after the completion of runway construction. Marine plants, macroinvertebrates, and reef fishes also declined at those monitoring stations that were inundated with sediments.

Biological monitoring should be required for any project that is proposed for construction in Inner Apra harbor , especially in the vicinity of Abo Cove, so that any damage to coral communities caused by sedimentation can be identified promptly and so that the necessary measures can be taken to minimize any damage. Monitoring is necessary to determine any direct or indirect biological impacts to the ecosystem caused by physical and/or chemical changes to the environment as a result of the project.

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