CUMULATIVE AND SECONDARY IMPACTS: SEAWALKER, SCUBA BOB AND THE FISH EYE UNDERWATER OBSERVATORY, PITI AND COCOS LAGOON, GUAM

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UNIVERSITY OF GUAM

Marine Laboratory

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INTRODUCTION

The Guam Coastal Management Program (GCMP) contracted the University of Guam

Marine Laboratory to assess the cumulative and secondary impacts, i.e., repetitive occurrences within a confined area, of three marine recreational activities, i.e., Fish Eye underwater observatory in Piti, seawalkers in Piti and Cocos Lagoon, and Scuba BOB (Breathing Observation Bubble) in Cocos Lagoon. The Memorandum of Understanding (MOU) between the Bureau of Statistics and Plans (BS&P) and University of Guam (UOG) Marine Laboratory was effectuated on 29 September 2003 with the Governor's signature; a copy of the effective MOU was provided to the UOG Marine Laboratory 17 days later on 16 October 2003. The later date of 16 October 2003 is used as the effective date of the project.

SCOPE OF WORK

The Scope of Work was four-fold, i.e., (1) to organize and summarize the historic physical, chemical and biological information of each recreational site, (2) to design a sampling plan whereby quantitative data were generated to assess impacts, if any, of the three marine recreational activities on their surrounding marine environments, (3) to conduct field studies and laboratory analyses applicable to the potential impact of the recreational activities, and (4) to provide a report, with analytical statistics, on the studies within six months of the effective date of the project which includes entering data into an appropriate database.

DESCRIPTION OF RECREATIONAL ACTIVITIES

Fish Eye Underwater Observatory, Piti

The Fish Eye underwater observatory, operated by Fish Eye Marine Park, is located in a natural sink (karst formation) at a depth of 30 to 32 feet (9.1 to 9.7 meters) at mean lower low water (MLLW) on the reef flats of Piti Bay. The observatory is accessed from shore via a 6-foot (1.8-m) wide and 950-foot (290-m) long ramp.

Underwater observations indicate that shading, though slight, can impact the marine environment, but only along the terminal 50 to 60 meters of the ramp. The slight shading is caused by the added presence of the 24-foot (7.3 m) wide and 33-foot (10.2 m) long seawalker pontoon raft, moored adjacent and west of the 6-foot wide ramp. The 36-foot (11-m) diameter underwater observatory structure is situated at the terminus of the ramp and only 46 meters seaward of the seawalker pontoon raft. The 6-foot (1.8 m) wide ramp is elevated approximately 16 feet (4.8 m) above MLLW in such manner that there is no visible shading effect along the remaining length beneath or adjacent to the ramp. The cylindrical concrete supports of the ramp are clean of fouling marine organisms, except for corals, and are obviously cleaned on a scheduled basis.

The second type of direct impact is the practice of fish feeding stations at the underwater observatory structure and the nearby seawalker site which attract a considerable amount of fish to the area; fish are already attracted to the underwater vertical underwater observatory and the pontoon raft.

Collateral marine recreational activities, i.e., snorkeling, kayaking and scuba diving in the area, must be considered as a third direct impact when studying the cumulative and secondary impact of the underwater observatory. Snorkeling and kayaking are available to seawalker customers. Dive companies use the shallow limestone pavement east of the ramp and the primary sink as their outdoor scuba classroom. On 3 November 2003, approximately 20 individuals were receiving scuba lessons in the water at 1000 in the morning.

Seawalkers, Piti and Cocos Lagoon

The seawalkers, operated by Seawalker Tours, allow individuals to walk with an aerated bubble helmet within confined areas on the bottom of the reef floor at a depth of 25 feet (7.6 meters) for approximately 20 minutes at both Piti, i.e., adjacent to the Fish Eye Underwater Observatory ramp, and at the southwest sector of Cocos Lagoon. At the Piti site, the customers walk on metal grills and are guided by a fence-like railing along a U-shaped trail. At Cocos, the customers descend the pontoon raft and walk on the sand guided by a rope. Employees with scuba gear accompany the seawalkers and feed the fish directly in front of them, thus, attracting a multitude of reef fish to the immediate area. The obvious cumulative and secondary impact of seawalkers is the routine fish feeding stations in the immediate vicinity of the underwater path.

Scuba BOB, Cocos Lagoon

The “Breathing Observation Bubble” or BOB, operated by Scuba BOB, allows an individual to navigate for approximately 20 minutes below the surface of the water but above the substrata in waters 15 feet (4.6 meters) deep in an upright 400-pound scooter, powered electrically, while tethered by a line to a surface buoy. The vehicle never touches the substrata and, thus, there is no impact on the substrata. Employees with scuba gear accompany the customers and feed the fish along the route.

HISTORICAL INFORMATION ON SITES

Piti Bay

A search of past references on physical, chemical and biological parameters of Piti Bay indicates that the majority of data is applicable to the southwest sector of the Bay adjacent to Tepungan Channel, i.e., associated with Piti and Cabras Power Plants, and located approximately 1.7 kilometers (km) west of the Fish Eye Underwater Observatory. Emery (1962) discussed the geological characteristics of Piti Bay. Taylor (1986) studied the diets of sand-living predatory gastropods in the sink which is presently occupied by the underwater observatory in Piti Bay.

PBEC, Inc. (1991) provided baseline physical and biological information of the sink prior to the construction of the underwater observatory. Water movement in the sink was erratic and ranged from 0.01 to 0.2 meters per second, and salinity measurements of surface and bottom samples were 32 and 33 parts per thousand (ppt), respectively. Based on four 5-minute counts, 23 species of fish were observed along the slope and 19 species of fish were observed at the bottom of the sink at a depth of 10 meters. Twenty five species of marine benthic algae were observed along the slope while 15 species were present on the bottom of the sink. PBEC, Inc. (1991) provided a quantitative checklist of the corals along the path of the ramp and in the sink. Other macroinvertebrate fauna were reported as sparse within the sink.

Cocos Lagoon

Matson (1989) includes information on the coastal marine sediments obtained from Cocos

Lagoon in his study of the biogeochemistry of coastal sediments from Guam and Saipan. Denton et al. (1997) reported high copper and zinc in sediments from the Merizo Pier. The algae, corals, other macroinvertebrates and fish within Cocos Lagoon are quantified in two technical reports (Randall et al., 1975 and Randall and Sherwood, 1982). The past studies, however, do not include any transects conducted within the present study area. Randall et al. (1975) reported 5 species of cyanobacteria and 41 species of macroalgae observed throughout the shallow lagoon waters; Davis (1982) reported 5 species of cyanobacteria, 34 species of macroalgae and 2 species of seagrasses in the shallow sandy lagoon habitat. Other studies conducted in Cocos Lagoon include geology (Emery, 1962), algal succession on artificial tire reefs (Tsuda and Kami, 1973), fish diversity (Jones and Chase, 1975), soft coral taxonomy (Gawel, 1977), herbivorous fish and seagrass interaction (Gates, 1986), and nutrient studies on algae and cyanobacteria (Kuffner and Paul, 2001).

METHODS

A fundamental requirement of acceptable impact studies is the comparison of an impact site with two or more control sites. Two control sites were established and surveyed with the same methods used for each impact site. The use of two control sites minimizes temporal variation within each site and spatial variation both within and between sites (Kingsford, 1999).

Fish Eye Underwater Observatory and Seawalker, Piti

The Piti seawalker recreational activity must be considered a part of the Fish Eye underwater observatory complex (Figure 1). The seawalker’s 7.3-m by 10.2-m pontoon raft which is docked adjacent and west of the ramp, and the 11-m diameter underwater observatory structure at the seaward end of the 290-m long ramp lie only 46 meters apart and are located within the same large sink. Both marine recreational facilities attract resident fish populations which are fed several times a day.

Figure 1. Location of transect sites and water sample stations at (A) Fish Eye Underwater Observatory and Seawalker, Piti, and (B) Scuba BOB and Seawalker, Cocos Lagoon.

The 36 50-m long belt transects (Figure 1) were conducted in three distinct biological zones adjacent to the ramp, i.e., within 219 m west of the ramp and 96 m east of the ramp. All transects were run in the morning hours during flooding high tide, i.e., tides greater than +1.5 feet during December 2003 and January 2004. Twelve transects were conducted in impacted areas and 24 transects were conducted in control areas.

● Nearshore seagrass bed (*Enhalus acoroides*) and sand (9 transects). Three transects were run in impacted areas adjacent and west of the ramp (Treatment1, T2 and T3) and 3 transects each in two control areas located west of impacted area (Control west1, Cw2, and Cw3) and east of ramp (Control east1, Ce2, and Ce3). All 9 transects were run perpendicular to shore, i.e., seaward of the low tide line. The nearshore impacted sites were identified as those areas where scuba participants walked diagonally across the western seagrass beds to reach the scuba class site just east of the ramp. The raised seagrass zone is subject to exposure during MLLW.

● Limestone reef pavement dominated by the cyanobacterium *Schizothrix calcicola* and the macroalga *Padina boryana* and sand (9 transects). Three transects were run in the impacted area adjacent and west of the ramp (T4, T5 and T6), and three transects each were run in two control areas located west of the impacted area (Cw4, Cw5 and Cw6) and east of the ramp (Ce4, Ce5 and Ce6). All 9 transects were run perpendicular to shore and began just seaward of the seagrass beds. The impacted area represented the sites traversed by scuba participants.

● Sinks (18 transects via scuba). Six transects were run in the 150-m long impacted sink, i.e., three transects west and parallel to the ramp at the Seawalker site (T7, T8 and T9) and three transects in a seaward direction from the underwater observatory structure (T10, T11 and T12). Control sinks 1 (westernmost with predominantly hard coral) and control sink 2 (predominantly with soft corals) were both approximately 75 m in diameter, up to 4 meters deep, and located west and downcurrent of the underwater observatory. Six transects, each radiating from a central point, were run in control sink 1 (Cs1-7, Cs1-8, Cs1-9, Cs1-10, Cs1-11 and Cs1-12) and six transects were run in control sink 2 (Cs2-13, Cs2-14, Cs2-15, Cs2-16, Cs2-17, Cs2-18).

SURVEY OF BENTHIC ALGAE, CYANOBACTERIA, SEAGRASSES AND MACROINVERTEBRATES

Aside from marine algae and seagrasses, initial underwater observations revealed that the conspicuous invertebrates in the Piti area are hard corals or scleractinians (Randall and Myers, 1983), soft corals or alcyonaceans (Gawel, 1977) and sea cucumbers or holothurians (Rowe and Doty, 1977). The identical 36 transect lines run in both impacted and control sites, used in the fish survey, were used to quantify the benthic algae, cyanobacteria, seagrasses and macroinvertebrates.

The percent cover of benthic algae, cyanobacteria, seagrasses, hard corals and soft corals along the transect line were quantified using a modified point-intercept method (Tsuda, 1972). A 50 x 50 cm quadrat frame divided into a grid of 25 squares, each 10 x 10 cm, provided 16 interior "points" where the grid line intersected. The quadrat frame was positioned within 1-meter on each side of the transect line at 5-meter intervals along the 50-meter long transect (n = 20). Each species and substrata type were recorded at every "point" at which it occurred, i.e., n/16 x 100% = % cover per quadrat. Each 50-meter long belt transect provided a total of 320 points (16 points per quadrat x 20 samples). A set of transects usually consisted of three transects (960 points); however, six transects (1,920 points) were run in the primary study areas of the impacted sink and two control sinks. The modified point-intercept method also provided percent cover of the substrata, i.e., sand, rubble (including limestone pavement) and live corals.

Sea cucumbers, sea stars and sea urchins within 1-meter of either side of the 50-meter transect line, i.e., covering an area of 100 sq. m., were counted. This method requires only one person, unlike the circular plot method recommended by Amesbury and Kerr (1996). A checklist of corals was recorded on 3 February 2004 by graduate students Teina Rongo and Jackie Holbrook at four sites, i.e., Seawalker site, around the underwater observatory, sink 1 and sink 2.

SURVEY OF FISHES

The fish community was the primary group of organisms targeted in this study because all recreational activities encouraged the schooling of fishes in the immediate vicinity of the

paying customers via feeding stations. The Piti area was of special interest since it is one of the five marine protected areas of Guam.

Because of visibility constraints at some transect sites, fishes were counted within a strip approximately 2.5 meters on either side of the transect line (area = 250 sq. m.). Counts were made with two passes along the transect line, i.e., on the first pass up the line, all large or mobile species were enumerated, and on the second pass down the line, all territorial and cryptic species of fishes were enumerated. Myers (1999) served as the basic reference for fish identification.

WATER QUALITY

Water currents at the Seawalker site and Underwater Observatory, i.e., 244 m and 290 m from shore, flows consistently from east (upstream) to west (downstream). Replicate water samples were obtained one meter below the water surface with 1-gallon plastic containers at four sites (8 water samples) at Piti, and stored upright in a cooler situated snugly in a 7-foot long inflatable plastic boat. The two set of samples (8 samples x 2 days = 16 samples) were obtained in the early morning during flooding high tide (+2.4 to 2.5 feet) on 16 and 18 February 2004.

- Water Sample A (WS-A). East edge of the impacted sink, water 2 meters deep.
- Water Sample B (WS-B). Under ramp between Seawalker and underwater observatory, water 7 meters deep in impacted sink.
- Water Sample C (WS-C). In control sink 2 (soft coral population), water 4 meters deep.
- Water Sample D (WS-D). In control sink 1 (hard coral population), water 4 meters deep.

The temperature of the water was obtained in situ with a total submersion thermometer. Salinity readings were obtained on shore with a refractometer. Water samples were delivered to the Water Quality Laboratory of the University of Guam Water and Environmental Research Institute within 1.7 hours from the time of the collection of the first water sample. Standard methods (APHA, 1992) were used to analyze samples for turbidity, suspended solids, settleable solids, nitrate-N and phosphate-P.

Seawalker and Scuba BOB, Cocos Lagoon

The pontoon rafts of the Seawalker (6m x 6m) and Scuba BOB (10m x 5m) are moored approximately 200 meters apart and are anchored over the inner sandy lagoon slope, up to 6 m deep, on the southwest sector of Cocos Lagoon. Water circulation normally moves in a southwest direction, i.e., towards Cocos Island; a reverse movement was seen on 27 January 2004 when waves were breaking over the west barrier reef. During rough seas, Scuba BOB moves its operation to the middle of the lagoon; thus, it operates at one of two sites depending on sea conditions. The study of Scuba BOB site, however, was restricted to the southwest sector of Cocos Lagoon.

Eighteen 50-m belt transects (Figure 1) with the use of scuba were run along the inner lagoon slope on the southwest sector of Cocos Lagoon.

- Scuba BOB (3 transects). Transects (Scuba BOB1, SB2 and SB3) were run perpendicular to the inner edge of the barrier reef, depth up to 6 m.

- Seawalker (3 transects). Transects (Seawalker1, SW2 and SW3) were run in a diagonal direction to the inner edge of the barrier reef, depth up to 6 m. The pontoon raft is situated approximately 200 meters north of the Scuba BOB activity.

- Up-current controls, 50 to 300 m north of the seawalker operation (9 Transects). Three sets of three transects (Set 1: Upcurrent1, UC2, UC3; Set 2: UC4, UC5, UC6; Set 3: UC7, UC8, UC9) were run parallel to the inner edge of the barrier reef at depths of 2 to 5 m. These transects were normally not affected by the fish feeding activities of both Scuba BOB and the Seawalker.

- Down-current controls, approximately 100 m south of the Scuba BOB operation (3 transects). Three transects (Downcurrent1, DC2 and DC3) were run nearly parallel to the inner edge of the barrier reef at depths of 3 to 5 m.

SURVEY OF BENTHIC ALGAE, CYANOBACTERIA AND MACROINVERTEBRATES

Hard corals, soft corals and sea cucumbers were also the conspicuous macroinvertebrates in the southwest sector of Cocos Lagoon. The benthic and fish surveys used the same 18 transect lines. The percent cover of benthic algae, cyanobacteria, seagrasses, hard corals and soft corals along the transect line were quantified with the same modified point-intercept method used in the Piti study. The modified point-intercept method, likewise, provided percent cover of the substrata, i.e., sand, rubble (including limestone pavement) and live corals. Sea cucumbers and other echinoderms were quantified along a 2-m wide belt along the 50-m long transect, i.e., an area of 100 square meters, as performed in the Piti area. A checklist of corals was recorded by graduate students Teina Rongo and

Jackie Holbrook on 27 January 2004 at four sites along the southwest sector of Cocos Lagoon, i.e., Scuba BOB site, seawalker site, upcurrent (towards Merizo Pier) and downcurrent (towards Cocos Island).

SURVEY OF FISHES

The Cocos Lagoon fish community was, likewise, the primary targeted group of organisms in the study because fishes were the primary attraction to tourists. Fishes were quantified in the same manner as previously described for the Piti area.

WATER QUALITY

Replicate water samples were obtained one meter below the water surface with 1-gallon plastic containers at four sites (8 water samples) in the southwest sector of Cocos Lagoon. Temperature readings were obtained directly after sampling. Salinity readings with a refractometer were taken directly after sampling on 27 January 2004 and after return to the Marine Laboratory on 12 February 2004. The two set of samples (8 samples x 2 days = 16 samples) were obtained in the mid morning hours during flooding high tide (+2.0 to 2.2 feet) on 27 January 2004 (0845 to 1010) and 12 February 2004 (1020 to 1030).

- Water Sample E (WS-E). Upcurrent, approximately 75 m north of seawalker, water 2-m deep.
- Water Sample F (WS-F). Seawalker site, water 6 m deep.
- Water Sample G (WS-G). Scuba BOB site, water 6 m deep.
- Water Sample H (WS-H). Downcurrent, approximately 75 m south of Scuba BOB, water 3-m deep.

Water samples were kept in a cooler with ice and delivered to the Water Quality Laboratory of the University of Guam Water and Environmental Research Institute within four hours from the time of the collection of the first water sample. Standard methods (APHA, 1992) were used to analyze samples for turbidity, suspended solids, settleable solids, nitrate-N and phosphate-P.

Statistical Analyses

The general null hypothesis in each test is that each impact or study site does not differ significantly from the control sites. The general alternate hypothesis is that the impact and control sites differ significantly from one another. During subsequent monitoring by future researchers, the second general null hypothesis is that the impact and control sites do not differ significantly from the respective baseline impacted and control sites. The second general alternate hypothesis is that the impacted and control sites taken subsequently differ significantly from the initial baseline data.

Because the biological data at all sites was expected to be quite variable, and because the focus was upon potential change within communities at each site, multivariate analysis methods were used to determine if significant differences existed between treatment and control transects in percent cover of substrata, in fish species similarity and diversity, and in relationships between substrata and patterns of fish similarity and diversity.

BENTHIC COVER

A similarity matrix (Euclidean distance) was constructed for each site (Piti: Seagrass and Sand Zone, Limestone and Sand Zone, Sink Hole Zone; Scuba Bob site; Seawalker sites) from percent cover values of sand, pavement, rubble, algae, cyanobacteria, hard coral and soft corals (echinoderms were excluded because of too few data) from treatment and control transects. Values were transformed with a square-root procedure prior to construction of the matrices. Then, the matrix was submitted to a cluster analysis (Clarke and Gorley, 2001, PRIMER, CLUSTER routine: group) with an additional square root transformation (now 4^{th} root) to determine groupings among transects at each site. If there were no differences between treatments and controls at each site, then transects would be expected to be distributed randomly within a single cluster on the cluster analysis dendrogram. This procedure was followed by submitting the square-root transformed matrix to a non-metric multidimensional scaling (MDS) analysis (Clarke and Warwick, 1994; Clarke and Gorley, 2001, PRIMER, MDS routine) that constructed a map of transects relative to their rank order of similarity; the greater the similarity the closer the placement. Finally, to determine significance if differences were found to exist the data matrix (square-root transformed) was analyzed with a one-way analysis of similarity (Clarke and Gorley, 2001, PRIMER, ANOSIM routine). This multivariate procedure is analogous to a one-way analysis of variance (Clarke and Warwick, 1994) and utilizes 999 permutation/randomization tests of between groups (treatments or controls) and samples (transect sites). The value generated, a global R, indicates the difference between average ranks between and within groups. If there are no differences between the groups, then between-group and within-group similarities will usually be equal or not differ by more than 15% by chance. If the value exceeds 0-0.15, then the null hypothesis is rejected at the 0.001 (0.1%) level (Clarke and Gorley, 2001).

FISHES

For analysis of fish data, a matrix consisting of Bray-Curtis similarity values (Clarke and Gorley, 2001: PRIMER, SIMILARITY routine with square root transformation) was constructed. This matrix was then submitted to cluster analysis, multidimensional scaling analysis, and analysis of similarity using the procedures described above for benthic substrata analysis. In addition, a series of diversity and evenness indices were calculated (Clarke and Gorley, 2001, PRIMER, DIVERSE routine). These in turn were analyzed by principal components analysis (PCA; Clarke and Gorley, 2001: PRIMER, PCA routine) to reflect diversity relationships between treatment and control transects at each site. Only the first two principal components (PC) axes were visualized but these accounted for most of the variation in the data.

RELATIONSHIPS BETWEEN BENTHIC COVER AND FISHES

The relationships between benthic cover and fish diversity (Shannon diversity index, H') were examined with single regression analysis (H' on substratum type) at each site, and by multiple regression analysis (H' on all substrata) for each site. H' was obtained from checklists of presence and abundance of fishes analyzed with the PRIMER DIVERSE routine (Clarke and Gourley, 2001). Both H' and percent cover data were treated with a square-root transformation routine prior to analysis. Data from treatment and control transects were pooled for each site in order to increase sample size and analytical power. This was done under the assumption that there was no difference between treatments and controls. Regressions were calculated with SYSTAT (SPSS, 1997) and displayed graphically by use of SIGMAPLOT (SPSS, 2000).

WATER QUALITY

The original statistical plan was to compare the values obtained from the analyses of the water samples at both impacted and control sites. The results of the water quality analyses, however, did not show any discernable patterns between impacted and control sites; even the replicate pair of samples showed large differences in values. Thus, the various parameters are presented in tabular form.

Data Base

Spreadsheets (MS-Excel and PRIMER) describing both physical and biological components of each site, and the distribution of each species within and between sites, are given in an electronic format provided to GCMP. Note that only Excel spreadsheets may be printed. For each site, the following values were recorded in separate fields: location; percent cover of sand, pavement, rubble, algae, seagrass, cyanobacteria, hard coral, soft coral and echinoderms for impact and control sites; number of species and diversity of species for each major taxonomic group for impact and control sites; most dominant species of algae and hard coral for impact and control sites; and date and transect number.

For fishes, checklists of fishes are given for Piti (Seagrass and Sand Zone, Limestone and Sand Zone, Sink Hole Zone, and all zones pooled) and Cocos (Scuba Bob and Seawalker sites) in MS-Excel and PRIMER formats. Data analyses, including matrix calculations, are given in these same formats. In addition, data files used for regression analyses and result or output files are given in the SYSTAT data format (.syd) as well as in the MS-Excel format.

For water quality, values for each parameter measured at each site are provided in tabular form in the text.

Separate files for each figure are given in one of the following formats: MS-Excel, PRIMTER, or SIGMAPLOT. Photographic plates are saved in the .JPG format.

RESULTS AND DISCUSSION

Fish Eye Underwater Observatory and Seawalker, Piti

WATER QUALITY

The analyses (Table 1) of the 16 water samples (i.e., 2 samples at each of the four sites) collected on 16 and 18 February 2004 at the underwater observatory and Seawalker site, and control sites upcurrent (east of observatory) and downcurrent (west of observatory) within the two control sinks revealed no discernable patterns. Water temperature at all sampling stations was consistent at 28^{o} C, and salinity measurements varied slightly between 33.5 and 34.0 ppt on one day and between 34.0 and 35.0 ppt on the second day of sampling. There was negligible settleable solids in all water samples, i.e., all samples contained less than 0.1 mg/liter. Suspended solids varied between 1.8 to 6.6 mg/liter and showed no distinct patterns among sampling stations. Only three sets of replicates, i.e., upcurrent, sink 2 and sink 1 collected on 16 February 2004, showed percent differences of less than 20%. Water turbidity at all sampling sites were similar, i.e., between 0.34 and 0.52 NTU, and showed no discernible patterns among the sampling stations.

Nitrate values ranged from less than 0.001 to 0.009 mg/liter; at least one of the replicates of each of the 8 sample sets showed values less than 0.001 mg/liter. Phosphate values ranged from less than 0.002 to 0.234 mg/liter. Likewise, at least one replicate of each of the 8 sample sets showed values less than 0.002 mg/liter; 11 of the 16 water samples showed phosphate values less than 0.002 mg/liter.

Table 1. Temperature (^{o}C), salinity (ppt), turbidity (NTU), suspended solids (mg/l), settleable solids (mg/l), nitrate (mg/l) and o-phosphate (mg/l) of replicate water samples collected during flooding tides at the Fish Eye Underwater Observatory site, Piti, on 16 and 18 February 2004.

Samples	Date/ Time	Temp.	Salinity	Turbidity	Solids Suspended	Solids Settleable	Nitrate	Phosphate
Upcurrent	1/16,0830	28	33.5	0.45	2.8	<0.1	0.002	<0.002
		28	33.5	0.51	2.9	<0.1	<0.001	<0.002
	1/18,0835	28	34.0	0.34	5.9	<0.1	<0.001	<0.002
		28	34.0	0.39	2.6	<0.1	0.011	0.234
Fish Eye/ Seawalker	1/16,0835	28	33.5	0.36	1.8	<0.1	0.006	<0.002
		28	33.5	0.38	2.6	<0.1	<0.001	0.021
	1/18,0838	28	34.0	0.36	6.6	<0.1	<0.001	<0.002
		28	34.0	0.44	4.7	<0.1	<0.001	<0.002
Sink 2	1/16,0845	28	34.0	0.46	2.4	<0.1	0.005	<0.002
		28	34.0	0.44	2.9	<0.1	<0.001	0.004
	1/18,0845	28	34.0	0.38	5.4	<0.1	0.009	<0.002
		28	34.0	0.45	2.2	<0.1	<0.001	<0.002
Sink 1	1/16,0850	28	34.0	0.42	4.2	<0.1	<0.001	0.002
		28	34.0	0.52	3.7	<0.1	0.002	<0.002
	1/18,0850	28	35.0	0.41	5.7	<0.1	0.009	0.013
		28	35.0	0.41	3.1	<0.1	<0.001	<0.002

BENTHIC ALGAE, CYANOBACTERIA AND SEAGRASSES

Within the inshore Seagrass and Sand Zone (Table 2), the seagrass *Enhalus acoroides* showed a greater percent cover within the impacted sites, i.e., T1 (3%), T2 (63%) and T3 (49%) and within the control sites west of the impacted area, i.e., Cw1 (51%), Cw2 (36%) and Cw3 (39%). The control area east of the ramp was covered by more algae, i.e., Ce1 (31%), Ce2 (26%) and Ce3 (13%) than seagrass, i.e., Ce1 (0%), Ce2 (14%) and Ce3 (21%). Cyanobacteria were observed on only two of the 9 transects, i.e., Ce2 (4%) and T1 (<1%).

In the Limestone and Sand Zone, cyanobacteria were 10 to 30 times more abundant than algae along 8 of the 9 transects. Only transect Ce6 showed less than 1% cover of cyanobacteria as opposed to the 12% cover of algae.

Both cyanobacteria, i.e., 0 to 14% cover, and algae, i.e., 0 to 9% cover, were scarce within the impacted sink (Sink Hole Zone). In control sink 1, cyanobacteria, i.e., 0 to 26% cover, were more abundant than algae, 0 to 9% cover; cyanobacteria, i.e., 11 to 57% cover, were 10-fold more abundant than algae, i.e., 0 to 14% cover. It seems obvious that the fish are feeding on the more desirable algae than on cyanobacteria.

HARD AND SOFT CORALS

Hard and soft corals were absent in the Seagrass and Sand Zone. In the Limestone and Sand Zone, hard corals, mainly *Leptastrea purpurea,* were scarce in both the impacted area, i.e., T5 (1%), as well as in the control sites, east and west of the ramp, i.e., less than 1% cover at Cw4, Cw6, Ce4 and Ce6. Soft corals were present in transects T4 (3%) and Cw6 (3%).

Hard corals were most abundant in the impacted sink (Sink Hole Zone), ranging from 16 to 39% cover, along six transects. Soft corals, i.e., 10% cover, were recorded along one of 6 transects. Control sink 1 consisted of 3 to 38% cover of hard corals, mainly *Porites cylindracea* and *Porites (S.) rus*, along six belt transects. Control sink 2 consisted of 3 to 28% cover of soft corals mainly *Sinularia polydactyla*, along 5 of 6 belt transects. The sixth transect consisted of 6% hard corals and no soft corals.

Table 2. Percent cover (100%) of substrata and benthic community along the 36 50-m long belt transects at Piti.

Sum represents pooled values from three (300%) or six (600%) transects.

SEAGRASS AND SAND ZONE

Substrata	Cw1	Cw2	Cw3	Sum	T1	T2	T3	Sum	Ce1	Ce2	Ce3	Sum
Sand	42%	63%	61%	166%	7%	22%	22%	51%	18%	17%	16%	51%
Pavement/Rubble	6%	<1%	0%	7%	54%	13%	24%	91%	51%	39%	50%	140%
Seagrasses	51%	36%	39%	126%	3%	63%	49%	115%	0%	14%	21%	35%
Algae	<1%	<1%	<1%	1%	36%	2%	5%	43%	31%	26%	13%	70%
Cyanobacteria	0%	0%	0%	0%	<1%	0%	0%	<1%	0%	4%	0%	4%
Hard Corals	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Soft Corals	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Echinoderms	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

LIMESTONE AND SAND ZONE

Substrata	Cw4	Cw5	Cw6	Sum	T4	T5	T6	Sum	Ce4	Ce5	Ce6	Sum
Sand	46%	46%	48%	140%	61%	38%	22%	121%	31%	64%	57%	152%
Pavement/Rubble	22%	8%	12%	42%	18%	23%	38%	79%	39%	20%	25%	84%
Seagrasses	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	5%
Algae	2%	2%	3%	7%	0%	2%	2%	4%	<1%	0%	12%	12%
Cyanobacteria	29%	43%	32%	104%	18%	34%	37%	89%	29%	15%	<1%	44%
Hard Corals	<1%	0%	<1%	2%	0%	1%	0%	1%	<1%	0%	<1%	1%
Soft Corals	0%	0%	3%	3%	3%	0%	0%	3%	0%	0%	0%	0%
Echinoderms	0%	1%	<1%	2%	<1%	2%	<1%	3%	0%	1%	<1%	2%

Table 2, continued.

SINK HOLES

Control Sink 1

Substrata	**Cs1-7**	**Cs1-8**	**Cs1-9**	**Cs1-10**	**Cs1-11**	**Cs1-12**	**Sum**
Sand	61%	71%	49%	32%	41%	83%	337%
Pavement	20%	3%	4%	6%	4%	0%	47%
Rubble	1%	0%	5%	0%	0%	0%	6%
Seagrasses	0%	0%	0%	0%	0%	0%	0%
Algae	1%	<1%	7%	9%	0%	0%	18%
Cyanobacteria	1%	0%	2%	26%	6%	7%	42%
Hard Corals	3%	25%	31%	3%	38%	10%	110%
Soft Corals	13%	<1%	2%	24%	<1%	0%	41%
Echinoderms	<1%	0%	0%	0%	0%	0%	<1%

Impacted Sink

Substrata	**T7**	**T8**	**T9**	**T10**	**T11**	**T12**	**Sum**
Sand	5%	47%	66%	36%	31%	35%	220%
Pavement	34%	8%	13%	15%	33%	21%	124%
Rubble	8%	21%	<1%	24%	0%	5%	59%
Seagrasses	0%	0%	0%	0%	0%	0%	0%
Algae	9%	2%	4%	0%	2%	0%	17%
Cyanobacteria	14%	2%	0%	0%	0%	0%	16
Hard Corals	20%	19%	16%	15%	34%	39%	153
Soft Corals	10%	0%	0%	0%	0%	0%	10%
Echinoderms	0%	0%	0%	0%	0%	0%	0%

Control Sink 2

Substrata	**Cs2-13**	**Cs2-14**	**Cs2-15**	**Cs2-16**	**Cs2-17**	**Cs2-18**	**Sum**
Sand	44%	84%	28%	17%	39%	71%	283%
Pavement	0%	0%	2%	8%	<1%	0%	10%
Rubble	7%	2%	23%	12%	12%	0%	56%
Seagrasses	0%	0%	0%	0%	0%	0%	0%
Algae	14%	0%	1%	0%	<1%	0%	16%
Cyanobacteria	21%	11%	16%	57%	31%	19%	155%
Hard Corals	<1%	0%	<1%	6%	<1%	0%	8%
Soft Corals	13%	3%	28%	0%	17%	9%	70%
Echinoderms	0%	0%	<1%	<1%	0%	<1%	2%

The coral surveys (Table 3) of the four sites at Piti revealed 10 species at the Seawalker site and 15 species at the underwater observatory. The diversity of hard corals was greater in the control sites, i.e., sink 1 with 18 species of corals and sink 2 with 23 species of corals. It was of interest that the diversity of hard corals was highest in control sink 2, although soft corals were the predominant fauna at this site. The dominant corals at all four sites were *Porites cylindrica* and *Porites rus*.

HOLOTHURIANS AND ASTEROIDS

At the Piti site (Table 4), holothurians (sea cucumbers) and asteroids (seastars) were the dominant macroinvertebrates observed within the 2-m wide and 50-m long transect, i.e., covering an area of 100 square meters. *Holothuria atra* was the only sea cucumber in the Seagrass and Sand Zone; however, only few were present, i.e., 4 organisms/300 sq. m. in the impacted site, 3 organisms/300 sq.m. in the west control site and 11 organisms/300 sq.m. in the east control site.

In the Limestone and Sand Zone, five species of sea cucumbers were recorded. *Holothuria atra* was most abundant in the impacted area, i.e., 204/300 sq.m.; 120 and 111 *H. atra* per 300 sq. m. were recorded in the west control site and east control site, respectively. Nine specimens of *Holothuria edulis* were recorded along three transects in the impacted site; 6 and 3 *H. edulis* per 300 sq. m. were recorded in the west control site and east control site, respectively.

Holothuria edulis was the dominant sea cucumber in the Sink Hole Zone; control sinks 1 and 2 possessed 134/600 sq. m. and 212/600 sq.m., respectively, and considerably more than in the impacted sink, i.e., 46 per 600 sq.m.

Only three species of asteroids were recorded along the 2-meter wide transects at Piti, i.e., one *Acanthaster planci,* one *Culcita novaeguineae* and six *Linckia laevigata*.

Table 3. Checklist of coral species observed at Piti on 3 February 2004. Survey conducted by Teina Rongo and Jackie Holbrook. Numbers 1, 2 and 3 represent ranking of the dominant corals.

Species	Seawalker	Observatory	Sink 1	Sink 2
Acropora aspera			x	
Acropora surculosa			x	
Acropora virgata			x	
Acropora wardi		x		
Astreopora elliptica	x			
Astreopora myriophthalma				x
Cyphastrea serallia				x
Fungia scutaria				x
Galaxea fascicularis				x
Goniastrea pectinata		x		x
Heliopora coerulea	x	x	x	x
Leptastrea purpurea	x		x	x
Leptoria phrygia				x
Lobophylia hemprichii				x
Montipora floweri				x
Montipora hoffmeisteri	x	x	x	x
Montipora elschneri	x		x	x
Montipora verrucosa		x		x
Pavona decussata		x		x
Pavona divaricata		x	x	
Pavona varians	2	2	3	2
Pavona venosa		x	x	x
Pocillopora damicornis		x	x	
Pocillopora setchelli			x	
Pocillopora verrucosa				x
Porites annae			x	
Porites cylindrica	1	1	1	1
Porites lutea	x	x		x
Porites rus	1	1	1	1
Porites solida			x	
Psammacora contigua				x
Psammacora digitata		x		
Psammacora obtusangula	x		2	x
Psammacora profundacella			x	
Stylocoeniella armata				x

Table 4. Counts of holothurians and asteroids along 36 50-meter long belt transects, 2 meters wide, each covering an area of 100 sq. m. at Piti, December 2003 to February 2004. Holothurians: *Actinopyga echinites (A.e.), Actinopyga miliaris (A.m.), Bohadschia argus (B.a.),*

Holothuria atra (H.a.), Holothuria edulis (H.e.), Holothuria hilla (H.h.), Stichopus chloronotus (S.c.), Thelenota ananas (T.a.); Asteroids: *Acanthaster planci (A.p.), Culcita novaeguineae (C.n.), Linckia laevigata (L.l.)*.

	Holothurians								Asteroids	
Transects	***A.e.***	***A.m.***	***B.a.***	***H.a.***	***H.e.***	***H.h.***	***S.c.***	***T.a.***	***A.p.***	***C.nL.l.***
Seagrass and Sand Zone										
Treatment1				3						
T2				1						
T3										
Controlwest1				1						
Cw2				1						
Cw3				1						
Controleast1				1						
Ce2				4						
Ce3				6						1
Limestone Pavement and Sand Zone										
T4				104	8					
T5				92	1					
T6				8						
Cw4				9						
Cw5		1		32	1					2
Cw6				79	5	1				1
Ce4				16						
Ce5	1			39	1					
Ce6	2			56	2					

Table 4. Continued.

	Holothurians								Asteroids	
Transects	***A.e.***	***A.m.***	***B.a.***	***H.a.***	***H.e.***	***H.h.***	***S.c.***	***T.a.***	***A.p.***	***C.nL.l.***
Sink Holes										
T7					8					
T8					5				1	
T9				15	7			1		
T10				2	4		1			
T11				1	12		1			
T12	3			7	10					
Csink1-7				24	24		1			
Cs1-8				9	14					
Cs1-9			1		27					1
Cs1-10					12					
Cs1-11					39					
Cs1-12					18					
Cs2-13					39					
Cs2-14				1	52					
Cs2-15				4	26					1
Cs2-16				2	27					
Cs2-17			1	5	15					1
Cs2-18					53					

RELATIONSHIPS BETWEEN BENTHIC SUBSTRATA WITHIN ZONES

Seagrass and Sand Zone

Similarity values (Euclidean distance) between treatment transects, control transects, and treatment x control transects for the Seagrass and Sand Zone are given in Table 5. Among treatment transects, the most similar were T1 and T2 while the least were T2 and T3. Among control transects, the most similar were Cw3 and Ce1 and the least were Ce1 and Ce2. Between treatment and control transects, the most similar were T1 and Cw3 while the least were T1 and Ce1. The dendrogram (Figure 2) generated from a cluster analysis of this matrix indicated that Cw2 and Cw3 formed a cluster allied with Cw1, that in turn was related to a cluster consisting of T2 and T3; Ce2 and Ce3 formed a cluster linked to a cluster consisting of Ce1 and T1. MDS analysis (Figure 3) showed that all Cw transects were distinct from Ce and T transects, that T2 and T3 were distinct from T1, and that T1 was more closely placed with the Ce transects. The stress value of 0.01 indicated a high degree of reliability in this result. The analysis of similarity between treatments and controls, however, indicated no significant differences in the percent coverage of benthic substrata within this zone (Global $R = -0.105$, $p = 0.679$).

Limestone and Sand Zone

Similarity values (Euclidean distance) between treatment transects, control transects, and treatment x control transects for the Limestone and Sand Zone are given in Table 6. Among treatment transects, the most similar were T4 and T6 while the least were T5 and T6. Among control transects, the most similar were Ce4 and Ce5 and the least were Cw5 and Cw6. Between treatment and control transects, the most similar were T6 and Ce5 while the least were T4 and Ce5. The dendrogram (Figure 4) generated from a cluster analysis of this matrix indicated that T6 and Ce4 formed a cluster allied with one consisting of T5 and Cw4 that in turn was related to a cluster consisting of Cw5 and Cw6; this was linked to the remaining treatment transect, T4, that formed a cluster with Ce5, and in turn, was linked to a cluster consisting of Ce6. MDS analysis (Figure 5) indicated a fair dispersion of treatment transects among control transects; T4 and Ce5, T5 and Cw4, and T6 and Ce4 were all in close proximity to one another, respectively. Cw5 and Cw6 were also close but Ce6 was distinct from the rest. The stress value of 0.05 indicated a high level of reliability in this result.

Table 5. Matrix of similarity values (Euclidean distance) between transects in the Seagrass and Sand

Zone at Piti. Higher values indicate greater similarity between two transects. Transect abbreviations are defined in the text.

Transect

	T1	T2	T3	Cw1	Cw2	Cw3	Ce1	Ce2	Ce3
T1	0	0	0	0	0	0	0	0	0
T2	81.6272	0	0	0	0	0	0	0	0
T3	64.83055	18.05547	0	0	0	0	0	0	0
Cw1	84.01786	24.37212	27.27636	0	0	0	0	0	0
Cw2	90.88454	50.54701	48.93874	26.28688	0	0	0	0	0
Cw3	91.40022	47.61302	47.04253	23.25941	3.741657	0	0	0	0
Ce1	12.84523	79.18333	61.82233	78.1153	81.98171	82.8915	0	0	0
Ce2	23.55844	60.77829	43.95452	61.02459	68.44706	68.72409	19.54482	0	0
Ce3	29.51271	59.24525	42.19005	65.39113	77.58221	77.41447	30.16621	21.81742	0

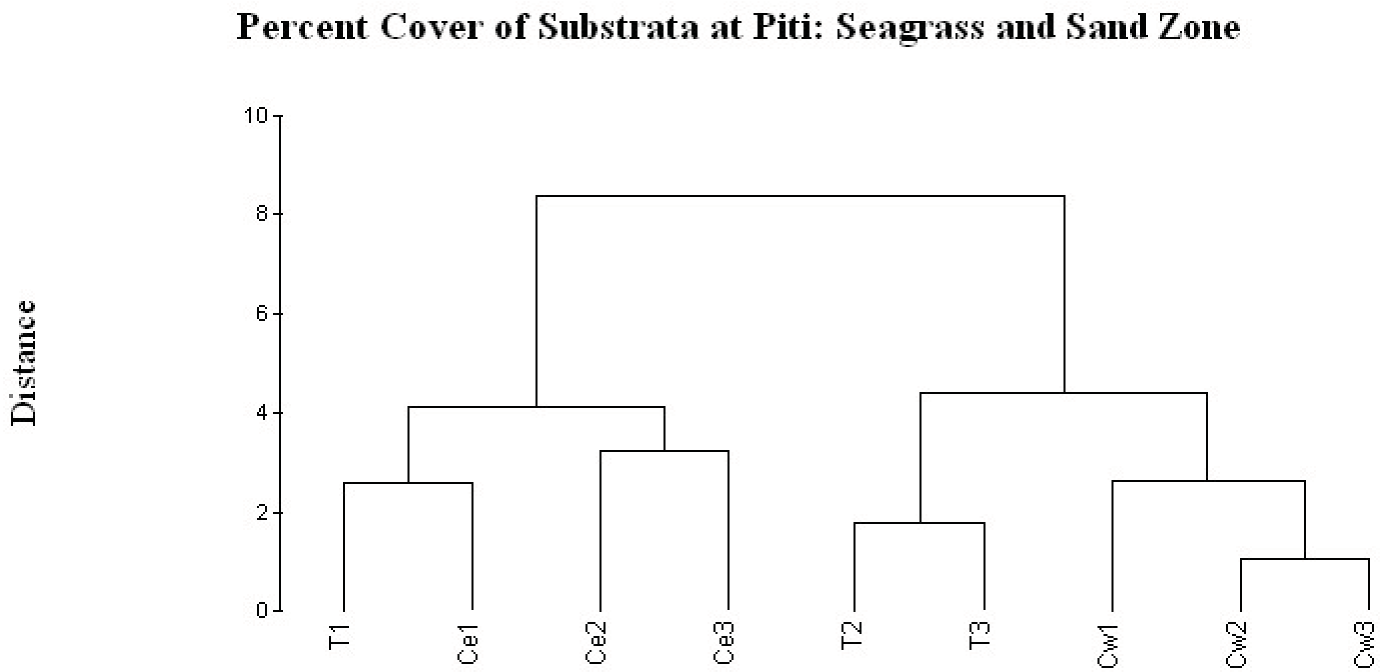


Figure 2. Cluster analysis dendrogram indicating relationships between treatment (T) and control (Cw and Ce) transects in the Seagrass and Sand Zone at Piti. The vertical axis indicates increasing distance and dissimilarity.

Table 6. Matrix of similarity values (Euclidean distance) between transects in the Limestone and Sand Zone at Piti. Higher values indicate greater similarity between two transects. Transect abbreviations are defined in the text.

	Transect								
	T4	T5	T6	Cw4	Cw5	Cw6	Ce4	Ce5	Ce6
T4	0	0	0	0	0	0	0	0	0
T5	28.72281	0	0	0	0	0	0	0	0
T6	47.90616	22.18107	0	0	0	0	0	0	0
Cw4	19.41649	9.69536	29.96665	0	0	0	0	0	0
Cw5	31.03224	19.2873	38.88444	19.84943	0	0	0	0	0
Cw6	20.27313	15.36229	37.25587	11.13553	12.32883	0	0	0	0
Ce4	38.39271	18.30301	12.20656	22.69361	37.21559	32.26453	0	0	0
Ce5	5.567764	32.43455	50.75431	23.02173	35.44009	25.05993	40.60788	0	0
Ce6	30.34798	24.28992	39.62323	22	23.19483	22.58318	35.31289	32.95451	0

Percent Cover of Substrata at Piti: Seagrass and Sand Zone

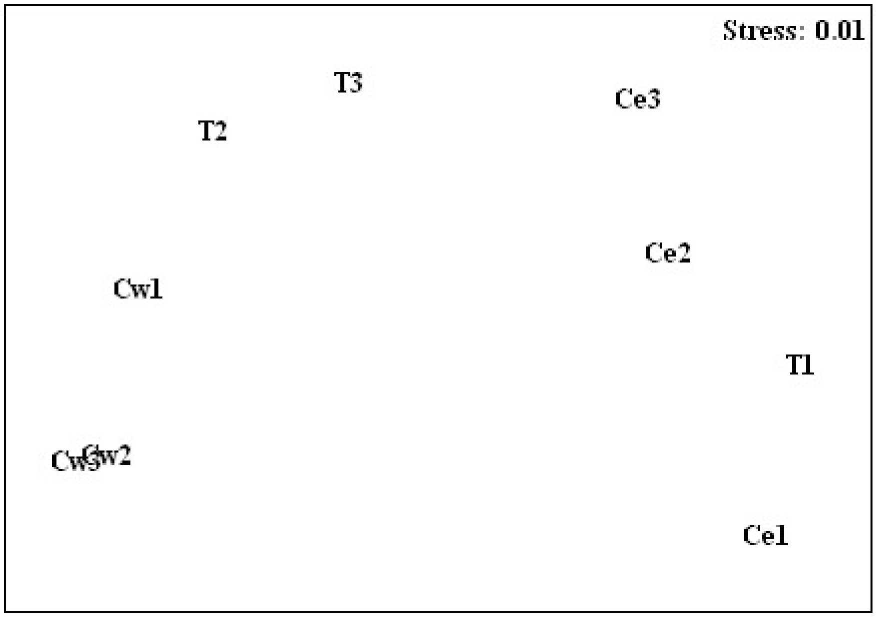


Figure 3. Multidimensional scaling (MDS) analysis of benthic transects in the Seagrass and Sand Zone at Piti. Treatment (T) and Control (Cw and Ce) transects are indicated.

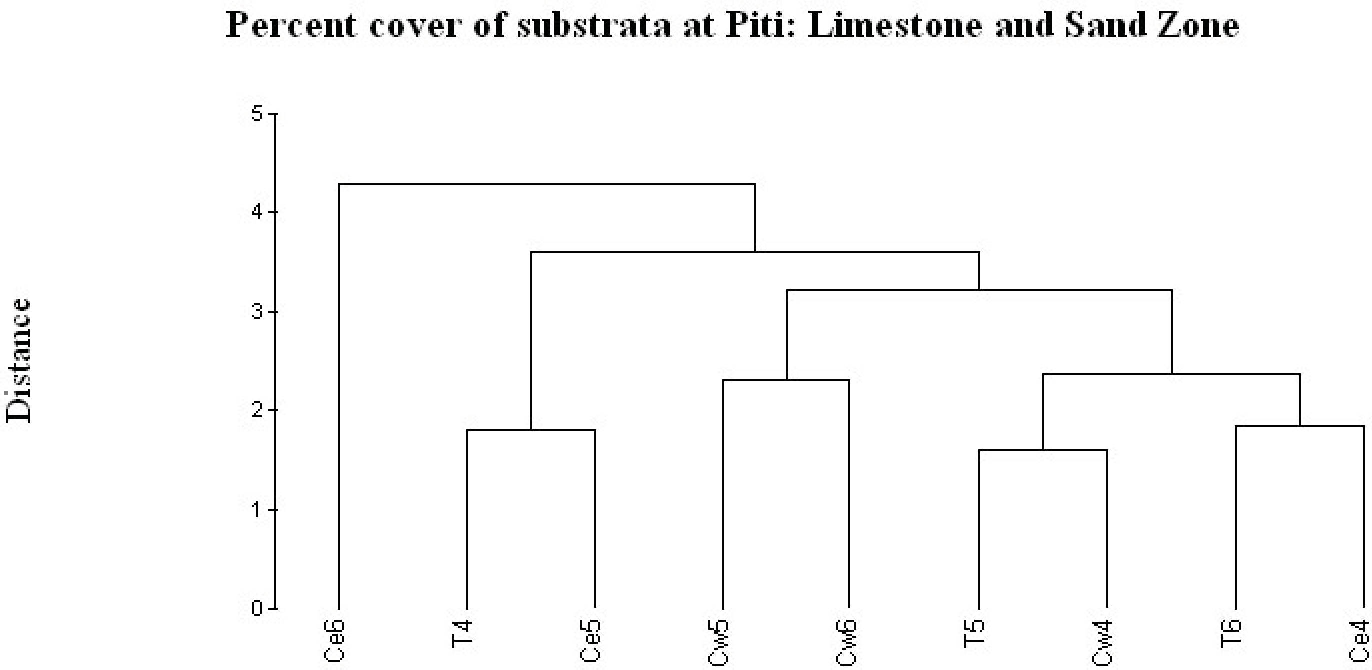


Figure 4. Cluster analysis dendrogram indicating relationships between treatment (T) and control (Cw and Ce) transects in the Limestone and Sand Zone at Piti. The vertical axis indicates increasing distance and dissimilarity.

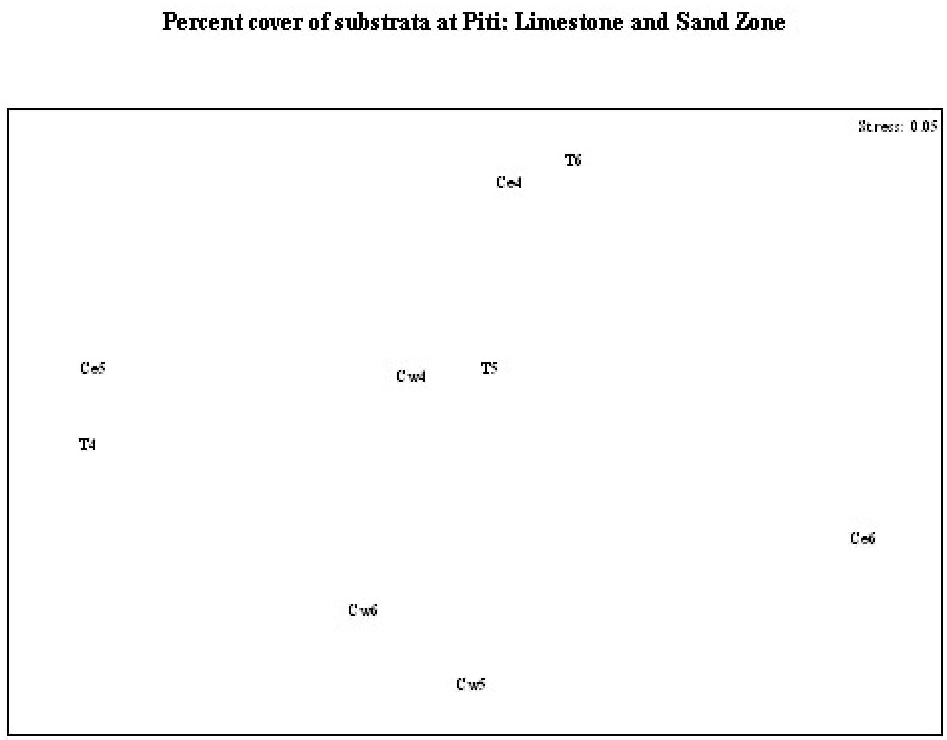


Figure 5. Multidimensional scaling (MDS) analysis of benthic transects in the Limestone and Sand Zone at Piti. Treatment (T) and Control (Cw and Ce) transects are indicated.

Analysis of similarity indicated no significant difference between treatments and controls in the similarity of benthic substrata (Global R = -0.142, p = 0.726).

Sink Hole Zone

Similarity values (Euclidean distance) between treatment transects, control transects, and treatment x control transects for the Sink Hole Zone are given in Table 7. Among treatment transects, the most similar were T7 and T9 while the least were T8 and T10. Among control transects, the most similar were Cs1-8 and Cs2-16 and the least were Cs1-9 and Cs1-11. Between treatment and control transects, the most similar were T7 and Cs2-14 while the least were T9 and Cs1-8. The dendrogram (Figure 6) generated from a cluster analysis of this matrix indicated that three major clusters were formed. One cluster consisted entirely of controls (both Cs1 and Cs2). The second consisted of five treatment transects and two control transects (both Cs1). The third consisted of the remaining treatment transect (T7) and one control (Cs2-16). MDS analysis (Figure 7) places treatment transects T8-T12 near three controls from Sink Hole 1, while the remaining treatment transect was positioned near but not too closely to a single control from Sink Hole 2. The remaining controls were relatively distinct from the above-mentioned groupings. The stress level of 0.12 indicated good reliability in this result. The analysis of similarity found significant differences in substratum benthic cover between treatment and control sites (Global R = 0.397, p = 0.006).

Table 7. Matrix of similarity values (Euclidean distance) between transects in the Sink Hole

Zone at Piti. Higher values indicate greater similarity between two transects. Transect abbreviations are defined in the text.

Transect

	T7	T8	T9	T10	T11	T12	Cs1-7	Cs1-8	Cs1-9
T7	0	0	0	0	0	0	0	0	0
T8	53.8795	0	0	0	0	0	0	0	0
T9	67.43886	28.33725	0	0	0	0	0	0	0
T10	44.49719	14.93318	39.11521	0	0	0	0	0	0
T11	35.80503	39.38274	44.20407	31.7805	0	0	0	0	0
T12	42.61455	31.257	39.82462	24.37212	14.62874	0	0	0	0
Cs1-7	62.55398	34.17601	20.56696	42.8369	46.93613	46.48656	0	0	0
Cs1-8	75.80897	32.92416	14.73092	44.12482	50.82322	42.93018	31.93744	0	0
Cs1-9	56.37375	21.18962	25.05993	27.27636	35.09986	24.61707	36.86462	24.22808	0
Cs1-10	46.96807	46.11941	51.49757	49.8999	54.69918	53.74012	43	57.29747	46.54031
Cs1-11	53.00943	29.5804	35.27038	30.46309	31.59114	19.69772	45.31004	33.27161	14.28286
Cs1-12	87.37276	43.71499	23.66432	57.3062	66.49812	60.49793	33.77869	20.71232	41.42463
Cs2-13	55.87486	35.59494	40.29888	44.27189	56.12486	52.68776	36.04164	46.01087	38.41875
Cs2-14	89.28606	47.42362	29.93326	61.38404	72.05553	67.09694	33.77869	30.54505	48.39421
Cs2-15	50.31898	41.31586	57.65414	43.03487	60.24948	56.74504	48.48711	62.77738	50.77401
Cs2-16	55.34438	64.65292	76.89603	64.53681	70.73189	69.86415	74.26978	81.84131	69.2315
Cs2-17	54.99091	40.60788	49.77951	46.64762	59.76621	56.21388	43.43961	54.45181	46.4758
Cs2-18	78	42.62628	30.16621	55.62374	65.51336	61.04097	29.1719	32.57299	43.28972

	Cs1-10	Cs1-11	Cs1-12	Cs2-13	Cs2-14	Cs2-15	Cs2-16	Cs2-17	Cs2-18
T7	0	0	0	0	0	0	0	0	0
T8	0	0	0	0	0	0	0	0	0
T9	0	0	0	0	0	0	0	0	0
T10	0	0	0	0	0	0	0	0	0
T11	0	0	0	0	0	0	0	0	0
T12	0	0	0	0	0	0	0	0	0
Cs1-7	0	0	0	0	0	0	0	0	0
Cs1-8	0	0	0	0	0	0	0	0	0
Cs1-9	0	0	0	0	0	0	0	0	0
Cs1-10	0	0	0	0	0	0	0	0	0
Cs1-11	48.16638	0	0	0	0	0	0	0	0
Cs1-12	60.8605	50.6557	0	0	0	0	0	0	0
Cs2-13	20.09975	44.81071	47.0319	0	0	0	0	0	0
Cs2-14	59.1608	57.81003	11.40175	44.96665	0	0	0	0	0
Cs2-15	27.313	53.87021	67.12675	30.59412	65.06919	0	0	0	0
Cs2-16	44.73254	66.05301	84.14868	50.04998	82.55301	52.62129	0	0	0
Cs2-17	18.97367	49.07138	55.02727	18.3303	52.19195	24.28992	39.05125	0	0
Cs2-18	43.84062	50.93133	21.67948	31.55947	16.55295	52.47857	68.44706	37.14835	0

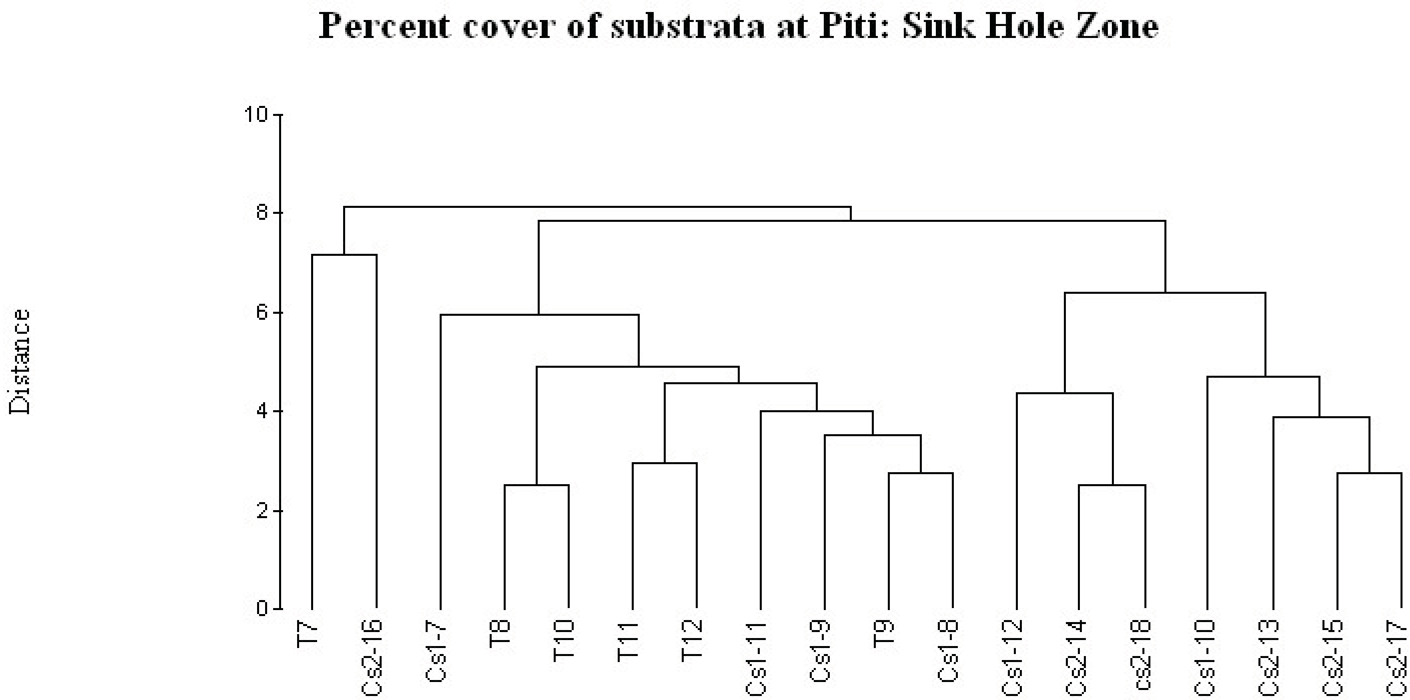


Figure 6. Cluster analysis dendrogram indicating relationships between treatment (T) and control (Cw and Ce) transects in the Sink Holes Zone at Piti. The vertical axis indicates increasing distance and dissimilarity.

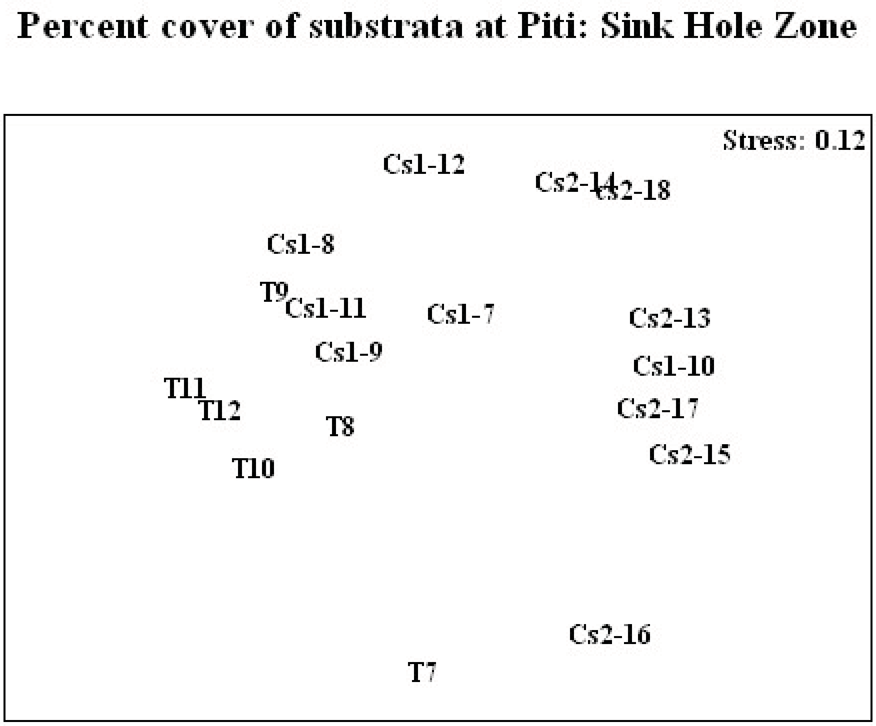


Figure 7. Multidimensional scaling (MDS) analysis of benthic transects in the Sink Hole Zone at Piti. Treatment (T) and Control (Cs1 and Cs2) transects are indicated.

FISH ASSEMBLAGE RELATIONSHIPS

Seagrass and Sand Zone

Similarity values (Bray-Curtis index) between treatment transects, control transects, and treatment x control transects for the Seagrass and Sand Zone are given in Table 8. Among treatment transects, the most similar were T2 and T3 while the least were T1 and T2. Among control transects, the most similar were Cw2 and Cw3 and five pair-wise comparisons had values of zero. Between treatment and control transects, the most similar were T2 and Cw2 while the least were T2 and Ce1. The dendrogram (Figure 8) generated from a cluster analysis of this matrix indicated that Cw2 and T2 formed a cluster allied with T3, that in turn was related to a cluster consisting of Cw1 and Cw3; Ce1 and T1 formed a cluster linked to this, and all were linked to Ce2 and Ce3. MDS analysis (Figure 9) showed that all control and treatment transects, with the exception of Ce3, were placed tightly. The stress value of 0.01 indicated a high degree of reliability in this result. The analysis of similarity between treatments and controls indicated no significant differences in the assemblage structure of fishes within this zone (Global $R = -0.213$, $p = 0.869$). Species diversity and evenness values (Table 9) indicated that among treatments T1 had the most species (S) and greatest diversity (d and H'), T1 had the highest diversity measured by Simpson's index (L), T3 had the greatest number of individuals of all species of fishes, and T1 had the highest value of evenness, J, a measure of how complete the sampling was out of the expected number of species. Among controls, Cw3 had the greatest number of species (S), the greatest number of individuals (N), and the highest value of Margalef's diversity (d), Cw1 had the greatest values of H' and L diversity, and Ce2 had the greatest value of evenness (J). Values of d, H', L and J could not be calculated for transect Ce3 because of insufficient data. An examination of the relationship between these values and those of percent cover of substrata by principal components analysis (Figure 10) explained 96.9% of the variation in the data. Fish checklists are given in Appendix C.

Limestone and Sand Zone

Similarity values (Bray-Curtis index) between treatment transects, control transects, and treatment x control transects for the Limestone and Sand Zone are given in Table 8. Among treatment transects, the most similar were T4 and T6 while the least were T5 and T6. Among control transects, the most similar were Cw5

Table 8. Bray-Curtis similarity index values for pair-wise comparisons of fish transects in the Seagrass and Sand Zone, the Limestone and Sand zone, and the Sink Hole Zone. Higher values indicate a greater similarity between paired transects.

Transect

Seagrass and Sand Zone

	CW1	CW2	CW3	CE3	CE2	CE1	T2	T1	T3
CW1	0	0	0	0	0	0	0	0	0
CW2	43.5267	0	0	0	0	0	0	0	0
CW3	61.7193	38.1636	0	0	0	0	0	0	0
CE3	0	0	0	0	0	0	0	0	0
CE2	0	0	4.87111	0	0	0	0	0	0
CE1	10.1248	28.8245	9.84151	0	23.7693	0	0	0	0
T2	53.5053	62.9391	49.5458	0	9.94373	20.3056	0	0	0
T1	12.4056	36.3277	12.0535	0	0	53.9504	25.2623	0	0
T3	38.5331	60.0987	38.5869	0	0	22.3456	45.4793	27.8861	0

Limestone and Sand Zone

	CE4	CE5	CE6	CW4	CW5	CW6	T4	T5	T6
CE4	0	0	0	0	0	0	0	0	0
CE5	43.9146	0	0	0	0	0	0	0	0
CE6	60.4081	46.1353	0	0	0	0	0	0	0
CW4	45.3152	56.7438	41.9118	0	0	0	0	0	0
CW5	60.8887	43.0218	52.3317	55.8512	0	0	0	0	0
CW6	47.5909	44.3663	49.8142	49.4532	60.5264	0	0	0	0
T4	46.5655	44.8492	43.2755	45.8612	46.7256	57.6542	0	0	0
T5	47.1393	36.8815	41.2608	50.9325	55.1716	65.7133	49.8386	0	0
T6	53.3708	45.3656	46.0558	47.3657	53.564	43.8191	56.2135	44.1969	0

Table 8, continued

Transect

Sink Hole Zone

	CS1-8	CS1-7	CS1-9	CS1-10	CS1-11	CS1-12	CS2-14	CS2-13	CS2-15
CS1-8	0	0	0	0	0	0	0	0	0
CS1-7	36.1676	0	0	0	0	0	0	0	0
CS1-9	48.6735	33.459	0	0	0	0	0	0	0
CS1-10	38.4375	40.1198	51.8566	0	0	0	0	0	0
CS1-11	9.81032	33.7709	9.8647	14.6968	0	0	0	0	0
CS1-12	35.754	35.1304	42.9268	39.4731	4.47726	0	0	0	0
CS2-14	29.232	45.5415	13.9323	32.4415	22.9365	31.6563	0	0	0
CS2-13	34.808	29.8228	34.0006	49.2759	9.65068	43.3856	33.7096	0	0
CS2-15	37.2015	38.3083	42.2203	42.1033	0	44.2213	36.9326	30.3125	0
CS2-16	43.7309	44.8458	37.163	45.8356	8.86743	39.2127	33.3603	46.4693	51.695
CS2-17	33.8793	29.5307	32.0873	41.0792	17.268	25.7991	38.7423	35.4982	13.649
CS2-18	41.2771	33.6352	35.8044	41.1775	4.36148	49.9436	32.49	41.4481	53.988
T7	34.7472	28.8271	40.0695	45.5514	11.7218	26.4334	25.0698	27.6654	29.745
T8	30.7932	26.9691	49.0696	53.5181	11.2193	31.3778	20.1357	33.9604	42.414
T9	26.4134	25.4924	36.9642	42.7085	15.9112	24.8364	26.8329	30.265	27.507
T10	34.4234	25.8396	29.9029	34.0802	4.9993	24.4808	18.7081	27.3134	28.814
T11	39.3735	40.7246	45.7266	42.1602	11.2558	32.3228	33.6392	31.8917	37.996
T12	44.8217	42.3725	49.0856	53.733	15.7331	45.9873	34.9713	34.4554	48.148

	CS2-16	CS2-17	CS2-18	T7	T8	T9	T10	T11	T12
CS1-8	0	0	0	0	0	0	0	0	0
CS1-7	0	0	0	0	0	0	0	0	0
CS1-9	0	0	0	0	0	0	0	0	0
CS1-10	0	0	0	0	0	0	0	0	0
CS1-11	0	0	0	0	0	0	0	0	0
CS1-12	0	0	0	0	0	0	0	0	0
CS2-14	0	0	0	0	0	0	0	0	0
CS2-13	0	0	0	0	0	0	0	0	0
CS2-15	0	0	0	0	0	0	0	0	0
CS2-16	0	0	0	0	0	0	0	0	0
CS2-17	25.999	0	0	0	0	0	0	0	0
CS2-18	45.3752	21.8197	0	0	0	0	0	0	0

Table 8, continued

Sink Hole Zone **Transect**

	CS2-16	CS2-17	CS2-18	T7	T8	T9	T10	T11	T12
T7	35.1914	35.6112	26.4461	0	0	0	0	0	0
T8	33.3593	33.8365	34.8954	50.2383	0	0	0	0	0
T9	30.5817	29.9533	30.0353	56.8047	47.9894	0	0	0	0
T10	31.258	28.229	26.3177	40.6739	36.637	45.7959	0	0	0
T11	34.6143	28.1767	36.302	41.4785	45.1974	46.9167	42.7006	0	0
T12	35.1099	34.0401	38.0834	44.6154	49.9987	45.7528	39.7683	46.4137	0

Figure 8. Cluster analysis dendrogram based upon Bray-Curtis similarity values (square root transformed) indicating fish assemblage structural relationships between Treatment (T) and Control (CW and CE) transects in the Piti Seagrass and Sand Zone. The descending vertical axis indicates increasing similarity.

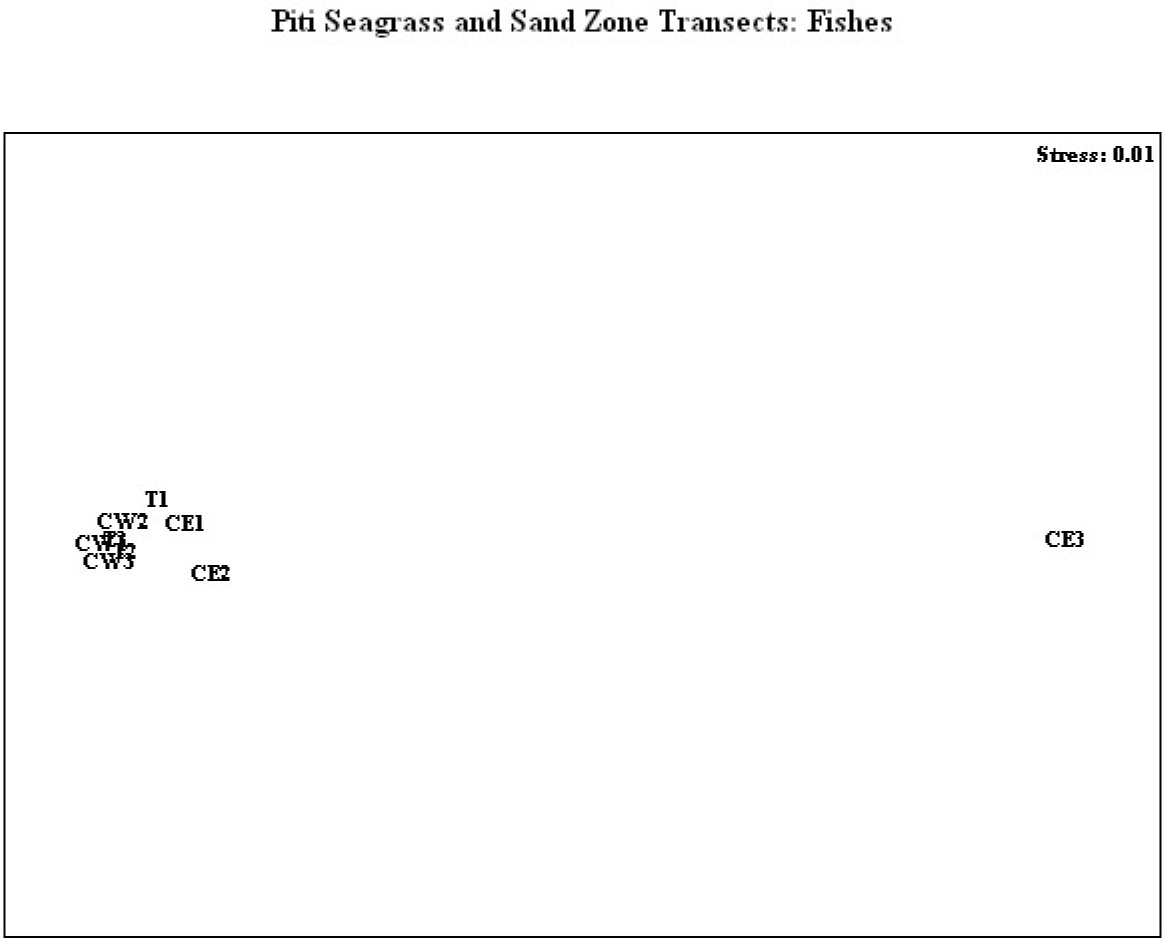


Figure 9. Multidimensional scaling (MDS) analysis of benthic transects in the Seagrass and Sand Zone at Piti. Treatment (T) and Control (CW and CE) transects are indicated.

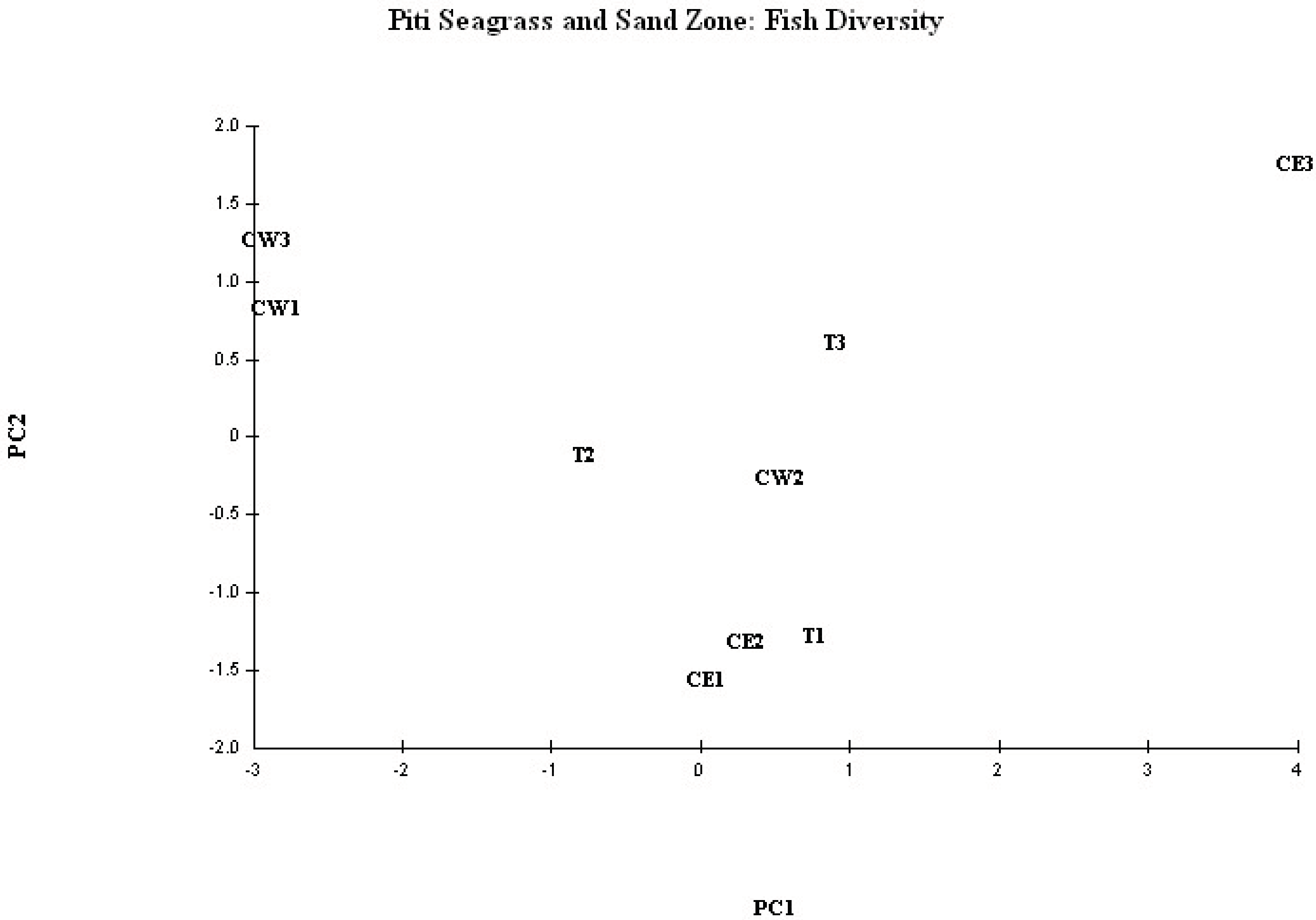


Figure 10. Principal components analysis (PCA) of fish diversity (all measures; see Table 9) in relation to Treatment (T) or Control (CW and CE) transects in the Seagrass and Sand Zone at Piti. Axis PC1 (benthic substrata) accounts for 72.6% and axis PC2 (diversity) accounts for 24.2% of the variation.

and Cw6 and the least were Cw4 and Ce6. Between treatment and control transects, the most similar were T5 and Cw6 while the least were T5 and Ce5. The dendrogram (Figure 11) generated from a cluster analysis of this matrix indicated that Cw5 and Ce4 formed a cluster allied with Ce3, that in turn was related to a cluster consisting of T6 and Cw6; T1 and T3 formed a another cluster linked to this and to a cluster consisting of Ce5 and Cw4. MDS analysis (Figure 12) showed that all control and treatment transects were widely dispersed with treatments being placed somewhat closer to controls positioned adjacently at the field site. The stress value of 0.15 indicated a moderate degree of reliability in this result. The analysis of similarity between treatments and controls indicated no significant differences in the assemblage structure of fishes within this zone (Global $R = 0.167$, $p = 0.167$). Species diversity and evenness values (Table 9) indicated that among treatments T4 had the most species (S) and greatest diversity (d, H' and L), T6 had the greatest number of individuals of all species of fishes, and T4 had the highest value of evenness (J). Among controls, Ce5 had the greatest number of species (S), number of individuals (N) and the highest diversity (d, H' and L), while Ce6 had the greatest evenness (J). An examination of the relationship between these values and those of percent cover of substrata by principal components analysis (Figure 13) explained 96.5% of the variation in the data. Fish checklists are given in Appendix C.

Sink Hole Zone

Similarity values (Bray-Curtis index) between treatment transects, control transects, and treatment x control transects for the Limestone and Sand Zone are given in Table 8. Among treatment transects, the most similar were T7 and T9 while the least were T8 and T10. Among control transects, the most similar were Cs1-9 and Cs1-10 and the least were Cs1-11 and Cs2-15. Between treatment and control transects, the most similar were T8 and Cs1-11 while the least were T10 and Cs1-11. The dendrogram (Figure 14) generated from a cluster analysis of this matrix produced three large clusters. The first consisted of Cs2-14 and Cs1-7 formed a cluster allied with Cs2-17.

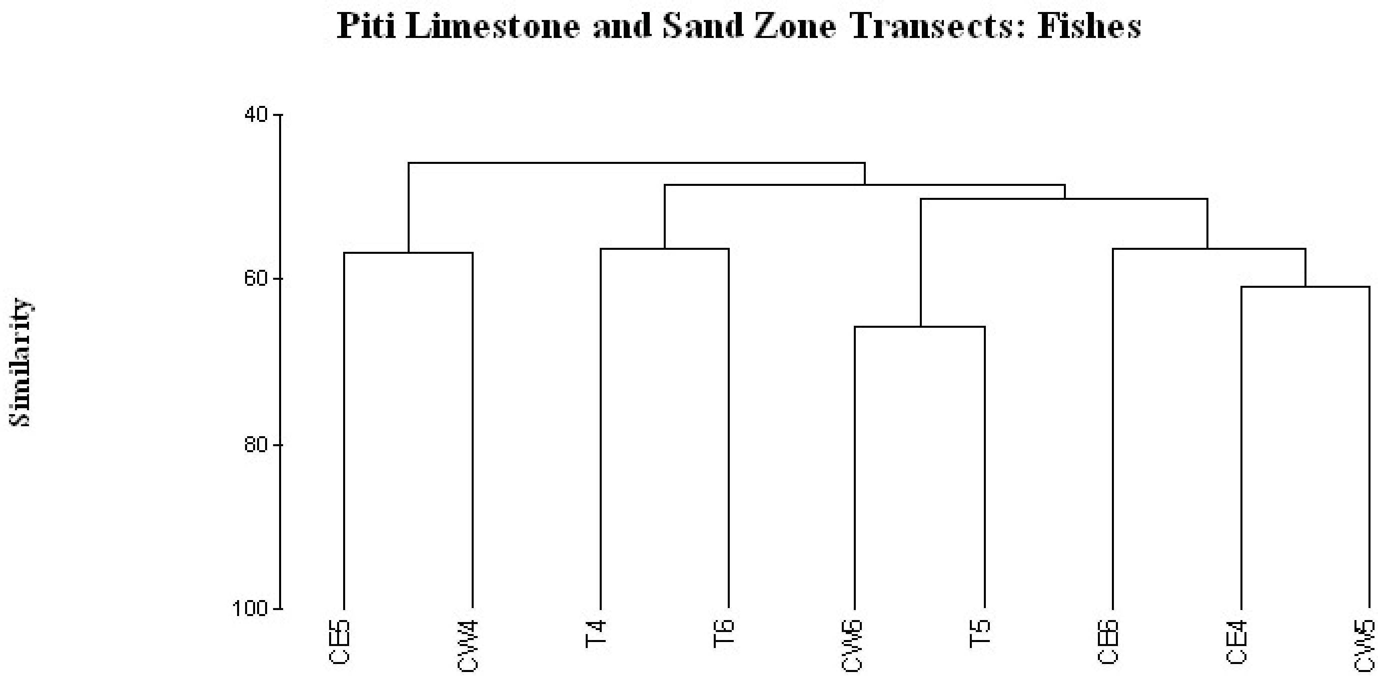


Figure 11. Cluster analysis dendrogram based upon Bray-Curtis similarity values (square root transformed) indicating fish assemblage structural relationships between Treatment (T) and Control (CW and CE) transects in the Piti Limestone and Sand Zone. The descending vertical axis indicates increasing similarity.

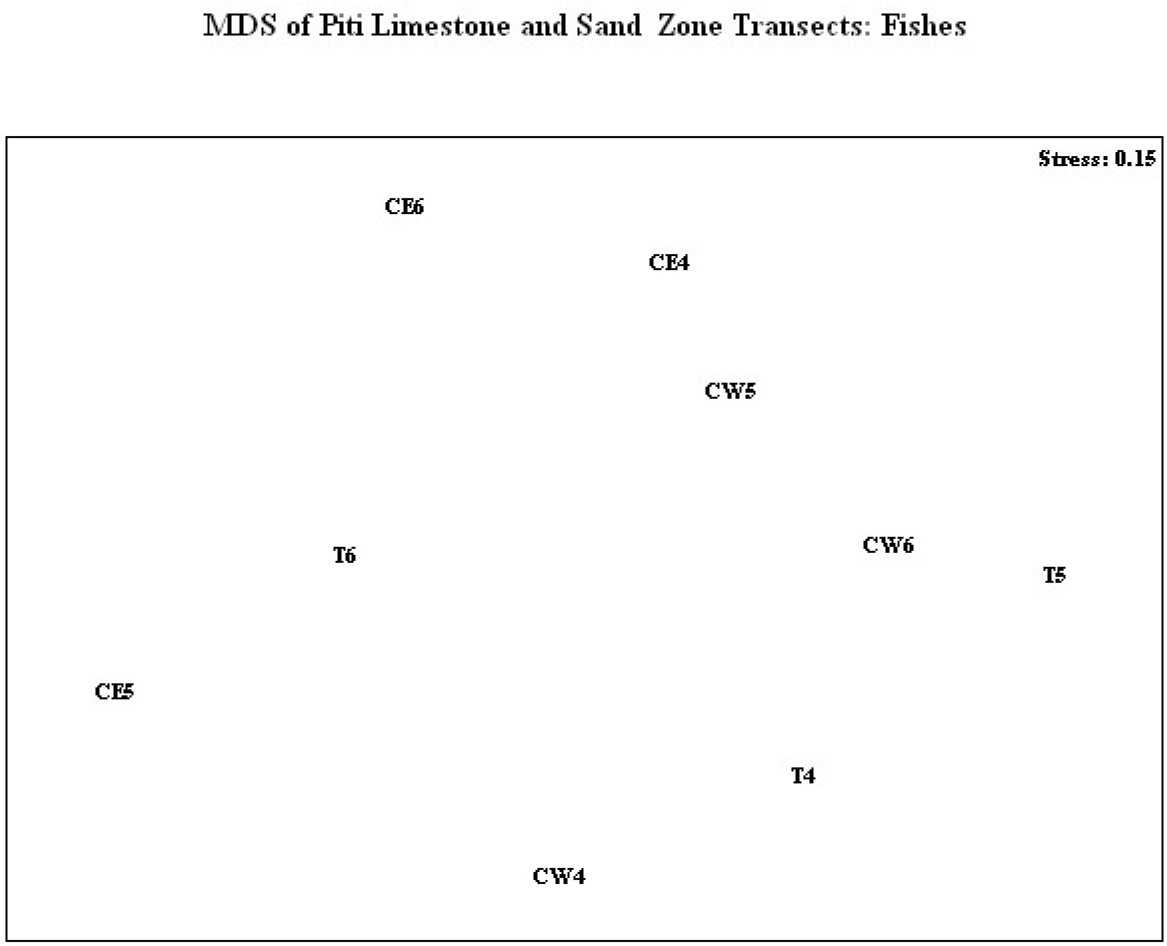


Figure 12. Multidimensional scaling (MDS) analysis of fishes on transects in the Limestone and Sand Zone at Piti. Treatment (T) and Control (CW and CE) transects are indicated.

Table 9. Species diversity and evenness indices for fishes at three sites in Piti. S = number of species, N = number of individuals, d = Margalef's index of species richness, J = Pielou's evenness, H' (log e) = Shannon diversity index, L = Simpson's 1-lambda index of diversity. Transect abbreviations are given in the text.

Index

Seagrass and Sand Zone

	S	N	d	J'	H'(loge)	L
T1	3	4	1.442695	0.946395	1.039721	0.833333
T2	11	28	3.001016	0.807189	1.935556	0.81746
T3	5	54	1.002762	0.639433	1.029127	0.549266
CW1	20	77	4.374045	0.874509	2.619796	0.91866
CW2	6	20	1.669041	0.766547	1.373469	0.684211
CW3	22	83	4.752378	0.795966	2.460364	0.869527
CE1	4	4	2.164043	1	1.386294	1
CE2	4	5	1.864005	0.960964	1.332179	0.9
CE3	1	1	0	0	0	0

Limestone and Sand Zone

	S	N	d	J'	H'(loge)	L
T4	17	37	4.431006	0.898964	2.546956	0.918919
T5	9	33	2.287997	0.751732	1.651724	0.763258
T6	14	61	3.162345	0.767953	2.026671	0.832787
CW4	14	50	3.323089	0.859949	2.269455	0.884082
CW5	8	29	2.078819	0.832429	1.730988	0.79803
CW6	10	36	2.511498	0.880708	2.027904	0.850794
CE4	6	19	1.698116	0.869291	1.55756	0.795322
CE5	17	49	4.111187	0.885178	2.507898	0.915816
CE6	10	26	2.762349	0.914577	2.105892	0.895385

Table 9, continued

	Index					
	S	N	d	J'	H'(loge)	L
Sink Hole Zone						
T7	41	326	6.912167	0.64102	2.380474	0.815517
T8	34	217	6.133946	0.788482	2.780472	0.90425
T9	39	307	6.635413	0.768834	2.81667	0.907496
T10	37	309	6.279061	0.673099	2.430505	0.84569
T11	32	123	6.441981	0.784148	2.717649	0.876849
T12	40	112	8.265341	0.869246	3.206545	0.941281
CS1-7	37	86	8.081992	0.887807	3.205797	0.950752
CS1-8	17	54	4.011046	0.788298	2.233416	0.843466
CS1-9	25	115	5.058028	0.703894	2.265748	0.821053
CS1-10	31	205	5.635909	0.699219	2.401108	0.850598
CS1-11	11	38	2.749076	0.825761	1.980088	0.847795
CS1-12	18	49	4.368136	0.827146	2.390759	0.87415
CS2H13	16	91	3.325309	0.747579	2.072728	0.817094
CS2-14	19	47	4.675145	0.838948	2.47023	0.886216
CS2-15	15	71	3.284319	0.685274	1.855756	0.734004
CS2-16	18	77	3.913619	0.808454	2.336732	0.875256
CS2-17	26	132	5.120011	0.683916	2.228265	0.773537
CS2-18	19	49	4.625085	0.858333	2.527309	0.904762

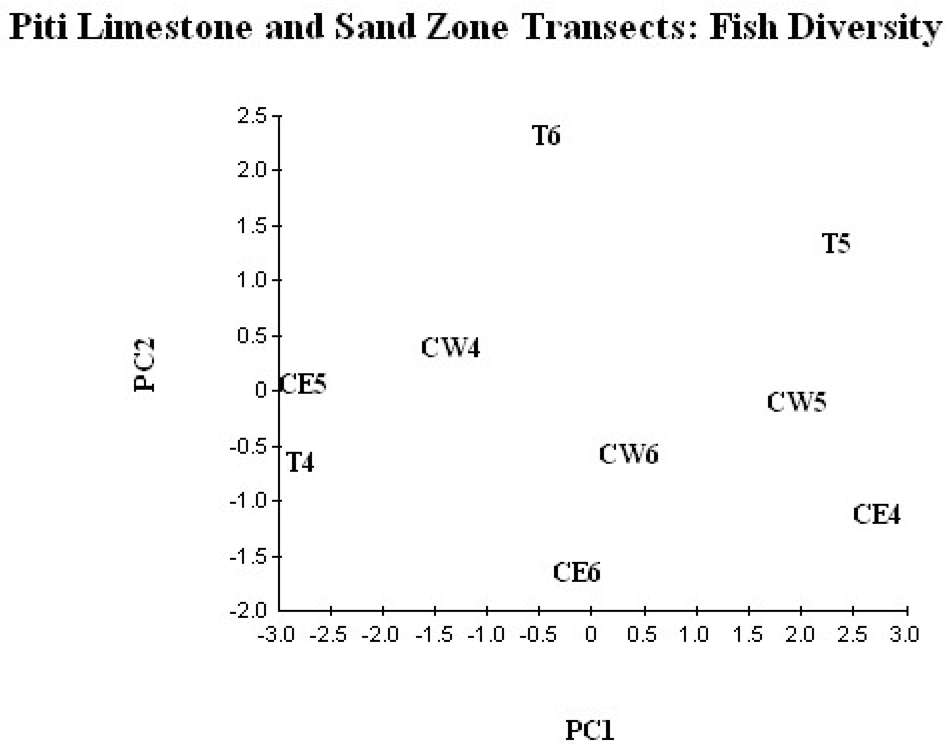


Figure 13. Principal components analysis (PCA) of fish diversity (all measures; see Table 9) in relation to Treatment (T) or Control (CW and CE) transects in the Limestone and Sand Zone at Piti. Axis PC1 (benthic substrata) accounts for 71.3% and axis PC2 (diversity) accounts for 25.3% of the variation.

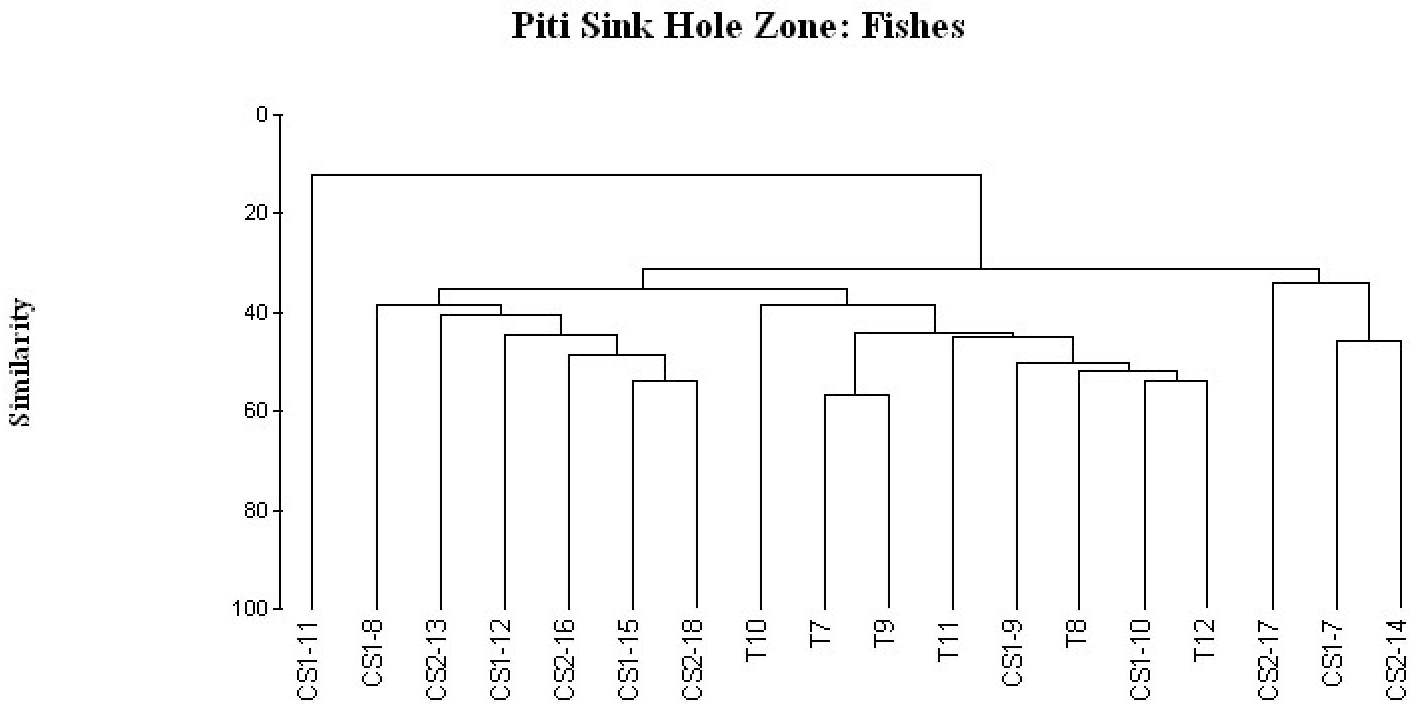


Figure 14. Cluster analysis dendrogram based upon Bray-Curtis similarity values (square root transformed) indicating fish assemblage structural relationships between Treatment (T) and Control (CS1 and CS2) transects in the Piti Sink Hole Zone. The descending vertical axis indicates increasing similarity.

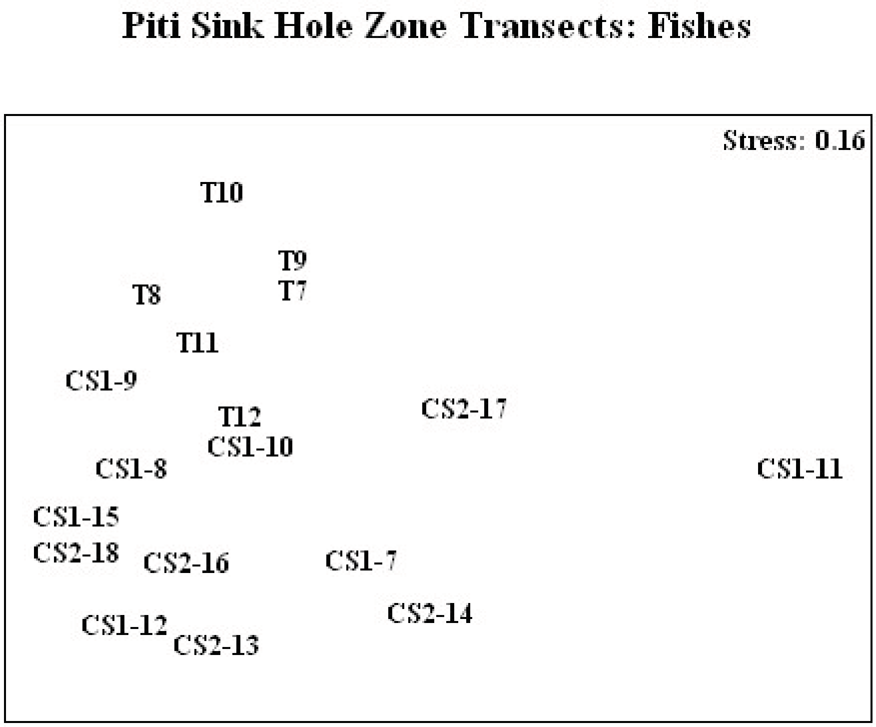


Figure 15. Multidimensional scaling (MDS) analysis of fish on transects in the Sink Hole Zone at Piti. Treatment (T) and Control (CS1 and CS2) transects are indicated.

The second had T12 and Cs1-10 linked in successive clusters to T8, Cs1-9, T11, T7 and T9, and T10. The third consisted of Cs2-18 and Cs2-15 linked in successive clusters consisting of Cs2-16, Cs1-12, Cs2-13, Cs1-8 and Cs1-11. MDS analysis (Figure 15) showed that all treatment transects were placed adjacent to all control transects except for Cs2-17, Cs1-7 and Cs2-14 while Cs1-11 was well separated from all other transects. The stress value of 0.16 indicated a moderate degree of reliability in this result. The analysis of similarity between treatments and controls indicated a significant difference in the assemblage structure of fishes within this zone (Global $R = 0.272$, $p = 0.014$) that may likely be attributed to the presence of fish feeding stations in impacted sink (site of treatment transects). Species diversity and evenness values (Table 9) indicated that among treatments T7 had the most species (S), greatest number of individuals (N) and greatest Margalef diversity (d), T12 had the greatest H' and L diversity, and the greatest value of evenness (J), as well. Among controls, Cs1-10 had the greatest number of species (S) and greatest number of individuals (N), Cs1-8 had the highest diversity (d, H' and L) and also the greatest evenness (J). An examination of the relationship between these values and those of percent cover of substrata by principal components analysis (Figure 16) explained 95.4% of the variation in the data. Fish checklists are given in Appendix C.

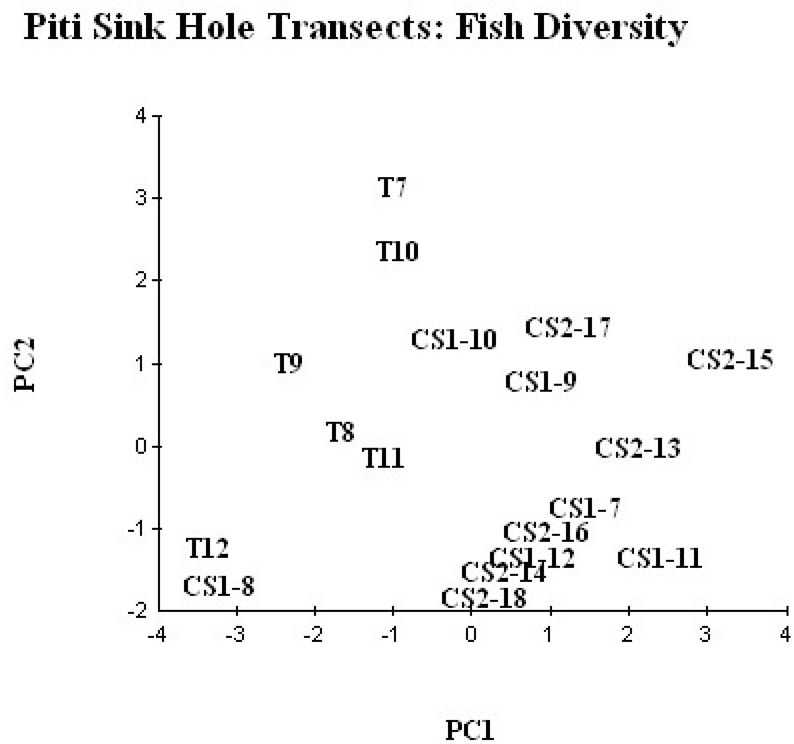


Figure 16. Principal components analysis (PCA) of fish diversity (all measures; see Table 9) in relation to Treatment (T) or Control (CS1 and CS2) transects in the Seagrass and Sand Zone at Piti. Axis PC1 (benthic substrata) accounts for 58.9 and axis PC2 (diversity) accounts for 36.5 of the variation.

RELATIONSHIPS BETWEEN FISH DIVERSITY AND BENTHIC SUBSTRATA WITHIN ZONES

No significant relationship occurred between substratum type (as percent cover) and fish species diversity (H'), either by multiple regression or single regression analyses, in the Seagrass and Sand Zone. In the Limestone and Sand Zone, significant relationships were found between H' and hard coral, and H' and sand. In addition, multiple regression analysis indicated a significant relationship between H' and all substrata. In the Sink Hole Zone, significant relationships were found between H' and hard corals, cyanobacteria, and soft corals, respectively, but the multiple regression analysis results found no significant relationship overall. Curiously, the relationship between hard coral cover and diversity was negative. The relationships between diversity and cyanobacteria, and diversity and soft corals, however, were positive. Summaries and plots for all regression analyses are in the CD-ROM provided to GCMP.

Scuba Bob and Seawalker Sites, Cocos Lagoon

WATER QUALITY

The 16 water samples (i.e., two replicate samples at each of four sites) collected on two days, 27 January and 12 February 2004, at the seawaker and Scuba BOB sites, and upcurrent and downcurrent of the marine recreational facilities in the southwest sector of Cocos Lagoon, likewise, did not show any discernable patterns (Table 10). The temperature readings on the first day of sampling were consistent at 28ºC; on the second day the readings were 27ºC. Salinity readings varied from 34 to 35 ppt. The settleable solids were similar to the Piti samples with all readings less than 0.1 mg/liter. Suspended solids ranged from 1.4 to 4.3 mg/liter. Replicate samples showed considerable difference; only three of the replicate samples showed differences of less than 15%. Nitrate values ranged from less than 0.001 to 0.018 mg/liter. The phosphate values were low, i.e., 14 of the 16 water samples showed less than 0.002 mg/liter of phosphate.

BENTHIC ALGAE AND CYANOBACTERIA

Although a few individuals of the seagrass *Halodule uninervis* were observed in the sandy lagoon slopes, none was recorded along the transects (Table 11). Cyanobacteria were overall more abundant than algae along two of the three transects at the Scuba BOB site. At the Seawalker site, algae were more abundant than cyanobacteria along all three transects. At the upcurrent controls, the first set of three transects (UC1, UC2 and UC3) was mainly in sandy areas and possessed very little algae and cyanobacteria. The second set of three upcurrent controls (UC4, UC5 and UC6) possessed more cyanobacteria than algae, while the third set of three upcurrent controls (UC7, UC8 and UC9) and the set of three downcurrent controls (DC1, DC2 and DC3) had more algae than cyanobacteria.

HARD AND SOFT CORALS

Based on the set of three transects in each of the predominantly sandy area, the Scuba BOB site had more corals than the Seawalker site (see Table 11). Hard corals covered 10% and 6% of Transects SB1 and SB2, respectively, while no corals were present along Transect SB3. Soft corals were absent along the three transect at the Scuba BOB site. A few soft corals and hard corals were recorded along two of the three transects, i.e., SW2 (<1% soft corals and 3% hard corals) and SW3 (3% soft corals and 1% hard corals). Soft corals were recorded on only one (UC2) of the 9 upcurrent control transects; none was recorded on any of the three downcurrent control transects. Only two of the 9 upcurrent control transects possessed hard corals with cover greater than 1%, i.e., UC6 (7%) and UC7 (5%). Only one of the three downcurrent control transects had hard coral cover greater than 1%, i.e., DC2 (3%).

The coral survey (Table 12) of the four sites at Cocos Lagoon revealed 39 species of hard corals at the Seawalker site and 30 species at the Scuba BOB site. Thirty six species of hard corals were observed downcurrent or south of the marine recreational sites; 29 species were observed upcurrent or north of the marine recreational sites. *Porites rus* was the dominant coral at both the Scuba BOB and Seawalker sites.

Table 10. Temperature (°C), salinity (ppt), turbidity (NTU), suspended solids (mg/l), settleable solids (mg/l), nitrate (mg/l) and o-phosphate (mg/l) of replicate water samples collected during flooding tides at the southwest sector of Cocos Lagoon on 27 January and 12 February 2004.

Samples	Date/ Time	Temp.	Salinity	Turbidity	Solids Suspended	Solids Settleable	Nitrate	Phosphate
Upcurrent	1/27,0945	28	35.0	0.70	2.7	<0.1	0.005	0.009
		28	35.0	0.45	3.9	<0.1	0.002	<0.002
	2/12,1020	27	34.0	0.69	3.3	<0.1	<0.001	<0.002
		27	34.0	0.84	3.1	<0.1	0.006	<0.002
Seawalker	1/27,0955	28	34.0	0.41	2.9	<0.1	0.002	<0.002
		28	34.0	0.45	4.3	<0.1	0.003	<0.002
	2/12,1024	27	34.0	0.78	3.0	<0.1	<0.001	<0.002
		27	34.0	0.76	2.0	<0.1	<0.001	<0.002
Scuba BOB	1/27,1000	28	34.0	0.26	2.8	<0.1	0.005	<0.002
		28	34.0	0.48	2.4	<0.1	0.012	<0.002
	2/12,1028	27	34.0	0.66	3.3	<0.1	0.002	<0.002
		27	34.0	0.69	1.4	<0.1	0.002	0.016
Down-current	1/27,1010	28	35.0	0.39	2.7	<0.1	0.018	<0.002
		28	35.0	0.36	1.9	<0.1	0.002	<0.002
	2/12,1030	27	34.5	0.74	2.6	<0.1	<0.001	<0.002
		27	34.0	0.75	2.7	<0.1	<0.001	<0.002

Table 11. Percent cover (100%) of substrata and benthic community along the 18 50-meter long belt transects along the southwest corner of Cocos Lagoon, Guam. Sum represents pooled values from three transects (300%). SB = Scuba Bob; SW = Seawalker.

Substrata	SB1	SB2	SB3	Sum		SW1	SW2	SW3	Sum
Sand	72%	60%	62%	194%		93%	52%	73%	218%
Pavement	0%	1%	10%	11%		0%	24%	12%	36%
Rubble	5%	8%	4%	17%		5%	15%	6%	26%
Seagrass	0%	0%	0%	0%		0%	0%	0%	0%
Algae	10%	4%	4%	18%		2%	5%	4%	11%
Cyanobacteria	4%	21%	19%	44%		0%	<1%	1%	1%
Hard Coral	10%	6%	0%	16		0%	3%	1%	4%
Soft Coral	0%	0%	0%	0%		0%	<1%	3%	4%
Echinoderms	0%	0%	0%	0%		0%	0%	0%	0%

				Upcurrent Controls					
Substrata	UC1	UC2	UC3	Sum		UC4	UC5	UC6	Sum
Sand	75%	88%	98%	261%		62%	55%	29%	146%
Pavement	3%	<1%	<1%	5%		2%	1%	9%	12%
Rubble	20%	5%	<1%	25%		7%	12%	33%	52%
Seagrass	0%	0%	0%	0%		0%	0%	0%	0%
Algae	2%	<1%	<1%	3%		12%	6%	4%	22%
Cyanobacteria	0%	1%	0%	1%		16%	26%	18%	60%
Hard Coral	<1%	0%	0%	<1%		<1%	0%	7%	8%
Soft Coral	0%	5%	0%	5%		0%	0%	0%	0%
Echinoderms	0%	0%	0%	0%		0%	0%	0%	0%

Table 11, continued.

		Upcurrent Controls						Downcurrent Controls	
Substrata	**UC7**	**UC8**	**UC9**	**Sum**		**DC1**	**DC2**	**DC3**	**Sum**
Sand	47%	28%	72%	147%		15%	7%	37%	59%
Pavement	5%	7%	0%	12%		22%	8%	3%	33%
Rubble	9%	18%	2%	29%		12%	24%	9%	45%
Seagrass	0%	0%	0%	0%		0%	0%	0%	0%
Algae	29%	33%	22%	84%		29%	47%	12%	88%
Cyanobacteria	5%	14%	3%	22%		22%	11%	39%	72
Hard Coral	5%	<1%	0%	6%		<1%	3%	0%	4%
Soft Coral	0%	0%	0%	0%		0%	0%	0%	0%
Echinoderms	0%	0%	0%	0%		0%	0%	0%	0%

Table 12. Checklist of coral species observed at Cocos Lagoon on 27 January 2004. Survey conducted by Teina Rongo and Jackie Holbrook. Numbers 1, 2 and 3 represent ranking of the dominant corals.

Species	Downcurrent (S)	Scuba BOB	Seawalker	Upcurrent (N)
Acropora humilis		x		
Astreopora elliptica	x		x	x
Astreopora gracilis	x	x	x	x
Astreopora listeri			x	
Astreopora myriophthalma	x	x	x	x
Astreopora ocelata				x
Astreopora randalli		x	x	
Cyphastrea chalcidicum	x	x	x	
Cyphastrea serallia	x	x	x	x
Euphylia glabrescens				3
Favia favus				x
Favia matthaii			x	
Favia pallida	x	x	x	
Favia stelligera				x
Favites russelli	x		x	x
Fungia scutaria		x	x	
Galaxea fascicularis	x		x	x
Goniastrea edwardsi	x	x	x	
Goniastrea pectinata		x	x	
Goniastrea retiformis	x		x	x
Goniopora fruiticosa		x		
Goniopora minor				x
Goniopora tenuidens	x			
Heliopora coerulea	x		x	x
Leptastrea agazzi		x		
Leptastrea purpurea	1	3	3	2
Leptoria phrygia	x		x	
Millepora dichotoma	x			
Millepora platyphylla	x			
Millepora tuberosa	x		x	x
Montastrea curta	x	x		

Table 12, continued.

Species	Downcurrent (S)	Scuba BOB	Seawalker	Upcurrent (N)
Montipora foveolata			x	
Montipora lobulata	x			
Montipora verrucosa	x		x	
Montipora sp. 1	x			
Montipora sp. 2		x	x	
Montipora sp. 3	x		x	
Pavona decussata			x	
Pavona divaricata		x		x
Pavona varians	x	x	x	x
Platygyra daedalea		x	x	x
Platygyra pini	x		x	x
Pocillopora damicornis	x	x	x	x
Pocillopora danae	x		x	
Pocillopora eydouxi	x			
Pocillopora verrucosa	x		x	
Porites annae	x	x		
Porites australiensis	x	x	x	x
Porites cylindrica		x	x	
Porites lichen	x	2	x	1
Porites lobata	x	x	x	
Porites lutea	2	x	2	x
Porites rus		1	1	x
Porites solida		x		x
Porites vaughani	x	x	x	x
Psammacora obtusangula	x			x
Psammacora stellata			x	x
Stylocoeniella armata	x	x	x	x
Stylophora mordax		x		

Table 13. Counts of holothurians and other echinoderms along 18 50-meter long belt transects, 2

meters wide, each covering an area of 100 sq. m., at the southwest sector of Cocos Lagoon, December 2003 to February 2004. Holothurians: *Actinopyga echinites (A.e.), Bohadschia argus (B.a.), Bohadschia marmorata (B.m), Holothuria atra (H.a.), Holothuria axiologa (H.ax.), Synapta maculata (S.m.)* Asteroids: *Culcita novaeguineae (C.n.), Linckia laevigata (L.l.)*; Echinoids: *Diadema setosum (D.s.), Echinothrix diadema (E.d.).*

		Holothurians					Asteroids		Echinoids
Transects	*A.e.*	*B.a.*	*B.m.*	*H.a.*	*H.ax.*	*S.m.*	*C.n.*	*L.l*	*D.s.E.d.*
Scuba BOB (SB)									
SB1		1		1	3				
SB2		1							
SB3		1	1	1					
Seawalker (SW)									
SW1					1				
SW2								1	
SW3				1					
Upcurrent (UC)									
UC1				1					
UC2					1				
UC3				1	1			1	
UC4				2	1			2	2 1
UC5				1				1	4 7
UC6				4			1	1	14 8
UC7	1			2				2	411
UC8				6				5	2 9
UC9				3		1			3
Downcurrent (DC)									
DC1				6				3	
DC2								3	
DC3				2				3	

HOLOTHURIANS AND OTHER ECHINODERMS

Counts of holothurians and other echinoderms (Table 13) revealed six species of holothurians, two species of asteroids and two species of echinoids in the Cocos Lagoon site. The Scuba BOB and Seawalker sites possessed only the harmless holothurians and asteroids; very few organisms were recorded along each of the 2-meter wide and 50-meter long belt transects, i.e., 9 holothurians per 300 sq.m. area at the Scuba BOB site, and two holothurians and one *Linckia laevigata* per 300 sq.m. area at the Seawalker site.

The nine upcurrent control transects had four species of holothurians, two species of asteroids and two species of echinoids. Twenty of the 25 holothurians were *Holothuria atra*; 12 specimens of *Linckia laevigata* and only 1 specimen of *Culcita novaeguineae* were recorded along the nine upcurrent control transects. The echinoids, *Diadema setosum* (26) and *Echinothrix diadema* (39), were recorded along 6 of the 9 upcurrent control transects, i.e., UC4 to UC9. Only 8 specimens of *Holothuria atra* and 9 specimens of *Linckia laevigata* were recorded along the three downcurrent control transects.

RELATIONSHIPS BETWEEN BENTHIC SUBSTRATA WITHIN ZONES

Scuba Bob Site

Similarity values (Euclidean distance) between treatment transects, control transects, and treatment x control transects for the Scuba Bob site are given in Table 14. Among treatment transects, the most similar were SB1 and SB3 while the least were SB1 and SB2. Among control transects, the most similar were DC1 and UC9 and the least were DC1 and DC8. Between treatment and control transects, the most similar were SB1 and DC2 while the least were SB3 and DC3. The dendrogram (Figure 17) generated from a cluster analysis of this matrix formed two major clusters. The first consisted of three smaller clusters, UC7-UC9, SB1-SB2, AND SB3-DC3, while the second consisted of DC1-UC8 and DC-2. Thus treatment (SB) transects were somewhat distinct from upcurrent controls (UC) and most downcurrent controls (DC) with the exception of SB3 and DC3. MDS analysis (Figure 18) indicated a similar pattern. The stress value of 0.05 indicated a high degree of reliability in this result. The analysis of similarity between treatments and controls, however, indicated significant differences in the percent coverage of benthic substrata within this site (Global R = 0.34, p = 0.006).

Seawalker Site

Similarity values (Euclidean distance) between treatment transects, control transects, and treatment x control transects for the Seawalker site are given in Table 14. Among treatment transects, the most similar were SB1 and SB2 while the least were SB2 and SB3. Among control transects, the most similar were UC3 and UC6 and the least were UC4 and UC5. Between treatment and control transects, the most similar were SB1 and UC6 while the least were SB1 and UC3. The dendrogram (Figure 19) generated from a cluster analysis of this matrix formed two major clusters. The first consisted of the controls UC4-UC5 and UC6. The second consisted of SW1-UC3 allied with UC2 that was linked to UC1; these in turn were linked to two treatments, SW2-SW3. Thus, two treatment (SW2-SW3) transects were somewhat distinct from all upcurrent controls (UC) and one treatment (SW1). MDS analysis (Figure 20) indicated a similar pattern, although control transects UC4-UC5 and UC6 were quite distinct from both the other control and treatment transects. The stress value of 0.05 indicated a high degree of reliability in this result. The analysis of similarity between treatments and controls, however, indicated no significant differences in the percent coverage of benthic substrata within this site (Global R = 0.-0.093, p = 0.631).

Table 14. Similarity values (Euclidean distance) of percent benthic cover on transects at two sites in Cocos Lagoon. Values are transformed (square-root). Higher values indicate greater similarity. Transect abbreviations are defined in the text.

Scuba Bob Site

Transect

	SB1	SB2	SB3	DC1	DC2	DC3	UC7	UC8	UC9
SB1	0	0	0	0	0	0	0	0	0
SB2	3.228952	0	0	0	0	0	0	0	0
SB3	5.229214	3.380556	0	0	0	0	0	0	0
DC1	7.850883	6.526503	5.749456	0	0	0	0	0	0
DC2	8.161574	7.703068	7.969562	3.408448	0	0	0	0	0
DC3	6.121013	3.773437	3.457611	4.577952	6.300731	0	0	0	0
UC7	3.75421	4.400107	4.884737	4.763111	5.026358	5.060968	0	0	0
UC8	5.966873	5.250029	5.231473	2.797907	3.068424	3.933486	2.842956	0	0
UC9	3.616967	4.991033	4.985526	7.596705	8.02763	5.758242	3.988372	5.599104	0

Seawalker Site

Transect

	SW1	SW2	SW3	UC1	UC2	UC3	UC4	UC5	UC6
SW1	0	0	0	0	0	0	0	0	0
SW2	6.186455	0	0	0	0	0	0	0	0
SW3	4.31253	2.64374	0	0	0	0	0	0	0
UC1	3.157067	3.962298	3.383453	0	0	0	0	0	0
UC2	2.690845	5.352101	3.01192	3.636853	0	0	0	0	0
UC3	1.662797	6.100114	4.001272	3.911383	2.792289	0	0	0	0
UC4	5.147962	5.112054	4.339706	4.925132	4.866388	5.482195	0	0	0
UC5	5.877194	6.021528	5.420072	5.583145	5.410252	6.351345	2.070783	0	0
UC6	8.049061	4.779987	6.105274	5.91647	7.469244	8.537567	4.818989	4.610968	0

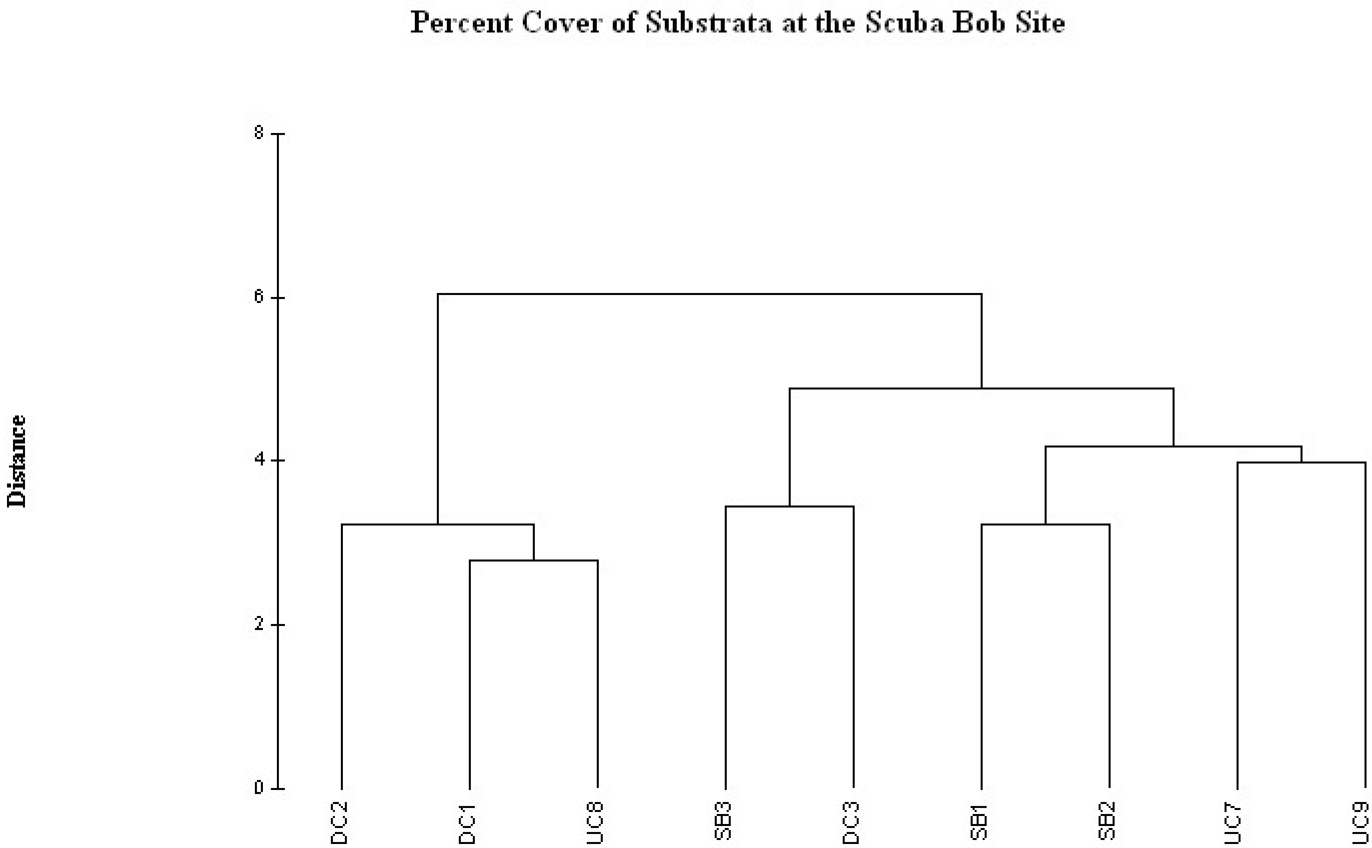


Figure 17. Cluster analysis dendrogram based upon similarity values (Euclidean distance square root transformed) indicating benthic substrata relationships between structural relationships between Treatment (SB) and Control (DC and UC) transects at the Scuba Bob site. The descending vertical axis indicates increasing similarity.

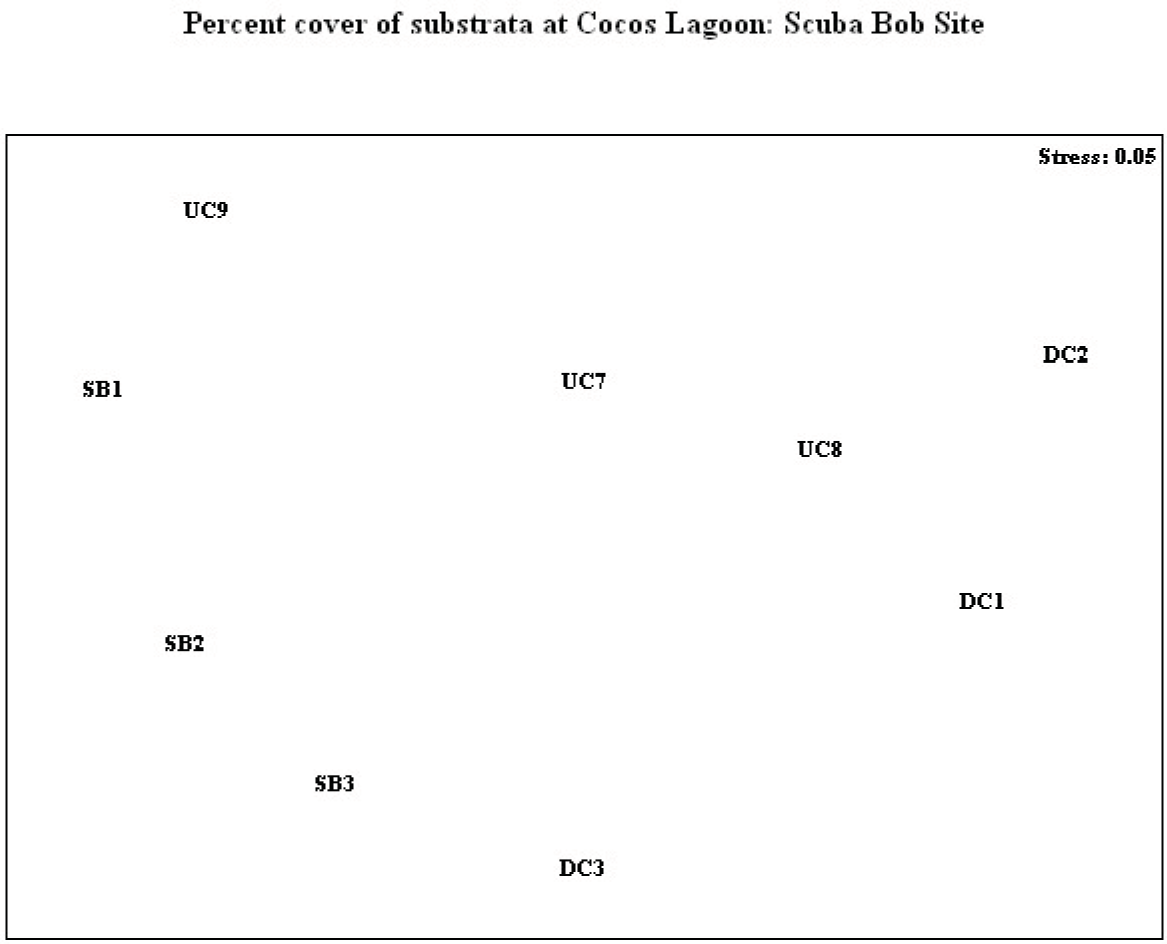


Figure 18. Multidimensional scaling (MDS) analysis of benthic transects at the Scuba Bob site. Treatment (SB) and Control (DC and UC) transects are indicated.

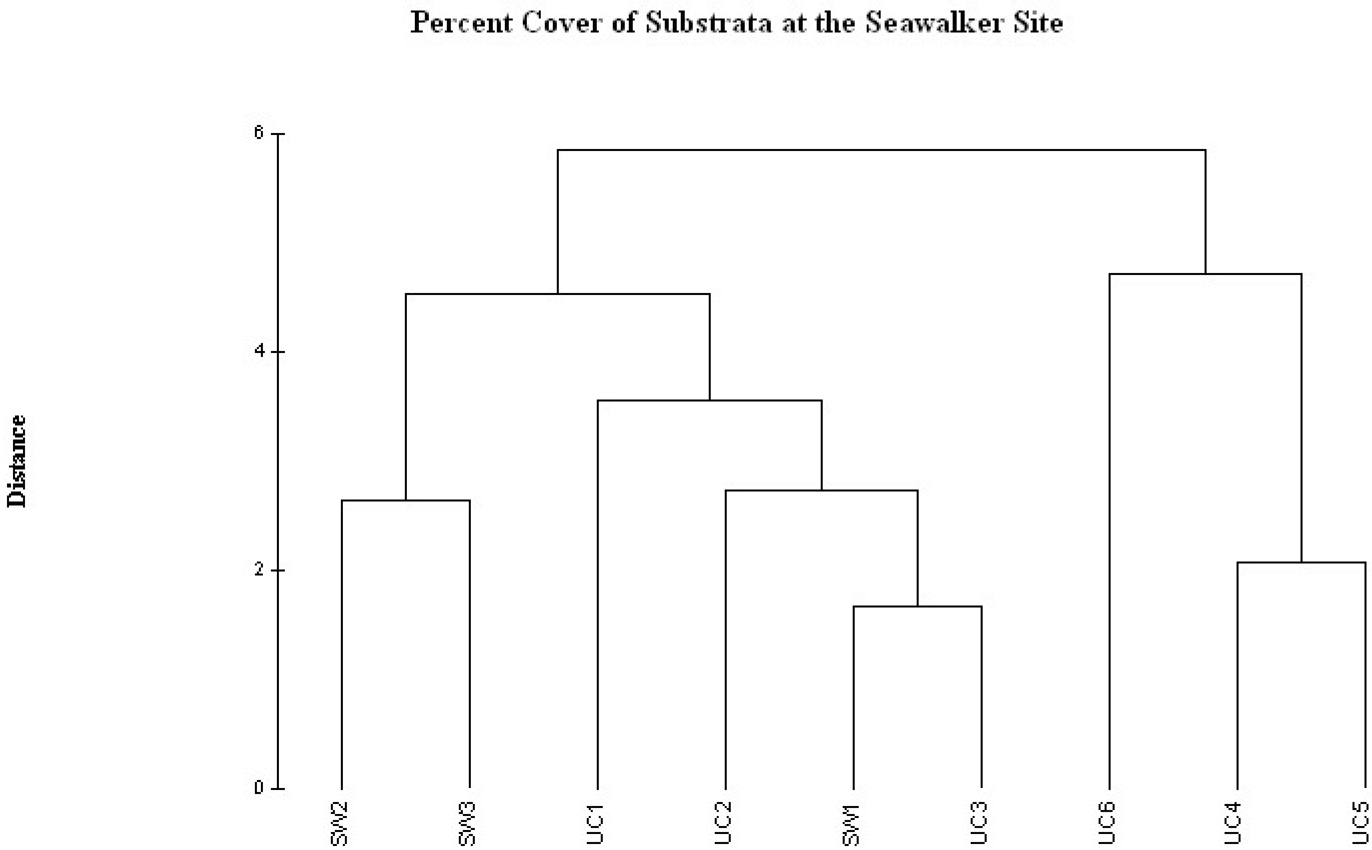
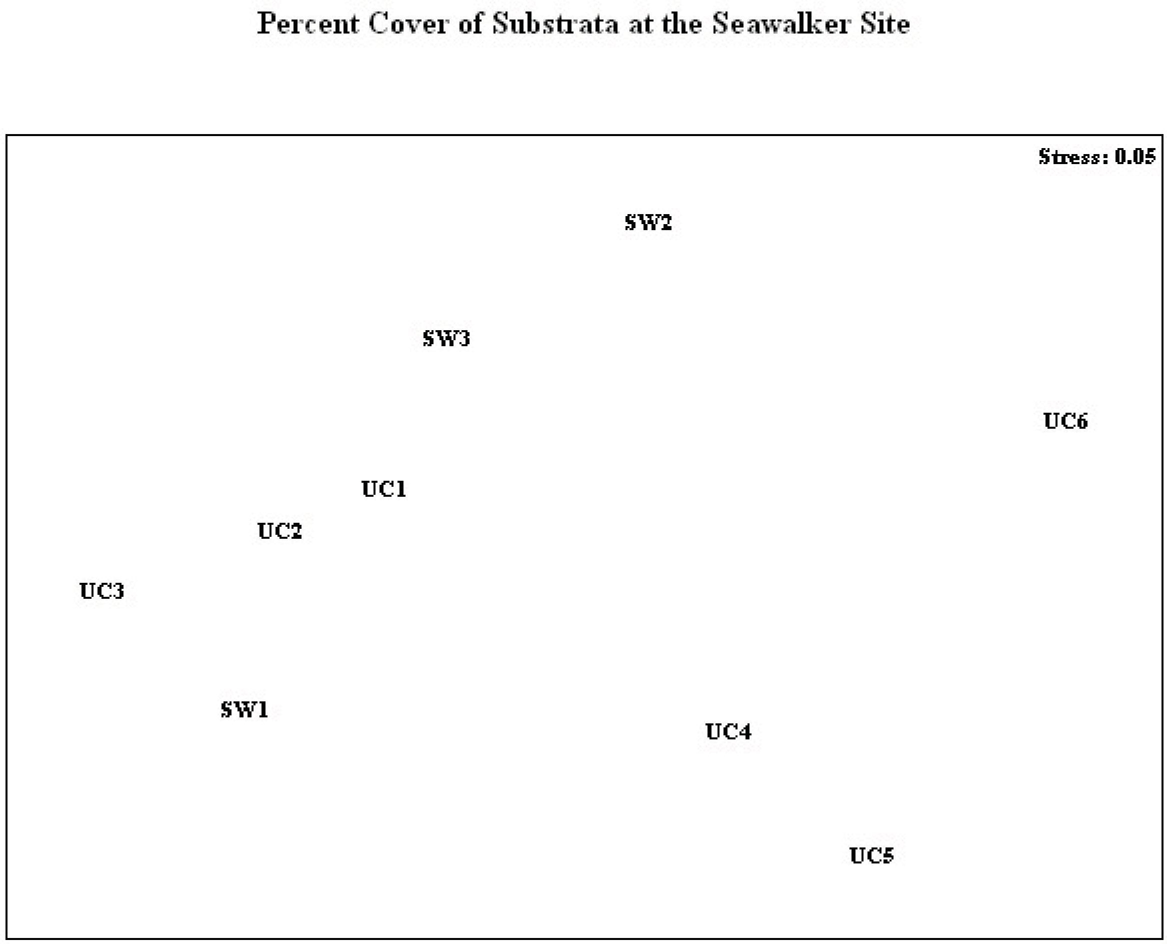


Figure 19. Cluster analysis dendrogram based upon similarity values (Euclidean distance square root transformed) indicating benthic substrata relationships between Treatment (SW) and Control (UC) transects in the Seawalker site. The descending vertical axis indicates increasing similarity.

Figure 20. Multidimensional scaling (MDS) analysis of benthic substrata at the Seawalker site.



Treatment (SW) and Control (UC) transects are indicated.

Table 15. Benthic biodiversity at impacted and control areas at Piti and Cocos Lagoon. Number of species obtained from pooled sets of three or six transects.

Transects	Seagrass	Non-Calc.	Calc.	Cyano-	Hard	Soft

		Algae	Algae	bacteria	Coral	Coral
PITI						
SEAGRASS ZONE						
Impacted, T1-T3	1	2	2	1	0	0
Control, Cw1-Cw3	1	3	1	0	0	0
Control, Ce1-Ce3	1	3	4	1	0	0
LIMESTONE ZONE						
Impacted, T4-T6	0	2	2	3	1	2
Control, Cw4-Cw6	0	2	3	3	1	1
Control, Ce4-Ce6	2	0	3	2	1	0
SINKS						
Seawalker, T7-T9	0	2	2	2	6	2
Observatory, T10-T12	0	1	0	0	3	0
Control Sink 1, Cs1-7 to12	0	6	1	4	3	3
Control Sink 2, Cs2-13 to18	0	3	1	3	4	3
COCOS LAGOON						
Scuba BOB, SB1-SB3	0	3	4	6	2	0
Seawalker, SW1-SW3	0	3	6	2	3	2
Upcurrent Control						
UC1-UC3	0	1	5	2	1	1
UC4-UC6	0	2	7	5	4	0
UC7-UC9	0	4	9	4	4	0
Downcurrent Control						
DC1-DC3	0	6	8	3	4	0

BIODIVERSITY OF BENTHIC FLORA AND INVERTEBRATE FAUNA AT PITI AND COCOS LAGOON SITES

Biodiversity of benthic flora and invertebrate fauna at both Piti and Cocos Lagoon sites (Table 15) was low for all groups of taxa. At Piti, there was one species of seagrass, 2-6 species of non-calcareous algae, 1-4 species of calcareous algae, 1-6 species of hard corals, and 1-3 species of soft corals. Overall species richness was greater in the Sink Hole Zone. At Cocos Lagoon, species richness was slightly greater compared to Piti but was still relatively low. There were 1-6 species of non-calcareous algae, 4-9 species of calcareous algae, 2-6 species of cyanobacteria, 1-4 species of hard corals, and 1-2 species of soft corals. Seagrasses were not present on the transects. Overall species richness on treatment transects at both Scuba Bob and Seawalker sites were comparable but there was greater variability at the control transects; calcareous algae were more speciose on the control transects compared to the treatment transects. See Appendices A and B for counts and percent cover of benthic organisms at Piti and Cocos Lagoon.

FISH ASSEMBLAGE RELATIONSHIPS

Scuba Bob Site

Similarity values (Bray-Curtis index) between treatment transects, control transects, and treatment x control transects for the Scuba Bob site are given in Table 16. Among treatment transects, the most similar were SB1 and SB2 while the least were SB1 and SB3. Among control transects, the most similar were UC7 and UC8 while the least were DC1 and UC9. Between treatment and control transects, the most similar were SB1 and UC7 while the least were SB2 and DC2. The dendrogram (Figure 21) generated from a cluster analysis of this matrix indicated two clusters. The first consisted of UC7-UC8 allied with DC-2, DC1 and DC3-UC9. The second consisted of the three treatment transects, SB1-SB2 and SB3. MDS analysis (Figure 22) provided a similar outcome. The stress value of 0.09 indicated a good degree of reliability in this result. Analysis of similarity between treatments and controls indicated a significant difference in the assemblage structure of fishes within this site (Global $R = 0.704$, $p = 0.012$). This is likely an outcome of the presence of a fish feeding station at the treatment site. Fish feeding attracts greater numbers of fishes but also

Table 16. Similarity values (Bray-Curtis index) of fish assemblage structure between treatment (SB) and control (UC and DC) transects at the Scuba Bob site. Higher values indicate greater similarity between transects.

Transect

	UC7	UC8	UC9	SB1	SB2	SB3	DC1	DC2	DC3
UC7	0	0	0	0	0	0	0	0	0
UC8	58.02256	0	0	0	0	0	0	0	0
UC9	44.91771	46.58891	0	0	0	0	0	0	0
SB1	42.29807	44.21374	32.39275	0	0	0	0	0	0
SB2	32.56321	31.55932	21.07423	50.20226	0	0	0	0	0
SB3	42.46767	40.62185	25.66188	43.09383	47.33661	0	0	0	0
DC1	44.4044	41.23089	30.48162	25.1317	26.90344	37.81677	0	0	0
DC2	47.35577	48.5058	38.95939	31.15489	18.91127	36.03385	35.34305	0	0
DC3	40.42959	31.052	46.07916	28.11013	19.87195	24.55595	39.11021	35.15969	0

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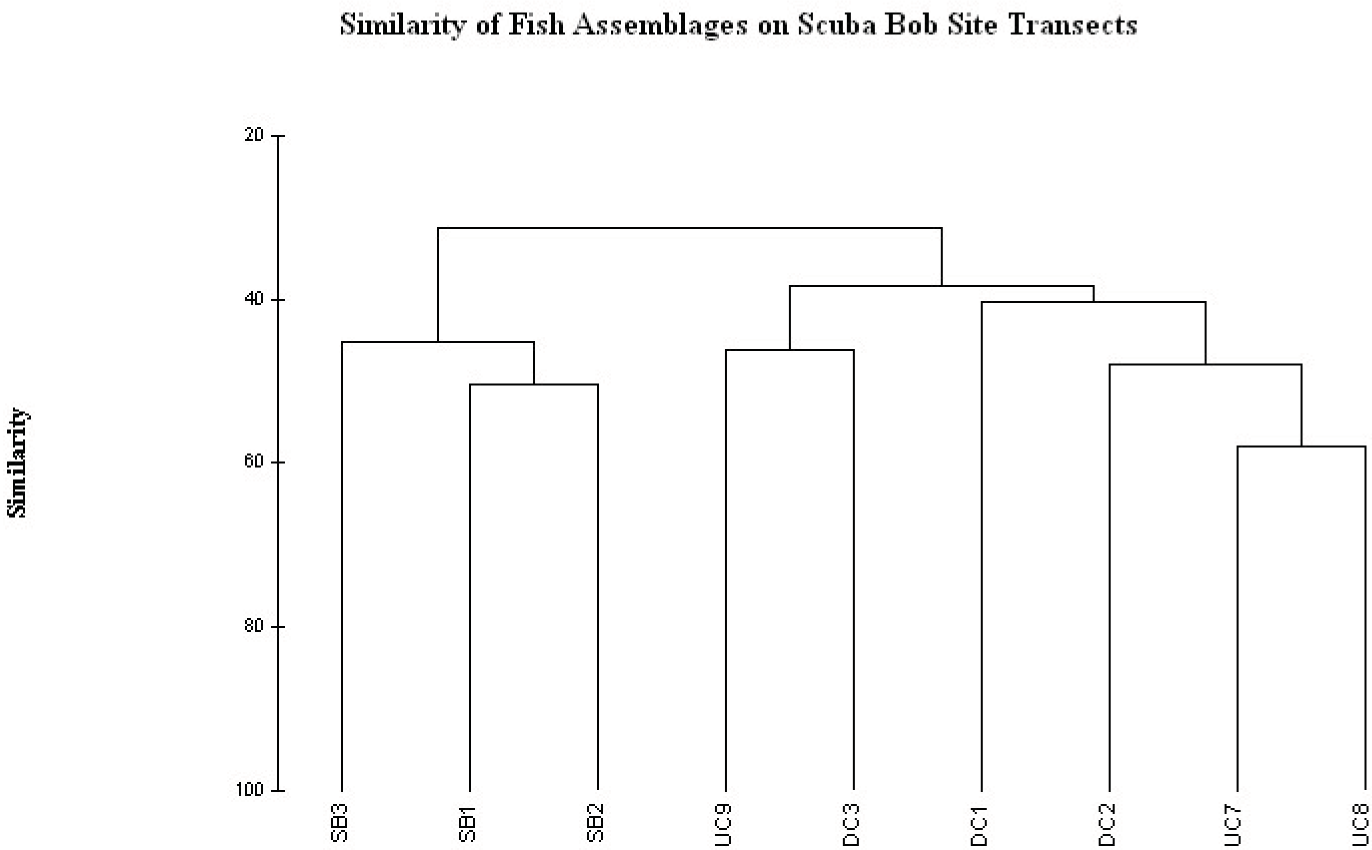
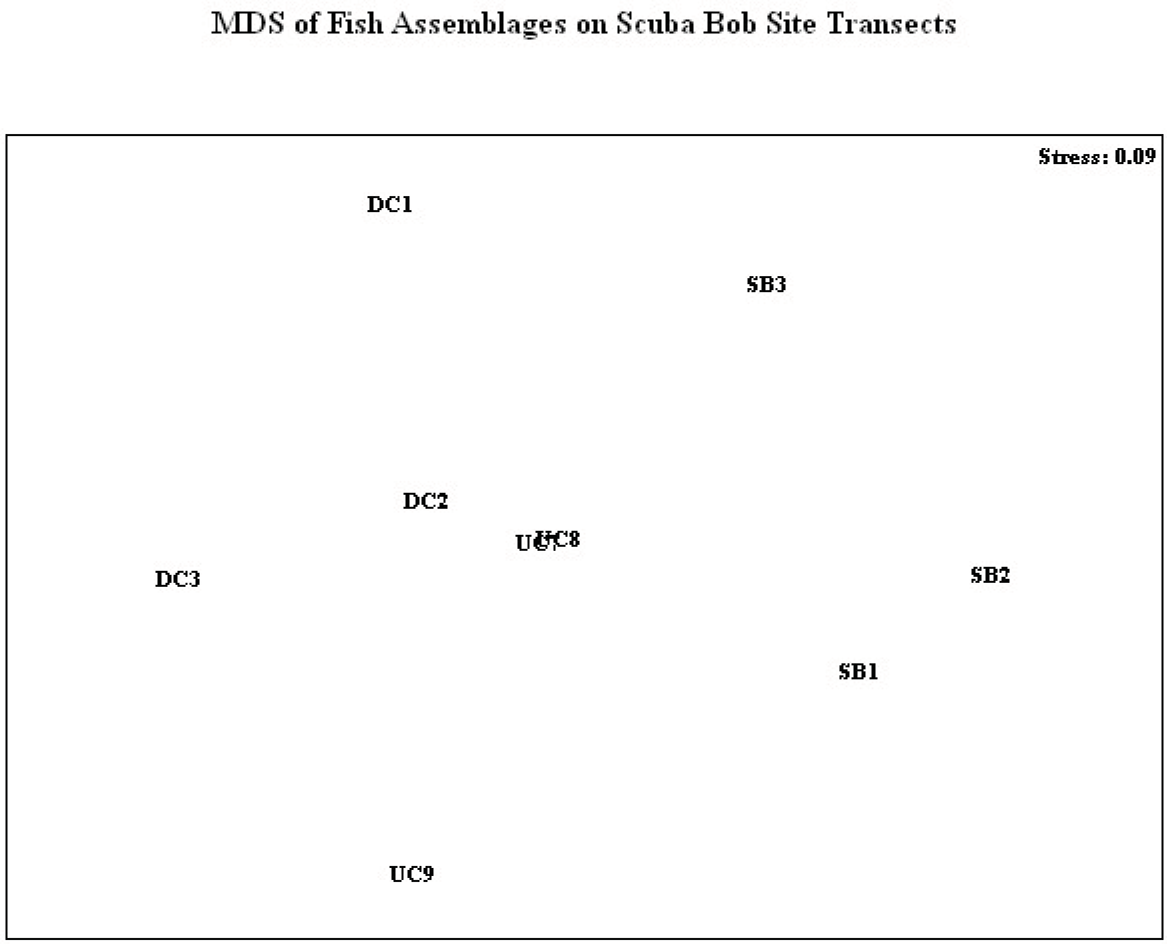


Figure 21. Cluster analysis dendrogram based upon Bray-Curtis similarity values (square root transformed) indicating fish assemblage structural relationships between Treatment (SB) and Control (DC and UC) transects at the Scuba Bob site. The descending vertical axis indicates increasing similarity.

Figure 22. Multidimensional scaling (MDS) analysis of fish transects at the Scuba Bob site. Treatment



(SB) and Control (DC and UC) transects are indicated.

Table 17. Species diversity and evenness indices for fish assemblages on treatment (SB) and control (UC and DC) transects at the Scuba Bob site. S = number of species, N = number of individuals, d = Margalef's index of species richness, J = Pielou's evenness, H' (loge) = Shannons diversity index, and L = Simpson's 1-lambda index of

diversity.

Transect	S	N	d	J'	H'(loge)	L
UC7	24	154	4.566253	0.778699	2.474746	0.868008
UC8	30	135	5.912003	0.860003	2.925041	0.929795
UC9	20	42	5.083381	0.864153	2.58877	0.89547
SB1	28	137	5.487826	0.803939	2.678889	0.889974
SB2	28	206	5.067685	0.578738	1.928475	0.722141
SB3	52	404	8.497996	0.604545	2.388703	0.740547
DC1	32	161	6.100676	0.800718	2.775077	0.913975
DC2	25	106	5.146417	0.79859	2.570563	0.884097
DC3	19	46	4.701407	0.884317	2.603817	0.919807

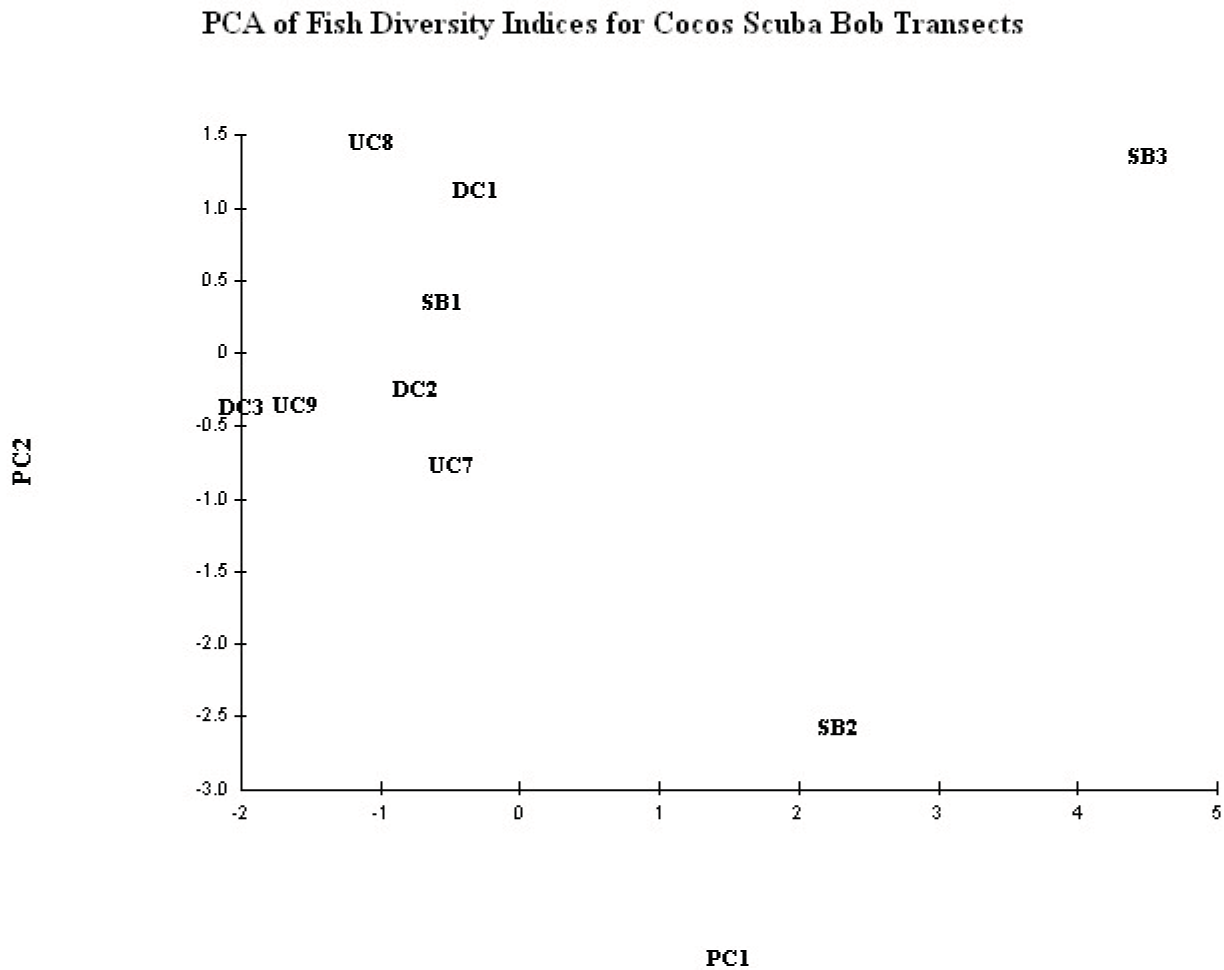


Figure 23. Principal components analysis (PCA) of fish diversity (all measures; see Table 17) in relation to Treatment (SB) or Control (DC and UC) transects at the Scuba Bob site. Axis PC1 (percent cover of benthic substrata) accounts for 71.6% and axis PC2 (diversity) accounts for 26.8% of the variation.

greater numbers of species of fishes to the site and immediate area where the feeding occurs. Species diversity and evenness values (Table 17) indicated that among treatments SB3 had the most species (S) and greatest diversity (d, H' and L), and the greatest number of individuals, while SB1 had the highest value of evenness (J). Among controls, DC1 had the greatest number of species (S), the greatest number of individuals (N), and the highest value of Margalef's diversity (d), UC8 had the greatest values of H' and L diversity, and DC3 had the greatest value of evenness (J). An examination of the relationship between these values and those of percent cover of substrata by principal components analysis (Figure 23) explained 98.4% of the variation in the data. Fish checklists are given in Appendix D.

Seawalker Site

Similarity values (Bray-Curtis index) between treatment transects, control transects, and treatment x control transects for the Seawalker site are given in Table 18. Among treatment transects, the most similar were SB1 and SB3 while the least were SB2 and SB3. Among control transects, the most similar were UC1 and UC3 while the least were UC2 and UC4. Between treatment and control transects, the most similar were SB1 and UC4 while the least were SW1 and UC2. The dendrogram (Figure 24) generated from a cluster analysis of this matrix indicated two clusters. The first cluster consisted of UC1-UC3 allied successively with UC-2 and SW2. The second consisted of UC5-SW3, UC4-SW1, and UC6. Thus, treatment and control transects were fairly mixed among one another. MDS analysis (Figure 25), however, showed that UC1, UC2 and UC3 were distinct from the other transects, that SW1 and SW3 were mixed with the remaining control sites, and that SW2 stood alone from all treatment and control transects. The stress value of 0.08 indicated a good degree of reliability in this result. In contrast, the analysis of similarity between treatments and controls indicated no significant difference in the assemblage structures of fishes within this site (Global R = -0.062, p = 0.631). Species diversity and evenness values (Table 19) indicated that among treatments SW1 had the most species (S) and greatest diversity (d, H' and L), SW3 had the greatest number of individuals, and SW2 had the highest value of evenness (J). Among controls, UC6 had the greatest number of species (S), the greatest diversity (d, H' and L), and the highest level of evenness (J), while UC4 had the greatest number of individuals. An examination of the relationship between these values and those of percent cover of substrata by principal components analysis (Figure 26) explained 95.8% of the variation in the data. Fish checklists are given in Appendix D.

RELATIONSHIPS BETWEEN FISH DIVERSITY AND BENTHIC SUBSTRATA WITHIN ZONES

No significant relationship between substratum type (as percent cover) and fish species diversity (H’), either by multiple regression or single regression analyses, at the either the Scuba Bob site or the Seawalker site, was found. Apparently, the benthic habitat within this portion of the lagoon cannot explain the levels of fish species diversity found there. A better comparison of diversity might be one-minute point counts, with replication, of fishes on transects with or adjacent to fish feeding sites versus transects without fish feeding sites.

Table 18. Similarity values (Bray-Curtis index) of fish assemblage structure on treatment (SW) and control (UC) transects at the Seawalker site. Higher values indicate greater similarity between transects.

Transect

	SW1	SW2	SW3	UC1	UC2	UC3	UC4	UC5	UC6
SW1	0	0	0	0	0	0	0	0	0
SW2	22.36094	0	0	0	0	0	0	0	0
SW3	48.64029	14.80508	0	0	0	0	0	0	0
UC1	30.45067	21.31223	21.29202	0	0	0	0	0	0
UC2	15.12895	17.63424	9.161541	45.44438	0	0	0	0	0
UC3	20.45384	28.54331	20.17103	57.83007	19.92834	0	0	0	0
UC4	55.47646	16.31739	50.81208	16.90219	8.470108	11.8092	0	0	0
UC5	46.86481	13.92782	52.10482	29.38216	13.06754	23.23588	51.68989	0	0
UC6	42.31392	20.55579	30.83569	29.42678	16.68763	16.68397	38.24171	35.3276	0

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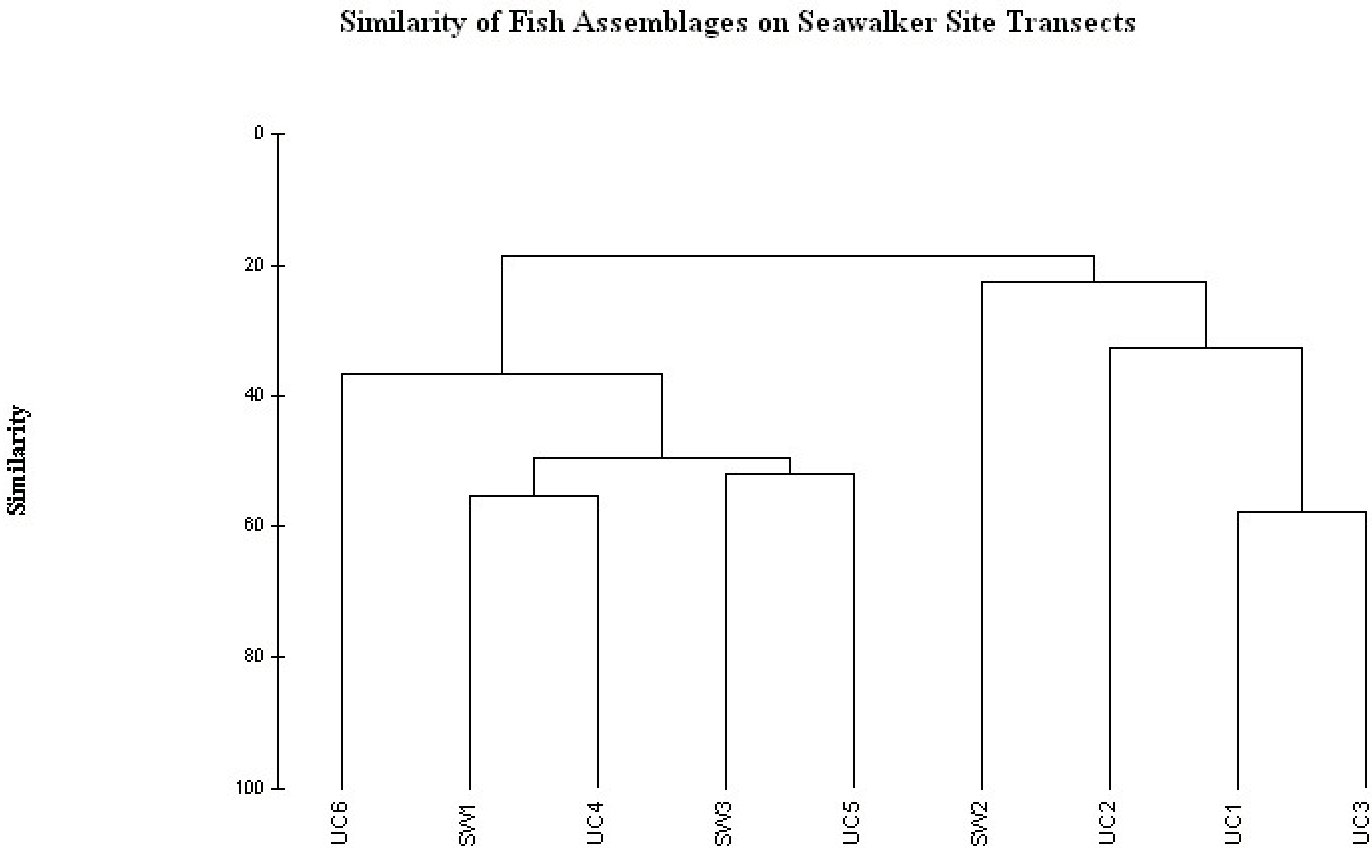

Figure 24. Cluster analysis dendrogram based upon Bray-Curtis similarity values (square root transformed) indicating fish assemblage structural relationships between Treatment (SW) and Control (UC) transects at the Seawalker site. The descending vertical axis indicates increasing similarity**.**

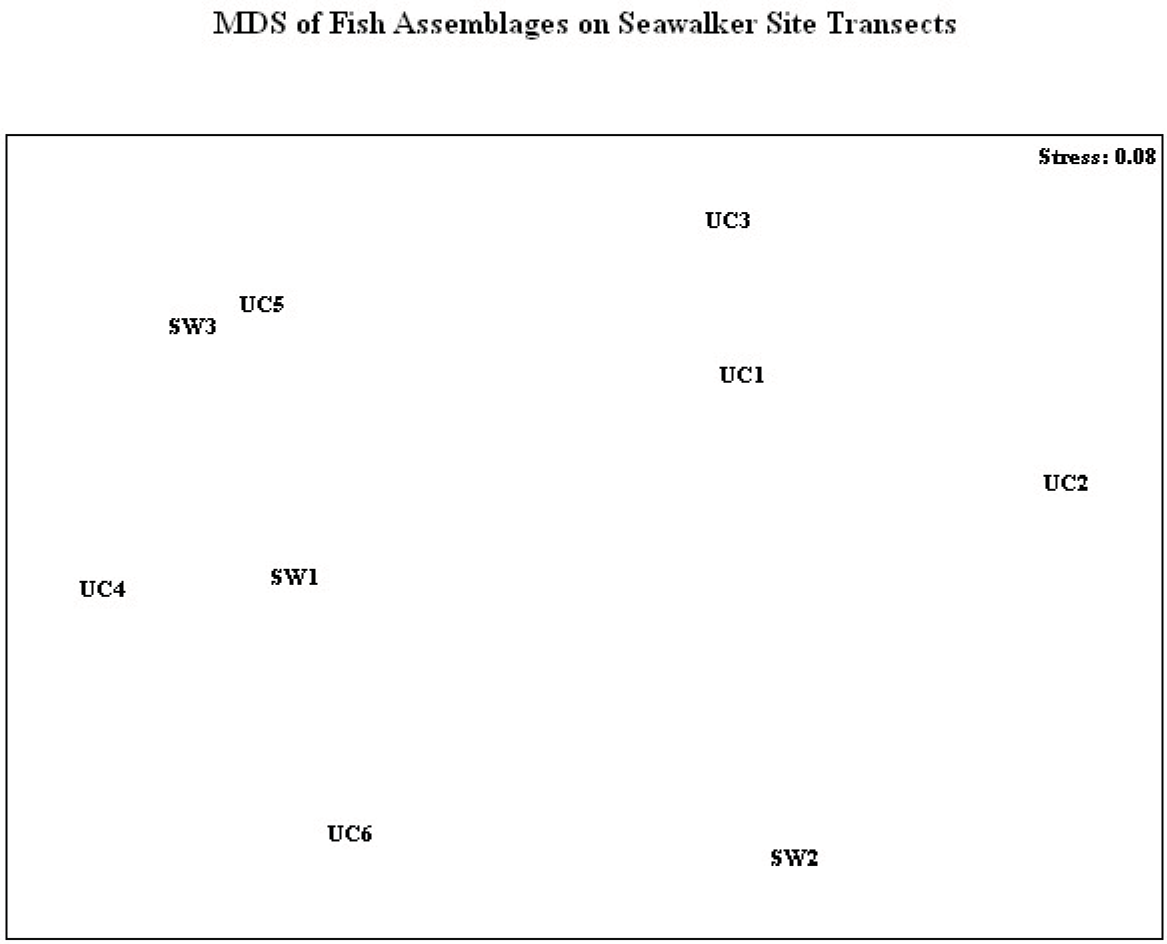

Figure 25. Multidimensional scaling (MDS) analysis of fish transects at the Seawalker site. Treatment (SW) and Control (UC) transects are indicated.

Table 19. Species diversity indices of fish assemblage structure on treatment (SW) and control (UC) transects at the Seawalker site. S = number of species, N = number of individuals, d = Margalef's index of species richness, J = Pielou's evenness, H' (log e) = Shannon's diversity index, and L = Simpson's 1-lambda index of diversity.

			Index			
Transect	S	N	d	J	H'(loge)	L
SW1	39	199	7.17888	0.832338	3.049322	0.932338
SW2	13	23	3.827148	0.902627	2.315191	0.913043
SW3	36	310	6.101204	0.684616	2.453334	0.860382
UC1	15	48	3.616449	0.80512	2.180306	0.858156
UC2	4	26	0.920783	0.703076	0.97467	0.563077
UC3	9	25	2.48534	0.787817	1.731011	0.776667
UC4	35	284	6.018792	0.629737	2.238933	0.787961
UC5	37	236	6.588783	0.704929	2.54544	0.823657
UC6	56	155	10.90529	0.881151	3.546943	0.960536

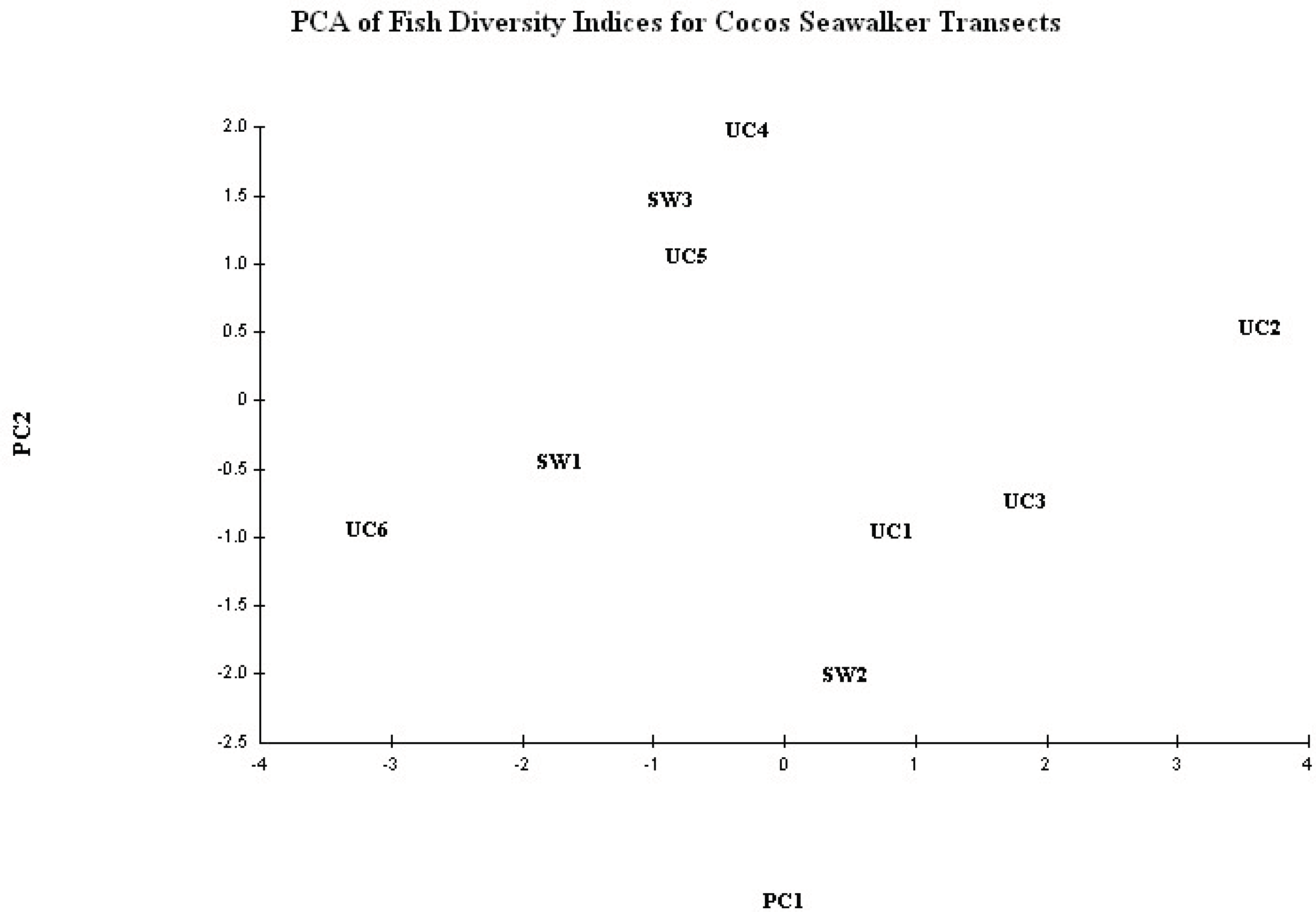

Figure 26. Principal components analysis (PCA) of fish diversity (all measures; see Table 19) in relation to Treatment (SW) or Control (UC) transects at the Seawalker site. Axis PC1 (percent cover of benthic subtrata) accounts for 66.6% and axis PC2 (diversity) accounts for 29.1% of the variation.

CONCLUSIONS AND RECOMMENDATIONS

This study provides a review of the physical, chemical and biological data from the Piti (Fish Eye Observatory and Seawalkers) and Cocos Lagoon (Scuba Bob and Seawalkers) sites on Guam. The data collected and analyzed during this recent study allow for the following conclusions.

Piti Site

1. No discernable pattern in physical and chemical data within and between zones was observed at this site.
2. Differences in percent cover of benthic substrata between treatment and control transects were not significant in the Seagrass and Sand Zone and the Limestone and Sand Zone, but were significant in the Sink Hole Zone. The significant differences may be attributable to the physical presence of the Fish Eye Observatory and Seawalker facility in the treatment sink hole, and also to the greater development of coral there compared with the control sink holes.
3. Differences in fish assemblage structure were not significant in the Seagrass and Sand Zone and the Limestone and Sand Zone, but were significant in the Sink Hole Zone. The significant differences may be attributable to the presence of the Fish Eye Observatory and Seawalker facility (structure attracts fishes), to the presence of one or more fish feeding stations in the treatment sink hole, or a combination of both. Further directed study is needed to resolve this question.
4. The relationship between fish diversity and percent cover of substrata was not significant in the Seagrass and Sand Zone, perhaps because fishes were often disturbed by divers and snorkelers transiting the seagrass bed either to or from the treatment sink hole. The relationship was significant in the Limestone and Sand Zone for diversity and hard coral cover, diversity and sand cover, and also for diversity and all substrata combined. The relationship was also significant for diversity versus hard coral, cyanobacteria, and sand, respectively, in the Sink Hole Zone.

The following recommendations are suggested for the Piti Site.

1. Scuba divers and snorkelers walking across the Seagrass and Sand Zone to and from the Sink Hole Zone (mainly, the Fish Eye Observatory sink hole) are causing considerable disturbance of the seagrass bed there. This disturbance takes the form of physical impacts upon the seagrasses, an apparent temporary increase in turbidity and suspended solids, and a decrease in fish abundance and

diversity (behavioral avoidance). A directed study should be made to test the effects of these impacts. Comparisons should be made between this site and a control site (no diver/snorkeler transits). Comparisons within the impacted site should also be made directly after a disturbance and at a time interval well after the disturbance (but during the same approximate tidal state, depth, and time of day) in order to see if the site recovers to some extent after the disturbance.

2. A directed comparative study should be made of the impact of fish feeding stations upon the diversity and abundance of reef fishes at a given site. Timed point-count sampling, with replication, at treatment and control sites, would allow for this comparison. On a second level, the same sampling should be done with the presence of the Fish Eye Observatory as a factor (the control site would be another sink hole without any man-made structure) in order to determine if fish feeding, and not the presence of the Observatory, has an impact upon fish diversity and abundance.

Cocos Lagoon Sites

1. There was also no discernable pattern in physical and chemical data collected at the Scuba Bob and Seawalker sites.

2. There was a significant difference in percent cover of benthic substrata between treatment and control transects at the Scuba Bob site but not at the Seawalker site.

3. There was a significant difference in fish assemblage structure between treatment and control transects at the Scuba Bob site. This difference is likely the result of the presence of one or more fish feeding stations at the location of the treatment transects. Differences in fish assemblage structure between treatment and control transects at the Seawalker site were not, however, significant.

Biodiversity of Benthic Flora and Invertebrate Fauna at Piti and Cocos Lagoon Sites

Biodiversity of benthic plants and invertebrates at Piti and Cocos Lagoon sites were generally low. The Sink Hole Zone at Piti tended to be most diverse while both Scuba Bob and Seawalker sites at Cocos Lagoon had comparable levels of diversity.

General Recommendations

This present study provides also a sampling plan to collect and analyze quantitative data necessary to test hypotheses about potential impacts caused by the development and operation of these recreational facilities at their respective sites. Emphasis has been placed upon multivariate analyses at the community level rather than simple analyses comparing abundance, density or percent cover. This is because the potential or actual impacts would likely be acting at the community level over time, and this should be the focus of further monitoring efforts using the same sampling and analytical methods. However, it would be a simple matter to extract specific data on abundance, density, or percent cover to make comparisons to detect changes over time. For example, one could compare changes in the abundance of a damselfish, *Abudefduf sexfasciatus* (Pomacentridae), at the Scuba Bob site by extracting the number of individuals of this species counted on transect SB3 at time A (this study; see Appendix D) and comparing it with the number counted on the same transect in subsequent monitoring events (annually, semi-annually, biannually, etc.). Similarly, the changes in the density of this species on transect SB3 could be detected by taking the abundance at time A, dividing this number by the area of the transect (50 m long x 5 m wide or 250 m^{-2}) to arrive at a density figure (the number per square meter) and then comparing this value with similar data from subsequent monitoring using appropriate univariate tests with log x + 1 transformation.

The results of this study include a CD-ROM disc that provides all tables, figures, spreadsheets and outputs used or produced. These are given in MS-Excel, PRIMER, and SYSTAT formats. Further analyses, especially multivariate analyses, should utilize these products in a time series approach that allows for comparison of this study and, incrementally, subsequent monitoring efforts. Subsequent data collection should follow the methods used here exactly. Subsequent analyses should also follow these methods and utilize the analytical packages used here. The results of these analyses should be compared against the results given here. For example, the MDS analysis of fishes in the Sink Hole Zone at Piti given here should be compared against a subsequent MDS analysis of the same transects. Differences in the position of the treatment and control data points would indicate changes at the site. While these changes might not be caused directly by the impact of the structure they may be attributed to an increase, decrease, or no change in the use of some activity associated with the structure (i.e., fish feeding stations). A long term monitoring program would provide a historical pattern reflecting these changes as a result of direct or indirect impacts. Subsequent analyses may also take advantage of time series data to test new hypotheses about potential impacts.

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REFERENCES CITED

Amesbury, S.S., and A.M. Kerr. 1996. Section 3. Data collection methods for beche-de-mer resource management in Micronesia. pp. 43-50. *In* R.H. Richmond (ed.), Suggestions for the Management of Sea Cucumber Resources in Micronesia. Univ. of Guam Mar. Lab., Tech. Rept. No. 101, 70 pp.

APHA. 1992. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Water Works Association and Water Environment Federation, 18th ed. American Public Health Association, Washington DC.

Clarke, K.R., and R.N. Gorley. 2001. PRIMER v5: User manual/tutorial. PRIMER-E, Ltd., Plymouth Marine Laboratory, Plymouth, United Kingdom, 91 pp.

Clarke, K.R., and R.M. Warwick. 1994. Change in marine communities: an approach to statistical analysis and interpretation. PRIMER-E, Ltd., Plymouth Marine Laboratory, Plymouth, United Kingdom, 144 pp.

Davis, G.W. 1982. Algae and seagrass survey of Cocos Lagoon. p. 3-11. *In* R.H. Randall and T.S.Sherwood (Eds.), Resurvey of Cocos Lagoon, Guam, Territory of Guam. Univ. Guam. Marine
Lab., Tech. Rept. No. 80, 103 pp.

Denton, G.R.W., H.R. Wood, L.P. Concepcion, H.G. Siegrist Jr., V.S. Eflin, D.K. Narcis and G.T. Pangelinan. 1997. Analysis of in-place contamination's in marine sediments from four harbor locations on Guam. Univ. Guam Water & Environmental Research Institute, Tech. Rept. No. 81, 120 pp. + Appendices.

Emery, K.O. 1962. Marine geology of Guam. U.S. Geol. Surv., Prof. Pap. 403-B: 1-76.

Gates, P.D. 1986. Browsing patterns of herbivorous fishes in a *Halodule uninervis* seagrass bed of a Pacific island coral reef (Guam, Micronesia). Univ. Guam M.S. Thesis in Biology, 40 pp.

Gawel, M.J. 1977. The common shallow-water soft corals (Alcyonacea) of Guam. Univ. Guam M.S. Thesis in Biology, 201 pp.

Jones, R.S., and J.A. Chase. 1975. Community structure and distribution of fishes in an enclosed high island lagoon in Guam. Micronesica 11: 127-148.

Kingsford, M.J. 1999. Fish attraction devices (FADs) and experimental designs. Scientia Marina 63 (3-4): 181-190.

Kuffner, I.B., and V.J. Paul. 2001. Effects of nitrate, phosphate and iron on the growth of macroalgae and benthic cyanobacteria from Cocos Lagoon, Guam. Marine Ecology Progress Series 222: 63-72.

Matson, E.A. 1989. Biogeochemistry of Mariana Island coastal sediments: Terrestrial influence on ðC, ash, $CaC0_3$, Al, Fe, Si and P. Coral Reefs 7:153-160.

Myers, R.F. 1999. Micronesian Reef Fishes, Third Ed. Coral Graphics, Barrigada, Guam.

Pacific Basin Environmental Consultants, Inc. (PBEC). 1991. Environmental Impact Assessment for the Guam Underwater Observatory, Piti, Guam. Prepared for Pacific Underwater Observatories, Inc. 99 pp. + Appendices A-F.

Randall, R.H., and R.F. Myers. 1983. Guide to the Coastal Resources of Guam: Volume 2. The Corals. Univ. of Guam Press, 128 pp.

Randall, R.H., and T.S. Sherwood (Eds.). 1982. Resurvey of Cocos Lagoon, Guam, Territory of Guam. Univ. Guam Marine Lab., Tech. Rept. No. 80, 103 pp.

Randall, R.H., R.T. Tsuda, R.S. Jones, M.J. Gawel, J.A. Chase and R. Rechebei. 1975. Marine biological survey of the Cocos barrier reef and enclosed lagoon. Univ. Guam Marine Lab., Tech. Rept. No. 17, 160 pp.

Rowe, F.W.E., and J.E. Doty. 1977. The shallow-water holothurians of Guam. Micronesica 13(2): 217-250.

SPSS. 1997. SYSTAT. 7.0 SPSS, Chicago, Illinois.

SPSS. 2000. SIGMAPLOT 2000. SPSS, Inc., Chicago, Illinois.

Taylor, J.D. 1986. Diets of sand-living predatory gastropods at Piti Bay, Guam. Asian Marine Biology 3: 47-58.

Tsuda, R.T. 1972. Morphological, zonational and seasonal studies of two species of *Sargassum* on the reefs of Guam. Proc. Seventh Intern. Seaweed Symp., Sapporo, University of Tokyo Press, pp. 40-44.

Tsuda, R.T., and H.T. Kami. 1973. Algal succession on artificial reefs in a marine lagoon environment in Guam. J. Phycology 9:260-264.

P L A T E S

APPENDICES

DATA BASE

Plate 1. Ramp leading to the Fish Eye Underwater Observatory at Piti with Seawalker's pontoon raft to the left (west) of ramp, February 2004.

Plate 2. Western study area on Piti reef flat; impacted area is adjacent to ramp and control sites are left (west) of westernmost beach shelter, February 2004.

Plate 3. Scuba BOB's pontoon raft at Cocos Lagoon. Two "breathing observation bubbles" (yellow) in water with surface buoys, March 2004.

Plate 4. Seawalker's pontoon raft at Cocos Lagoon. "Bubble helmets" in foreground attached to air lines, March 2004.

Plate 5. Terry Donaldson conducting fish counts in Cocos Lagoon. Photo by Michael J. Gawel, January 2004.

Plate 6. Roy Tsuda obtaining percent cover of benthic organisms in Cocos Lagoon. Photo by Michael J. Gawel, January 2004.