ENVIRONMENTAL IMPACT OF THE COOLING WATER INTAKE STRUCTURE, TANGUISSON POWER PLANT SECTION 316B STUDY, PHASE I A SCREENING ANALYSIS

by

Barry D. Smith, Susanne de C. Wilkins, and Terry J. Donaldson

UNIVERSITY OF GUAM
Marine Laboratory
Technical Report No. 111

May 2005

ENVIRONMENTAL IMPACT OF THE COOLING WATER INTAKE STRUCTURE, TANGUISSON POWER PLANT SECTION 316B STUDY, PHASE I A SCREENING ANALYSIS

by

Barry D. Smith, Susanne de C. Wilkins, and Terry J. Donaldson

Final Report

Submitted to

Julianne T. Duwel, P.E.
Environmental Engineering
and
Pruvient Energy, Inc., Guam

UNIVERSITY OF GUAM
Marine Laboratory
Technical Report No. 111

May 2005

Cover Photo: View of Tanguisson Power Plant from the Philippine Sea. The cooling water intake channel passes between the breaking waves.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

We are grateful for the cooperation and assistance provided by the staff and management of both Hawaiian Electric, Inc. and Pruvient Energy, Inc. during the performance of this study. Frank A. Cushing, Jr. designed and fabricated frames for the plankton nets and drogues for current studies; he also assisted us in performing the current studies and the 24-hr plankton sampling. Richard Chang sorted and identified plankters collected during the study. John Jocson of the Water and Environmental Research Institute, University of Guam provided a satellite image upon which maps of the Tanguisson area are based.

INTRODUCTION

Renewal of the National Pollution Discharge Elimination System (NPDES) permit for Tanguisson Power Plant requires that a Section 316(b) Demonstration Study be conducted to determine if the Cooling Water Intake Structure (CWIS) is in compliance with the conditions set forth in the "Best Technology Available" of Section 316(b) of the Clean Water Act (CWA). The purpose of the demonstration study was to assess the likelihood of adverse impacts on the environmental resources within the potential zone of influence caused by the operation of the Cooling Water Intake Structure.

The Section 316(b) demonstration study consists of two parts. Phase I is a screening analysis that includes an assessment of marine communities potentially affected by the operation of the cooling water intake structure, as well as a summary and evaluation of existing information. Phase II is a comprehensive biological study that is based on the results of the Phase I Study and that is conducted if deemed necessary by U.S. EPA.

The University of Guam Marine Laboratory was originally contracted by Hawaiian Electric, Inc. to conduct Phase I of the 316(b) Demonstration Study for the Tanguisson Power Plant. This contract was issued in response to a technical review (Science Applications International Corporation, 1999) of the Guam Power Authority's (GPA) Section 316(b) analysis for the Tanguisson Power Plant submitted to the Environmental Protection Agency. The purpose of the technical review was to assess an earlier Section 316(b) analysis (Beck, 1995) prepared for GPA, as required under the NPDES permit and the Clean Water Act (CWA). The conclusion of the Science Applications International Corporation (SAIC) review was that GPA failed to demonstrate adequately that the cooling water intake structure incorporates the Best Technology Available for minimizing adverse environmental impacts caused by entrainment and impingement. This conclusion was based on several deficiencies identified by SAIC in the analysis by Beck (1995). Among the deficiencies, GPA failed to complete any impingement and entrainment monitoring, and did not evaluate the existence of potential impacts from impingement and entrainment; failed to conduct biological field sampling program to identify the abundance and diversity of marine organisms in the study area; did not provide information on the potential zone of influence and failed to collect data to assess adverse environmental impacts, either through biological monitoring or by gathering more recent existing data; and failed to address possible adverse impacts on threatened, endangered, and commercially valuable species by the operation of the intake structure.

SITE DESCRIPTION AND LITERATURE REVIEW

The Tanguisson Power Plant is located between Dos Amantes Point and Tanguisson Point on the northwest coast of Guam. The power plant is situated on an elevated terrace covered with bioclastic material that was formerly a coconut plantation. The fringing reef platform along this section is relatively narrow, ranging between 70 to 110 m in width (Jones and Randall, 1973a; Randall and Holloman, 1974). The plant's cooling water intake structure is located adjacent to the shore line northwest of the facility and draws water from the Philippine Sea. It has been designed to accommodate the required cooling water volume with a low intake velocity of 0.93 ft/sec in the channel and 1.55 ft/sec in the intake pipes. The cooling water is drawn through an intake channel cut through the reef margin and reef flat. The intake channel is 14 m wide and 2 m below the mean tide level. A retaining wall on either side of the channel flanks a portion of the intake, thus separating it from sections of the reef flat.

The fringing reef of this area has a westerly exposure to the sea and can be divided into a series of reef zones (Jones and Randall, 1973a). The first zone, the intertidal, is located in the immediate vicinity of the plant and consists of remnants of an elevated fossil reef that is exposed most of the time. Seaward of the intertidal zone is the reef flat, a limestone platform that is mostly flat and pavement-like, except for a few holes and channels. The reef flat area is reported to be biologically depauperate, because much of its surface is exposed during low tides. The last visible zone of the reef flat is the reef margin, the part of the reef where waves break. The reef margin is dissected by a multitude of surge channels, and is usually characterized by a biologically rich and diverse fauna. The relief of the seaward slope is irregular with occasional coral mounds or pinnacles and shallow channels. Sediments found in holes, cracks, and shallow channels range from sand and rubble to rounded boulders.

Much of the scientific knowledge of the Tanguisson reef flat was collected to satisfy federal permit requirements for the site selection, construction, and subsequent operation of the Tanguisson Power Plant and to compile current, temperature, and chemical profile data of the surrounding body of water (Jones and Randall, 1973a). Additional studies have examined the effects of thermal effluent on marine biota and the effectiveness of mitigation measures (Neudecker, 1976, 1977a, 1977b; Kohn and White,1977; Birkeland et al., 1979).

Several biological surveys in the Tanguisson area were conducted to document the effects and the extent of damage caused by the population irruptions of the coral-eating seastar *Acanthaster planci* (Randall, 1971, 1973b; Jones and Randall, 1973a). Recovery of coral communities following decimation by *Acanthaster planci* at Tanguisson has been studied repeatedly (Randall, 1973a; Colgan, 1981, 1982, 1987; Randall et al., 1992; Bonito, 2002).

In a preliminary marine survey for the northern sewage system, Jones and Randall (1973b) reported data from sections of fringing reef between the Naval Communications (NCS) Beach and Hilaan Point, north of Tanguisson. The purpose of this study was to identify locations most suitable for an offshore submarine sewage outfall. The results of their current studies showed a pronounced offshore movement to the north or northeast during ebb tides and southerly drifts during floods. Inshore water movement on the Tanguisson reef flat is primarily generated by tidal changes and wave action (Jones and Randall, 1973a). The water often forms longshore currents on reef flats and eventually returns to the sea as rip currents via naturally low spots or surge channels in the reef margin. The Cooling Water Intake Channel provides a natural escape for the water during falling tide conditions.

Randall et al. (1992) reassessed the coral community in the area affected by the thermal power plant effluent. These authors also examined the extent of bioerosion within the reef framework caused by long-term exposure to elevated temperature.

The Tanguisson Power Plant Oil Recovery System Report of Activities from July 1st to September 30th states that one of the primary environmental concerns at the Tanguisson Power Plant is the ongoing release of oil into the Philippine Sea via underground seeps (Duwel, 2002). The release, discovered in 1986, originated from damage to a buried pipeline for No. 6 fuel oil.

Subsequently, an Oil Recovery System was constructed, and shoreline cleanup activities were established and are continuing. Sorbent booms continue to be placed in front of the Cooling Water Intake Structure.

A list of the ten top marine species harvested between 1990 and 2000 in the area between Dos Amantes Point and Faifai Beach was produced by the Division of Aquatic and Wildlife Resources (DAWR), Guam Department of Agriculture in 2003 (DAWR, 2003). The list was based upon creel surveys, and the ten most harvested species were reported by weight and by number. Four of the top six species were surgeonfishes (Acanthuridae); and two of the top ten were invertebrates species.

The channel area in front of the Cooling Water Intake Structure and the Intake was dredged twice during the course of this study. However, information regarding the amount of material dredged from this area was not made available. A noticeable increase in the velocity of the intake flow was observed by the authors after dredging had occurred.

METHODS

Determination of the potential zone of influence.

The potential zone of influence was determined by mapping water circulation patterns of the reef platform adjacent to the Cooling Water Intake Channel and of the area beyond the reef margin on either side of mouth of the channel. Water circulation patterns were investigated during ebb and flow stages of both spring tides and neap tides by releasing subsurface drift drogues fitted with vanes suspended 1 m below the surface at predetermined locations. The drogues were allowed to float with the current for a recorded time interval, and starting and ending points were determined by triangulation of fixed points along the shoreline. The distance traveled was determined by plotting vectors on a scaled satellite image of the Tanguisson area. In areas that were too shallow for drogues, fluorescein dye was injected into the water at predetermined stations; the distance the dye patch traveled, the elapsed time, and the direction of movement were recorded. Current velocity and direction were derived from these data. Wind velocity and bearing were recorded at the time of release and recovery of the drogues.

Preliminary biological assessment within the zone of influence.

A. Estimation of biomass accumulation and composition.

Four sets of four settling plates were mounted on stretch metal and affixed directly to the metal intake structure, approximately 1 m from the bottom. Each month, one plexiglass settling plate was removed from each set. The monthly collection of settling plates was performed systematically from left to right. The plates were taken to the laboratory, preserved in 5% formalin, and examined under a stereo microscope to determine the composition of the fouling community.

A grid with 60 points of intersection was placed over the surface of the settling plate, and whatever was observed under each of the intersections was identified. The plates were then rinsed with freshwater and dried. The fouling community was scraped from the surface and placed into pre-weighed weighing dishes. The contents of the weighing dishes were dried to constant weight in an oven at 50° C and weighed to the nearest 0.01 g to calculate the dry weight of the accumulated fouling biota.

B. Estimation of plankton entrainment and potential impingement.

Estimation of plankton entrainment was based on a 24-hr study of plankton sampled in two drift nets that were mounted in the center of the channel, approximately 12 m from the cooling water intake structure. The nets were mounted in stationary frames. One was deployed just above the floor of the channel, and the other just below the water surface.

Plankters trapped in the cod-end of the net were collected every 3 hr during the 24-hr study period. The contents of the collection container were emptied into a specimen jar and fixed with 5% formalin. Readings from current meters mounted in the center of the opening of each of the nets were recorded at each 3-hr interval to allow calculation of the volume of water that passed through the net.

The preserved specimens were taken to the laboratory, and the entrained organisms examined under a stereomicroscope. Species of plankton, including fish and macroinvertebrate larvae, were identified to the lowest taxon possible. The volume of water that passed through the net during the study was calculated from the current meter data.

Samples obtained from plankton nets were fractionated to facilitate the counting of the organisms. A plankton splitter was used to divide the first surface sample from Tanguisson into 8 aliquots. The remaining samples from Tanguisson were divided into 16 aliquots. One aliquot from each sample was transferred to a modified Bogorov counting tray. The organisms were identified and counted under a dissecting microscope. The counts were then multiplied by the respective number of aliquots to obtain an estimate of the numbers of organisms present in each sample.

C. <u>Coral reef communities within the zone of influence of the Cooling Water Intake Structure</u>.

Identification of Zonation

A transect line was established parallel to the channel, extending from shore to the reef margin. Zonation along this transect was determined by sampling the surface cover of the substrate with a point-quadrat. Zonation was based on the predominant features observed, including both biotic or abiotic components of the substrate. Fifty-meter belt transects were then established running perpendicular to the original transect line in each of the identified zones.

In the channel, 50-m belt transects were established along either side of the channel wall, approximately 1 m from the bottom of the channel. A third belt transect was established in the center of the channel.

Benthic Marine Fauna and Substrate Cover

Marine plant communities and substrate types in each zone were quantified by a modified point-quadrat method (Tsuda, 1972). This method consists of tallying organisms under the points of intersection of strings stretched across a 1/16 m^2 (25 cm x 25 cm) quadrat. Four strings stretched from each side of the quadrat provide 16 points (intersections). The quadrat was tossed twice randomly at 5-m intervals along the length of the transect. Organisms under the points of intersection were tallied. The quadrat was tossed a total of 20 times, providing 320 data points on a 50-m transect. Percent cover was calculated from these points. Species within the study area, but not encountered along the transect line, were also recorded.

Macroinvertebrates

All conspicuous epibenthic macroinvertebrates occurring within 1 m of either side of the transect lines were identified and enumerated by an observer swimming along the transect line. For this study, conspicuous is defined as being larger than 15 mm in size and as being clearly visible to an observer without need of overturning rocks or digging in the substrate. Cryptic, microscopic, and nocturnal species were not included within the scope of this study.

Species diversity and abundance were recorded in 10-m intervals along the transect line. Therefore, for statistical purposes, each belt transect consisted of five 20-m^2 plots. Species observed in the study area, but not encountered along the transect line, were also recorded.

Fishes

Coral reef fishes were assessed by conducting a visual fish census along transect lines (English et al., 1997). Fishes were surveyed at transect sites by counting the number of individuals of each species observed within 2.5 m either side of a 50-m transect line laid at the site. Observations were made by a single snorkeler swimming at a constant speed. Fishes were identified to species and taxonomic designations following Myers (1999). Data were recorded on underwater paper with pencil.

Data were grouped into spreadsheets (Quattro Pro and PRIMER) to provide a checklist of species and for analyses. Measures of species richness (S), species diversity (Shannon's diversity index, H', taken to log e), an index of sampling evenness or completeness (Pielou's J'), and the number of individuals of all species on each transect were calculated with PRIMER (Clarke and Gourley, 2001; routine DIVERSE). The relationships between S and N, and H' and N for controls and treatments were plotted with SYSTAT 7.0 (SPSS, 1997). A Bray-Curtis similarity index matrix was calculated for pair-wise comparisons of data (square root transformed) (PRIMER, Clarke and Gorley, 2001; routine: SIMILARITY). This matrix was then analyzed with a cluster analysis (PRIMER, Clarke and Gorley, 2001: routine: CLUSTER) to depict relationships between transect sites. Then, the same matrix was analyzed by multi-dimensional scaling (MDS) to indicate rank similarity between transects. Tightly-packed transect points on the MDS plot indicate closer similarity to one another. The stress value given indicates the degree of reliability in the representation of ranked similarities.

Assessment of threatened and endangered species

An assessment of threatened and endangered species, as well as species of recreational and commercial value, was made based upon data collected by previous investigators and upon observations made during this study.

RESULTS AND DISCUSSION

Currents and the Zone of Influence

Current velocity, current bearing, and tide stage are presented in Tables 1–3 and Figures 1–2. Dye patches released up to 60 m to the east and about 15 m to the west of the Cooling Water Intake Channel show a distinct movement toward the channel. Reef front currents show a predominant westerly to southwesterly movement during neap and spring tide conditions (Figures 1–2). Current velocities between 0.02 m sec^{-1} and 0.5 m sec^{-1} were recorded on the reef flat on either side of the channel (Table 1), while the currents along the reef front ranged between 0.03 m sec^{-1} to 0.13 m sec^{-1} (Table 2). Wind velocity and bearing were variable and did not appear to affect tidal currents under the atmospheric conditions prevailing during this study.

On the reef front, only drift drogues released near the mouth of the channel were directly affected by the operation of the Cooling Water Intake Structure. Four drogues released within 60 m of the entrance to the channel moved onto the reef margin, and another was pulled through the middle of the channel to the intake structure. The results of this study indicate that the zone of influence of the Cooling Water Intake Structure extends 13 m onto the bench on the west side of the channel, 60 meters onto the outer reef flat platform on the east side of the channel, and about 60 m seaward of the mouth of the channel (Figure 3).

Table 1. Water current data for spring tides on the Tanguisson reef flat east and west of the Cooling Water Intake Channel. Individual tracks are plotted in Figures 2 and 3. Tidal stages are indicated as (+) for flooding and (–) for ebbing tides.

East Reef Flat — August 22, 2002

High Tide at 0626 = 0.70 m
Low Tide at 1338 = –0.06 m
High Tide at 2045 = 0.73 m

Station No.	Time (min)	Distance Traveled (m)	Current Velocity (m sec^{-1})	Current Bearing (deg)	Wind Bearing/Velocity (deg)/(knots)	Tidal Stage
1a	0'43"	24	0.5	116	310/2	–
1b	2'07"	41	0.3	239		–
1c	28"	14	0.5	160		–
	3'01"	34	0.2	224		–
2a	3'30"	19	0.1	188		–
	2'50"	40	0.2	232		–
2b	4'20"	26	0.1	141		–
3a	3'25"	20	0.1	156		–
3b	3'30"	21	0.1	105		–
	2'	12	0.1	95		–
4a	4'56"	27	0.1	80		–
4b	4'15"	22	0.1	75		–
5a	4'11"	7	0.03	148		–
	2'35"	14	0.1	177		–
6a	3'02"	18	0.1	82		–
1a	2'34"	14	0.1	123	65/2	+
	2'38"	27	0.2	221		+
1b	2'08"	29	0.2	130		+
	2'05"	15	0.1	55		+
1c	1'50"	17	0.2	139		+
	5'16"	23	0.07	220		+
2a	2'	14	0.1	143		+
	3'50"	27	0.1	195		+
	2'13"	34	0.3	256		+
2b	1'30"	25	0.3	175		+
	2'08"	30	0.2	236		+
3a	1'39"	21	0.2	143		+
	3'45"	14	0.1	141		+
3b	2'24"	18	0.1	104		+
	4'40"	18	0.1	95		+
4a	2'03"	10	0.1	137		+
	2'25"	11	0.1	145		+
4b	1'27"	10	0.1	101		+
5a	2'10"	13	0.1	145		+
5b	1'50"	11	0.1	107		+
6a	2'40"	16	0.1	101		+

Table 1. Continued.

West Reef Flat		August 22, 2002		High Tide at	0626 = 0.70 m	
				Low Tide at	1338 = –0.06 m	
				High Tide at	2045 = 0.73 m	
Station No.	Time (min)	Distance Traveled (m)	Current Velocity (m sec^{-1})	Current Bearing (deg)	Wind Bearing/Velocity (deg)/(knots)	Tidal Stage
1a	2'05"	17	0.1	156	15/2	+
1b	2'23"	12	0.08	170		+
2a	0'56"	13	0.2	94		+
2b	0'49"	10	0.2	74		+

West Reef Flat		August 23, 2002		High Tide at	0709 = 0.70 m	
				Low Tide at	1410 = –0.06 m	
				High Tide at	2114 = 0.70 m	
Station No.	Time (min)	Distance Traveled (m)	Current Velocity (m sec^{-1})	Current Bearing (deg)	Wind Bearing/Velocity (deg)/(knots)	Tidal Stage
1a	1'03"	14	0.2	140	323/2	–
1b	1'28"	12	0.1	167		–
2a	0'35"	8	0.2	160		–
2b	0'16"	8	0.5	169		–

Table 2. Water current data for neap tides on the Tanguisson reef flat east and west of the Cooling Water Intake Channel. Individual tracks are plotted in Figures 2 and 3. Tidal stages are indicated as (+) for flooding and (–) for ebbing tides.

East Reef Flat — August 29, 2002

Low Tide at 0626 = 0.21 m
High Tide at 1139 = –0.58 m
Low Tide at 1721 = 0.30 m

Station No.	Time (min)	Distance Traveled (m)	Current Velocity (m sec^{-1})	Current Bearing (deg)	Wind Bearing/Velocity (deg)/(knots)	Tidal Stage
1a	1'07"	19	0.3	218	250/13–15	–
1b	0'58"	23	0.4	147		–
2a	3'40"	22	0.1	160		–
2b	3'08"	22	0.1	156		–
3a	1'30"	17	0.1	250		–
3b	1'12"	22	0.3	119		–
3c	1'50"	25	0.2	160		–
4a	2'12"	1	0.01	235		–
4b	3'14"	14	0.5	187		–
5a	2 46"	14	0.1	276		–
5b	5'02"	9	0.02	88		–
5c	4'43"	10	0.04	88		–
6a	4'09"	8	0.03	108	267/20–25	–

East Reef Flat — September 12, 2002

Low Tide at 0523 = 0.30 m
High Tide at 1206 = 0.67 m

Station No.	Time (min)	Distance Traveled (m)	Current Velocity (m sec^{-1})	Current Bearing (deg)	Wind Bearing/Velocity (deg)/(knots)	Tidal Stage
1a	3'25"	18	0.09	141	30/2	+
1b	3'05"	17	0.09	139		+
2a	5'15"	7	0.02	54		+
2b	4'55"	5	0.02	11		+
3a	3'12"	14	0.07	300		+
3b	3'59"	10	0.04	300		+
4a	3'42"	9	0.04	307		+
4b	3'28"	8	0.04	260		+
5a	3'07"	10	0.05	102		+
5b	4'18"	7	0.03	66		+
6a	2'53"	7	0.04	148		+
6b	1'32"	7	0.08	148		+

Table 3. Water current data for neap and spring tides along the reef front adjacent to the Cooling Water Intake Channel at Tanguisson. Individual drogue tracks are plotted in Figures 1–2. Tidal stages are indicated as (+) for flooding and (–) for ebbing tides.

Neap Tide — October 29, 2002

Low Tide at 0648 = 0.03 m
High Tide at 1455 = 0.67 m
Low Tide at 2024 = 0.52 m

Station No.	Time (min)	Distance Traveled (m)	Current Velocity (m sec^{-1})	Bearing (deg)	Wind Bearing/Velocity (deg)/(knots)	Tidal Stage
Ia	43	120	0.05	242	30/4–6	+
IIa	18	80*		156		+
IIIa	49	80	0.03	230		+
IVa	38	140	0.06	238		+
Ia	42	137	0.05	264	70/7.5	–
IIa	38	131	0.06	240		–
IIIa	42	164	0.06	241		–
IVa	34	160	0.08	243		–

* grounded

Spring Tide — June 13, 2003

High Tide at 0525 = 0.79 m
Low Tide at 1244 = –0.15 m
High Tide at 1957 = 0.73 m

Station No.	Time (min)	Distance Traveled (m)	Current Velocity (m sec^{-1})	Current Bearing (deg)	Wind Bearing/Velocity (deg)/(knots)	Tidal Stage
Ia	34	141	0.07	241	60/3–5	–
IIa	35	145	0.07	244	Gusts 8	–
IIIa	27	173	0.11	255		–
IVa	24	159	0.11	250		
Ib	24	187	0.13	308		–
IIb	32	63*		131		–
IIIb	29	63*		123		–
Ia	35	144	0.07	259	95/2	+
IIa	18	59*		153	Gusts 6	+
IIIa	35	156	0.07	262		+
IVa	36	179	0.08	251		+
Ib	45	104	0.04	267		+
IIb	21	127*		134		+
IIIb	37	113	0.05	271		+
IVb	33	175	0.09	262		+

*grounded

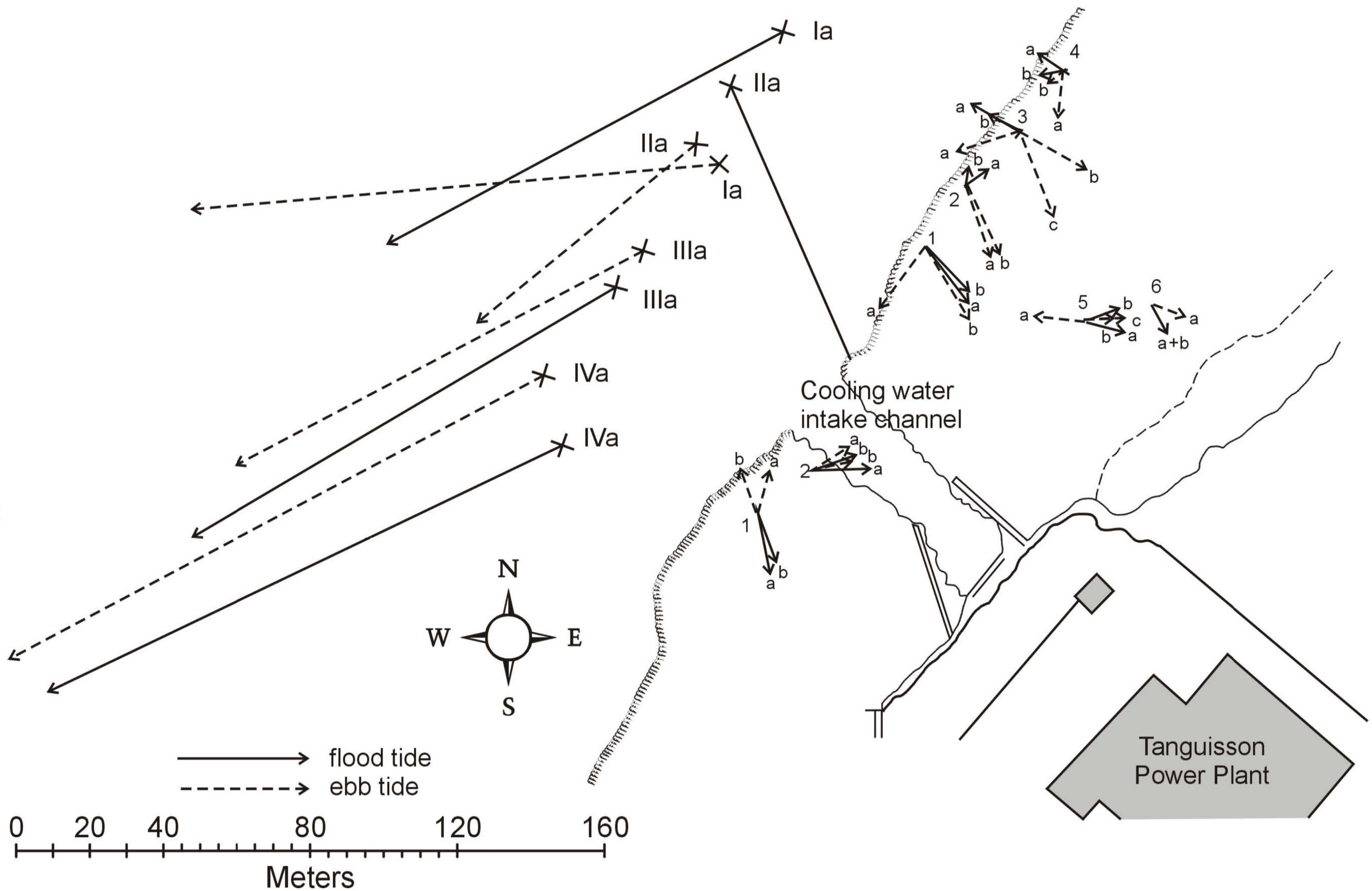

Figure 1. Neap tide currents on the Tanguisson reef flat east west of the Cooling Water Intake Channel and the reef front seaward of the channel during ebb and flood tides.

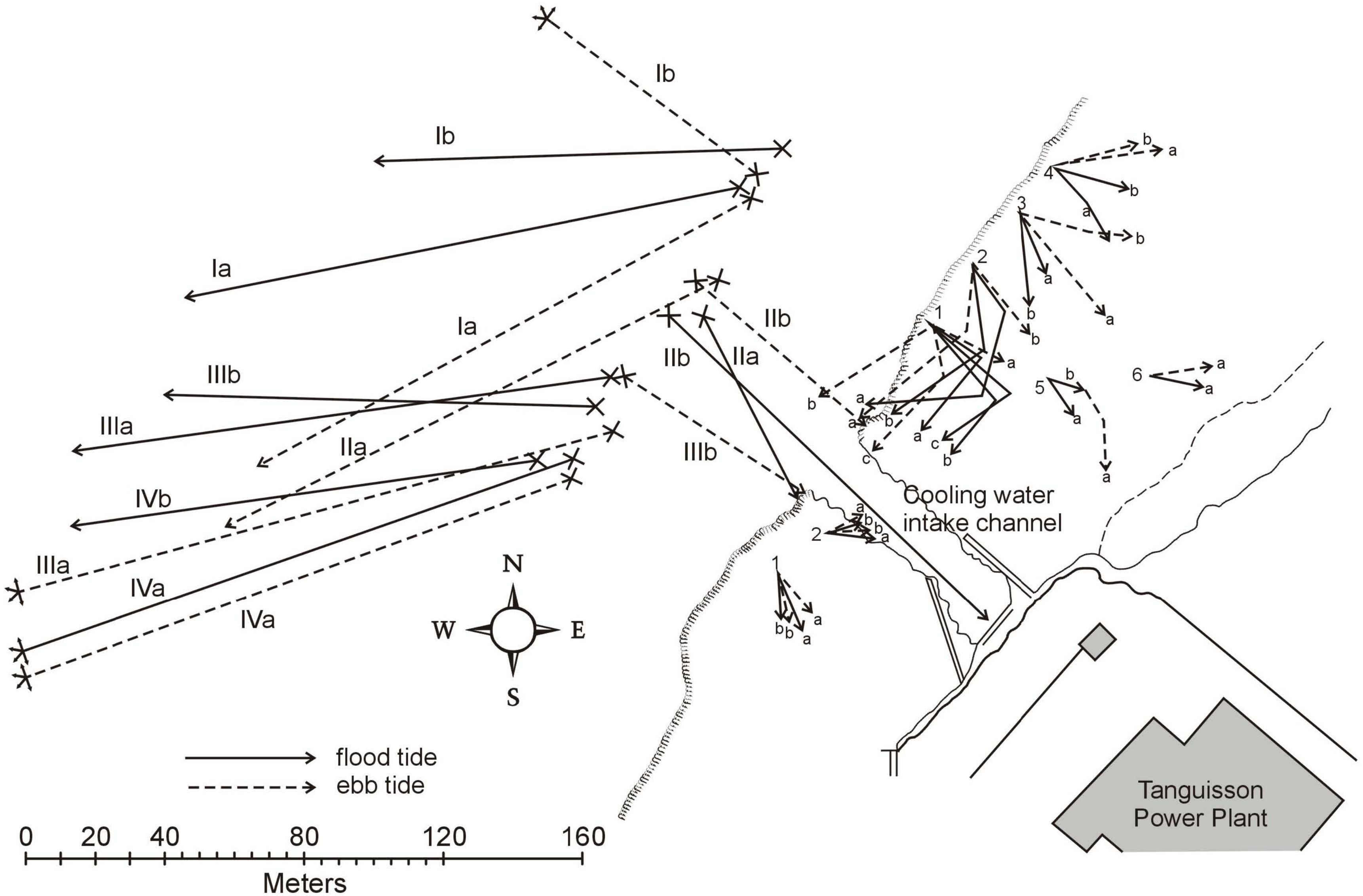

Figure 2. Spring tide currents on the Tanguisson reef flat east and west of the Cooling Water Intake Channel and the reef front seaward of the channel during ebb and flood tides.

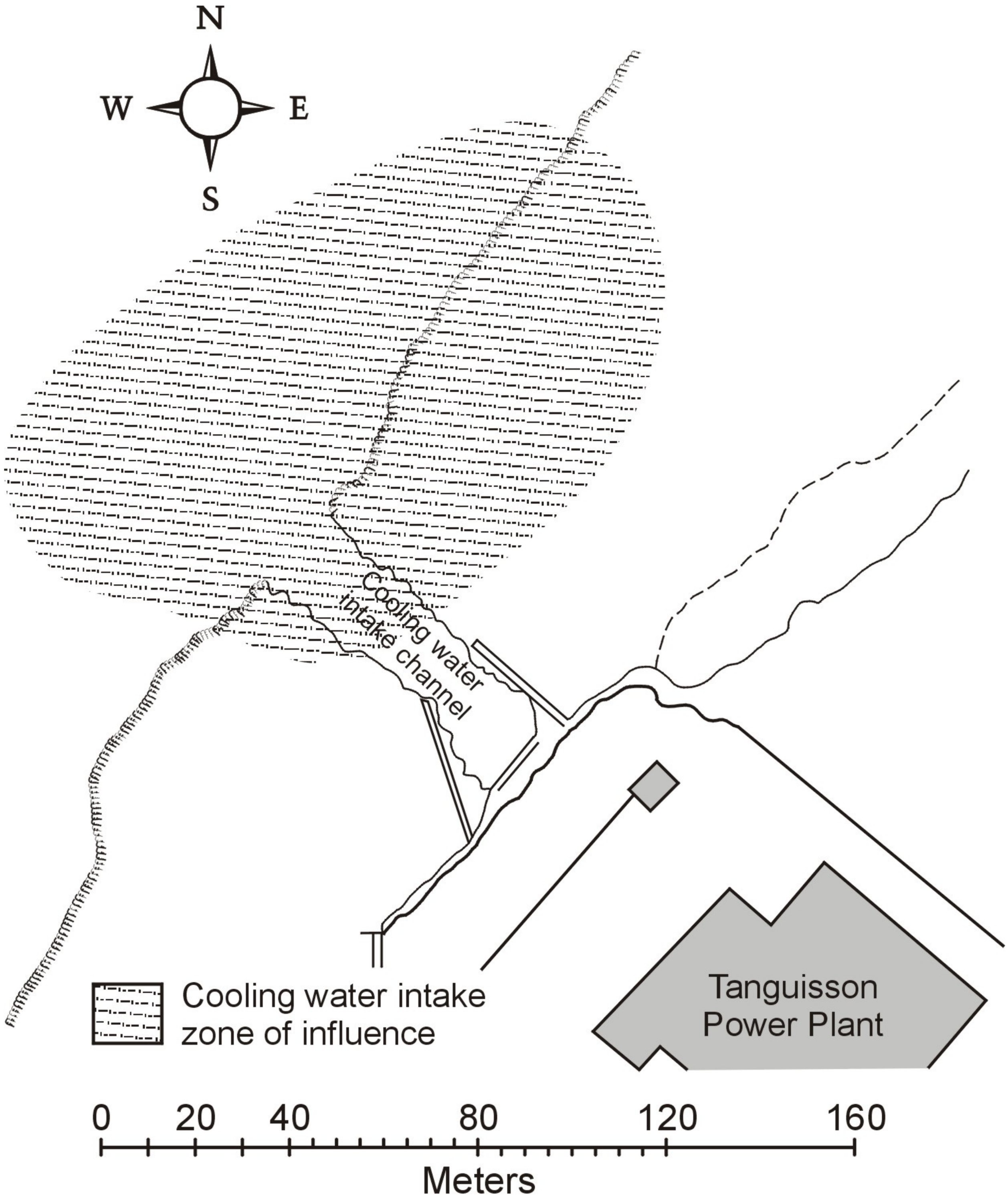

Figure 3. Estimated extent of the zone of influence of the Cooling Water Intake System at the Tanguisson Power Plant.

Zonation of the Reef Flat

Three zones were identified on the reef flat east of the intake channel, based upon of percent surface coverage of the substrate along a transect extending from the shoreline to the reef margin (Table 4). The substrate of the first zone was predominantly covered by sand, the second by *Boodlea composita* and algal turf, and the third by *Halimeda opuntia* and algal turf. Within each of these zones, 50-m transect lines were placed perpendicular to the one established for the identification of the zones, and algae, macroinvertebrates, and fishes were surveyed (Figure 4).

The reef flat west of the channel is characterized by weathered, raised limestone bench that is exposed most of the time, leaving only a narrow band of intertidal reef flat. Two reef flat zones were identified for this study. One was adjacent to the raised limestone bench, and it was characterized by reef pavement with cyanobacteria. The outer zone was nearer the reef margin, and it was inhabited by macroalgae. After determination of the zone of influence, four additional 50-m transects lines were established seaward of the reef flat, one along the reef margin and one along the 6-m contour of the reef slope on either side of the mouth of the Cooling Water Intake Channel (Figure 4).

Biomass Accumulation and Composition

Changes in the composition of the fouling community over a period of four months are reported in Figure 5. Biomass accumulation increased with exposure, and coralline and filamentous algae were the predominant colonizers on the settling plates during the four months of study (Table 5). No coral recruits were recorded. Total dry weight of the fouling communities ranged from 0.47 g in the first month to 7.79 g in the fourth month. These data are comparable to those reported by Rowley (1980) for Luminao Reef.

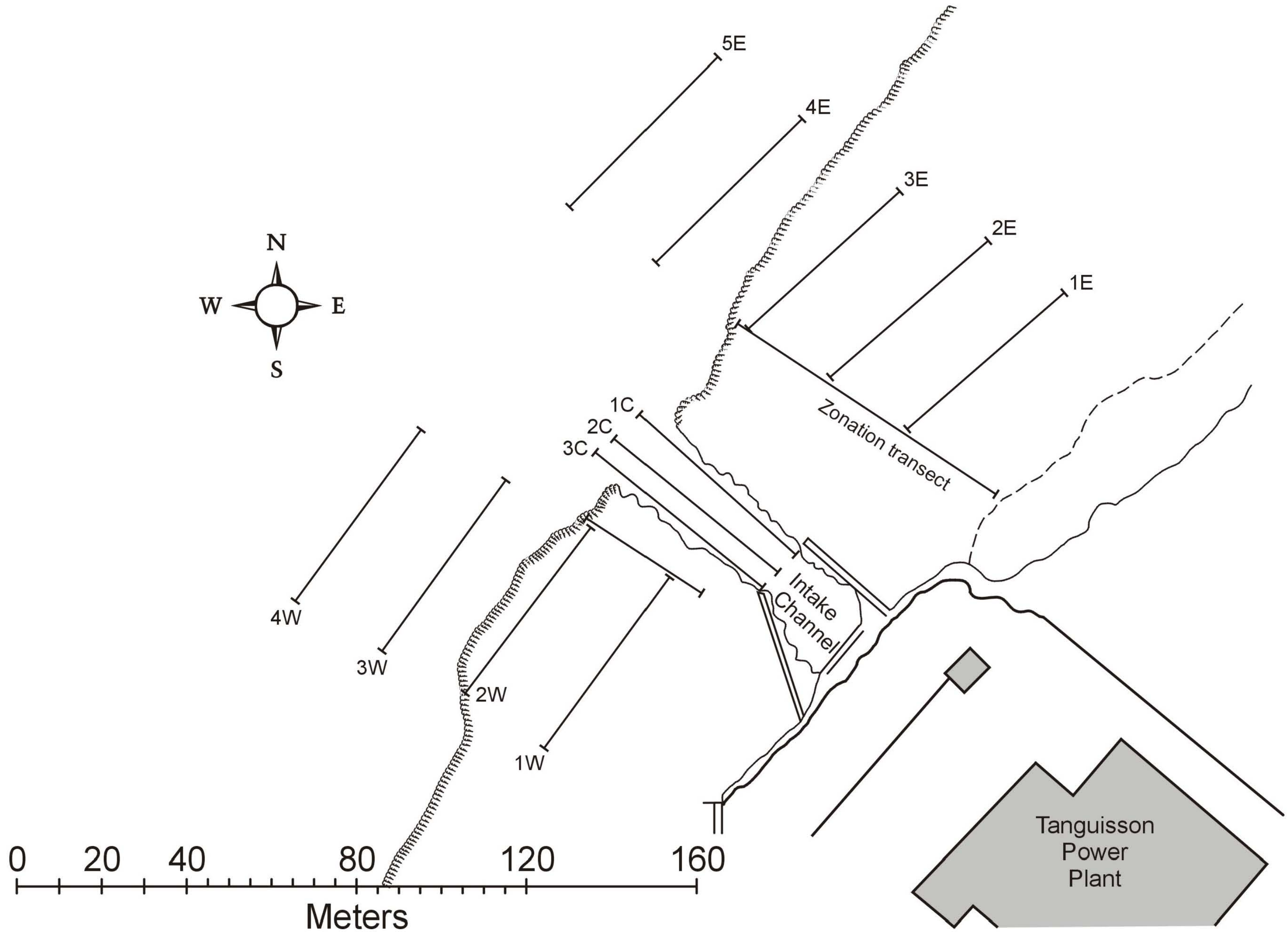

Figure 4. Location of 50-m transects lines established for assessment of biological communities within the Cooling Water Intake System zone of influence.

Table 4. Substrate composition, expressed in number of predominant features recorded within each zone to the East of the Tanguisson Cooling Water Intake Channel. The substrate components characteristic for each zone are typed in bold.

	Zone		
Substrate	**1**	**2**	**3**
Sand	**32**		5
Rubble	1	1	2
Reef Rock	7	2	
Cyanophyta			
Microcoleus lyngbyaceus	1	2	2
Schizothrix calcicola	2	1	2
Schizothrix mexicana			1
Chlorophyta			
Boergensonia forbesii		3	4
Boodlea composita	**31**		1
Bryopsis pennata	1	3	
Caulerpa antoensis		1	
Caulerpa racemosa	3	1	4
Chladophoropsis sudanensis	2		2
Chlorodesmis fastigiata			1
Codium			2
Dictyospaeria versluysii		2	1
Enteromorpha clathrata	4		
Halimeda opuntia	6	8	**22**
Neomeris annulata		2	1
Phaeophyta			
Dictyota bartayresiana	4	2	1
Hinksia indica	2	1	
Lobophora variegata		1	
Padina boryana	6	1	1
Sphacelaria tribuloides	1	1	1
Turbinaria ornata	3	3	1
Rhodophyta			
Amphiroa fragilissima	2	4	3
Centrocera clavulatum	2		2
Centrocerus minutum		1	
Ceramium mazatlenese		1	1
Champia parvula			1
Galaxaura marginata			1
Gelidiella acerosa	3	**16**	7
Geliella tenuissima		3	1
Gelidium pussilum	3	1	1

Table 4. Continued.

Substrate	Zone 1	2	3
Gracilaria salicornia	1	2	3
Gracilaria tsudai		1	
Hydrolithon reinboldii	1	4	
Jania capillacae	3	4	4
Leveillea jungermannoides			1
Mastophora rosea	2		2
Paysionalia rubra		6	
Porolithon		4	3
Rhodomenia divericata		7	9
Tolipiocladia divericata		5	4
Turf	2	**32**	**24**
Live Coral		1	7
Sponge			1
Snail			1

Figure 5. Changes in the composition of the fouling community composition over a period of 4 months. Fouling community composition is expressed in percent surface coverage of settling plates attached to the Cooling Water Intake Structure. (Blank – No growth; Fil. Alg. – Filamentous Algae; Cor. Alg. – Coralline Algae; Macro Alg. - Macro Algae)

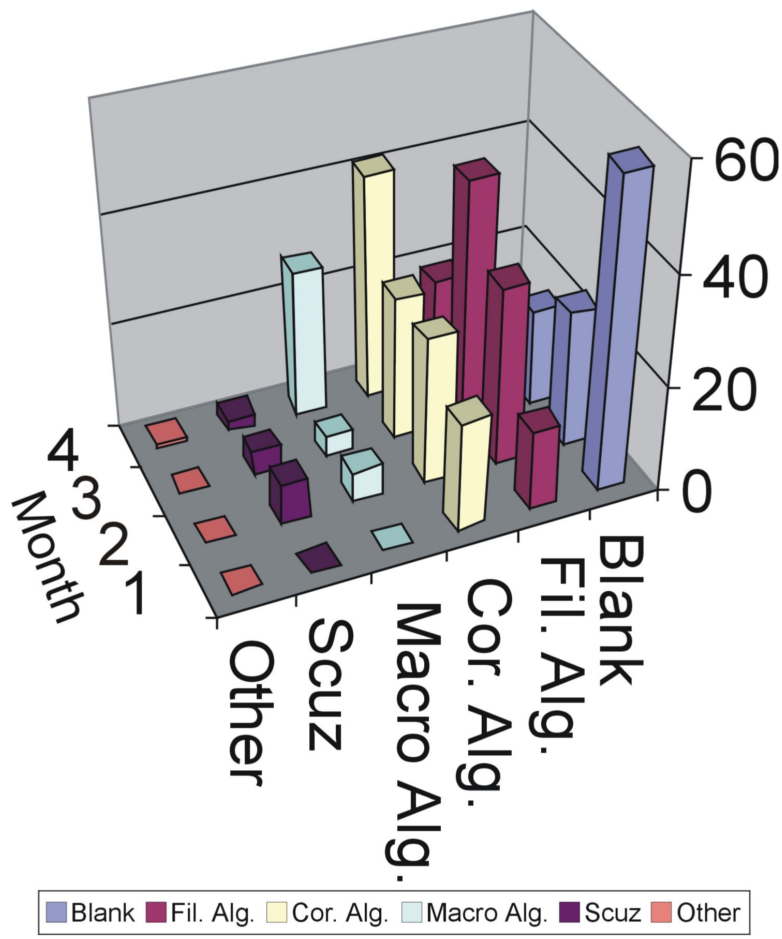

Table 5. Dry weight (g) of fouling community on settling plates mounted on the Tanguisson Cooling Water Intake Structure.

	Month			
Plate	1	2	3	4
1	0.10	0.61	1.18	2.16
2	0.14	0.85	1.20	1.43
3	0.12	1.36	1.31	1.66
4	0.11	0.13	1.37	2.54
Total	0.47	2.95	5.06	7.79
Mean	0.12	0.72	1.28	1.95
SD	0.02	0.43	0.09	0.26

Plankton Entrainment and Potential Impingement

The velocity of the current and volume of the water that passed through the stationary nets positioned near the surface and bottom of the channel are presented in Table 6. The average speed of the current flowing through the nets was 12.57 cm sec^{-1} near the surface and 8.82 cm sec^{-1} near the bottom of the channel. A total of 127,363.16 m^3 of water passed through the net near the surface and 89,393.76 m^3 near the bottom over the 24-hr sampling period.

Large numbers of amphipods, ascidian juveniles, calanoids, isopods, harpacticoids, juvenile fishes, megalopa, mysids, nauplii, ostracods, polychaetes, and zoea were collected during evening, night, and early morning hours from both the surface and bottom nets (Tables 7 and 8). A remarkably large number of eggs was collected (8,184) near the surface during the first sampling period, which started at 12:00 noon to 3:00 p.m. The water of volume passing through the net during this period was 16,661.40 m^3 at a velocity of 13 cm sec^{-1}. The numbers of eggs slowly decreased over the entire 24-hr sampling period. Coral larvae (16–48 larvae/sample) were collected during the first three sampling periods near the surface and during the first sampling period (32 larvae) near the bottom.

Because our sampling was limited to a single 24-hr period, any projections about the magnitude of the entrainment of plankters at Tanguisson would not be statistically valid. Until similar studies are conducted throughout complete lunar and annual cycles and further data obtained, we will not know if this sampling period was typical or atypical for any given day.

Many coral reef organisms base their reproductive periods on lunar cycles, whether monthly or annually. Our samples were taken four days after the full moon and three days before the first quarter in September. Consequently, our sampling period did not include the large annual reproductive event that is characteristic of perhaps 85% of the reef-building corals in Guam, which spawn 7–10 days after the full moon in July (Richmond and Hunter, 1990; Richmond, 1997). Similarly, soft corals in Guam spawn annually following the full moon in March (Richmond, personal communication). Many other coral reef organisms synchronize their spawning with the new moon phase. The large coral reef vetigastropods, such as the commercial topshell *Trochus niloticus* and the silver-mouth turban *Turbo argyrostomus*, spawn monthly within the first three days after the new moon (Heslinga and Hillmann, 1981; Yamaguchi, personal communication).

Despite the limitations with this study, there are several interesting trends in the data that could be evaluated in future entrainment studies at this site (see Tables 7 and 8). The number of eggs collected in the surface net was approximately double the number collected in the bottom net, indicating that organisms with floating eggs are more heavily affected by entrainment than organisms with demersal eggs. Planktonic arthropods were virtually absent in daytime samples, but their numbers increased dramatically into the thousands during darkness, suggesting that demersal plankton may be of considerable importance in this type of environment. For many taxa, greater numbers of planters were collected near the surface than near the bottom. Further sampling is necessary to determine if this disparity is a factor of the volume of water sampled or if these plankters aggregate near the surface. Finally, larval impingement was beyond the scope of this study, so additional studies will be required to estimate mortality caused by the cooling water intake structure.

Table 6. Current and volume measurements for 24-hr plankton study in Tanguisson Cooling Water Intake Channel. Samples were taken near the surface (S) and bottom (B) of the center of the channel. Rotor constant = 57,560; drift net area = 1173 cm². Readings and samples were collected every 3 hr.

Date	Sample	Time	Distance (m)	Speed (cm sec^{-1})	Volume (cm^3)
9/12/02	S1	15:25	1,420.41	13.15	1,666,140
	S2	18:25	1,547.21	14.33	1,814,882
	S3	21:25	1,132.15	10.48	1,328,011
9/13/02	S4	0:25	1,046.56	9.69	1,227,611
	S5	3:25	1,402.05	12.98	1,644,602
	S6	6:25	1,914.10	17.72	2,245,242
	S7	9:25	1,531.16	14.78	1,796,045
	S8	12:25	864.26	8.00	1,013,782
Mean			1,357.24	12.57	1,592,039.4
SD			± 332.23	±3.08	± 389,707.8
Total Volume Sampled					**127,363.16 m³**
9/12/02	B1	15:25	928.73	8.60	1,089,402
	B2	18:25	1,120.18	10.37	1,313,967
	B3	21:25	750.47	6.95	880,299
9/13/02	B4	0:25	888.09	8.22	1,041,734
	B5	3:25	1,058.30	9.80	1,241,385
	B6	6:25	1,270.12	11.76	1,489,851
	B7	9:25	971.73	9.00	1,139,838
	B8	12:25	633.33	5.86	742,900
Mean			952.62	8.82	1,117,422
SD			±202.82	±1.88	± 237,910.64
Total Volume Sampled					**89,393.76 m³**

Table 7. Estimated numbers of entrained organisms collected with a drift net located near the surface of the intake channel. Specimens were collected every 3 hr over a 24-hr period. Estimates are based on counts in a 1/16th aliquot of the sample, except for Sample S1, which is based on a 1/8th aliquot.

Taxon	Sample No.							
	S1	S2	S3	S4	S5	S6	S7	S8
	3 p.m.	6 p.m.	9 p.m.	12 a.m.	3 a.m.	6 a.m.	9 a.m.	12 p.m.
Amphipods	24	0	80	240	80	112	0	0
Ant Crustaceans	8	0	48	0	16	0	0	0
Anthomedusae	0	0	32	0	0	0	0	0
Ascidian Juvenile?	0	0	0	2480	112	16	0	0
Calanoid	24	256	2048	4016	3104	1088	128	48
Canthigaster	0	0	16	0	0	0	0	0
Coral Larvae?	48	16	16	0	0	0	0	0
Crustacean	0	0	0	16	0	16	0	0
Cumacean	0	0	1328	48	64	272	0	0
Cyclopoid	0	0	0	128	48	0	16	0
Cylinder	24	0	0	0	0	0	0	0
Eggs	8184	1152	640	1200	528	192	432	816
Harpacticoid	152	160	400	416	512	288	128	32
Isopod	0	0	128	272	176	48	32	0
Juvenile Cephalopod	0	0	0	16	0	0	0	0
Juvenile *Canthigaster*	0	0	0	0	0	0	0	0
Juvenile Fish	0	0	496	192	0	0	0	16
Medusae?	0	0	0	0	0	0	0	0
Megalopa	0	0	16	592	320	384	16	16
Mysid	0	32	14608	19328	864	448	0	0
Nauplius	0	16	560	384	16	0	0	0
Ostracod	0	0	272	48	16	16	0	0
Polychaete	0	16	208	16	0	0	16	0
Siphonophore	0	16	0	0	0	0	0	0
Taneid	8	64	80	0	0	0	0	0
Zoea	744	80	4464	15312	7168	352	288	32

Table 8. Estimated numbers of entrained organisms collected with a drift net located near the bottom of the intake channel. Specimens were collected every 3 hr over a 24-hr period. Estimates are based on counts in a 1/16th aliquot of the sample.

Taxon	Sample No.							
	B1	B2	B3	B4	B5	B6	B7	B8
	3 p.m.	6 p.m.	9 p.m.	12 a.m.	3 a.m.	6 a.m.	9 a.m.	12 p.m.
Amphipods (gammarid)	32	32	176	96	112	384	32	0
Ant Crustaceans	0	0	128	96	160	32	16	0
Anthomedusae	0	0	0	0	0	0	0	0
Ascidian Juvenile?	0	0	0	0	0	0	0	0
Calanoid	16	16	848	560	1024	560	16	0
Canthigaster	0	0	0	0	0	0	0	0
Coral Larvae?	32	0	0	0	0	0	0	0
Crustacean	0	0	0	0	16	0	0	0
Cumacean	0	0	1312	128	16	112	0	16
Cyclopoid	16	0	0	16	0	16	0	0
Cylinder	16	16	0	0	0	16	0	0
Eggs	4832	576	288	304	176	272	0	0
Harpacticoid	48	32	544	368	592	240	16	32
Isopod	0	16	240	304	176	272	0	0
Juvenile Cephalopod	0	0	0	16	0	0	0	0
Juvenile *Canthigaster*	0	0	16	0	0	0	0	0
Juvenile Fish	0	0	640	64	16	0	0	0
Medusae?	32	0	0	0	0	0	0	0
Megalopa	0	0	656	1552	1168	560	32	48
Mysid	0	0	23072	14416	2192	544	0	0
Nauplius	0	0	112	32	0	0	0	0
Ostracod	0	0	240	0	48	16	0	0
Polychaete	0	16	304	32	96	48	16	0
Siphonophore	16	0	0	0	0	0	0	0
Taneid	0	0	16	16	16	48	16	0
Zoea	32	0	5936	7776	5664	1808	16	0

Benthic Marine Flora and Substrate Cover

Results of quantitative surveys of the marine benthic community and species diversity of algae recorded within the study site are presented in Figures 5–7 and Table 9. Seventy-two species of marine benthic algae were encountered within the study area. The overall percent cover of the marine benthic algal community ranged from 73.9 to 81.6 on the reef flat on either side of the channel. The dominant features of the reef front and slope transects were corals, coralline algae, and turf algal species. Percent cover of these components ranged from 26.6 to 53.1, 11.4 to 38.5, and 6.9 to 17.8, respectively. A 53.6 to 80.0 percent algal cover was recorded along the side transect in the channel, while the predominant feature of the bottom was sand.

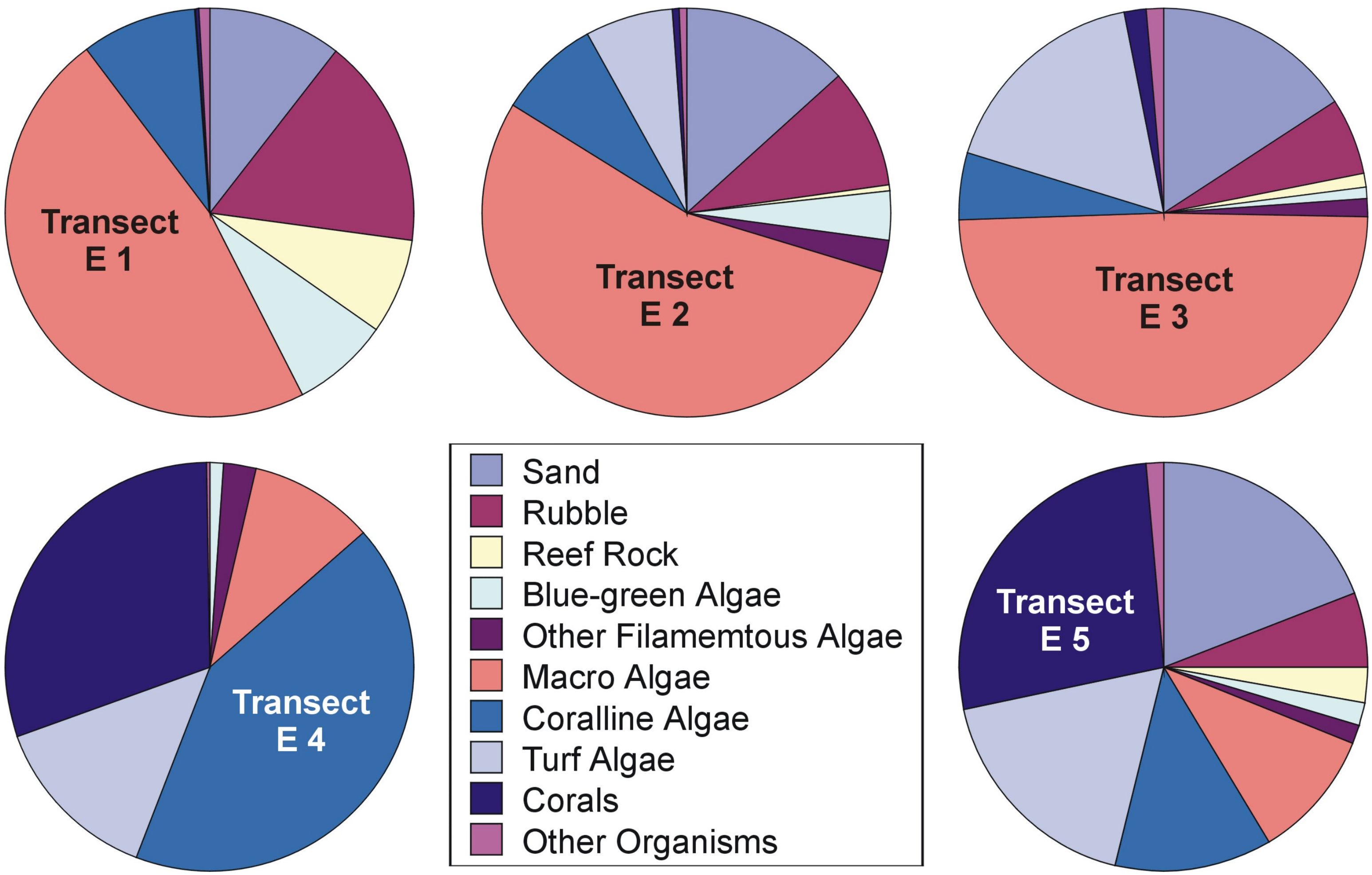

Figure 6. Surface coverage of the benthic community recorded along five transects on the east wall of the Cooling Water Intake Channel at Tanguisson, expressed in percent.

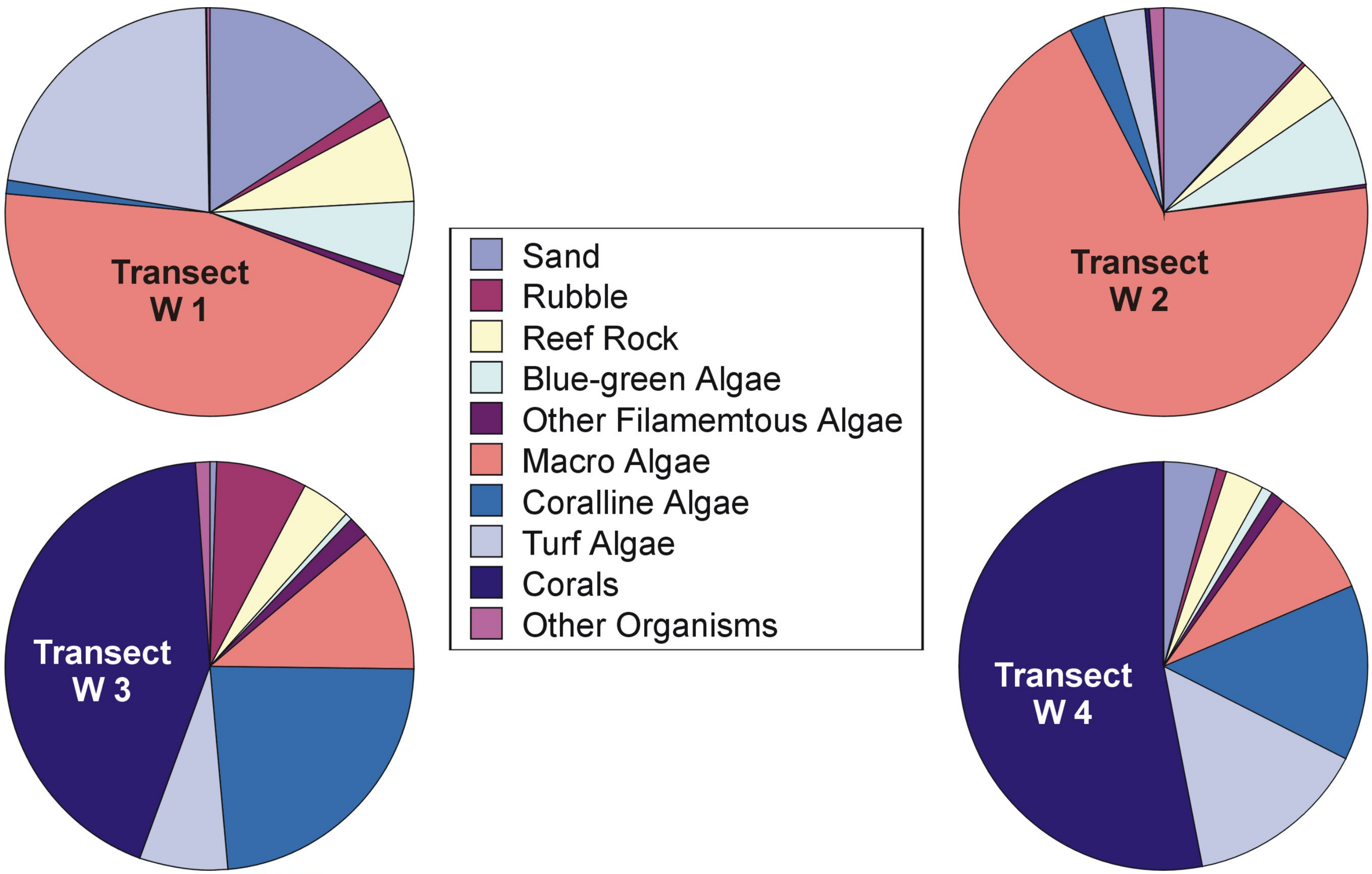

Figure 7. Surface coverage of the benthic community recorded along four transects on the west wall of the Cooling Water Intake Channel at Tanguisson, expressed in percent.

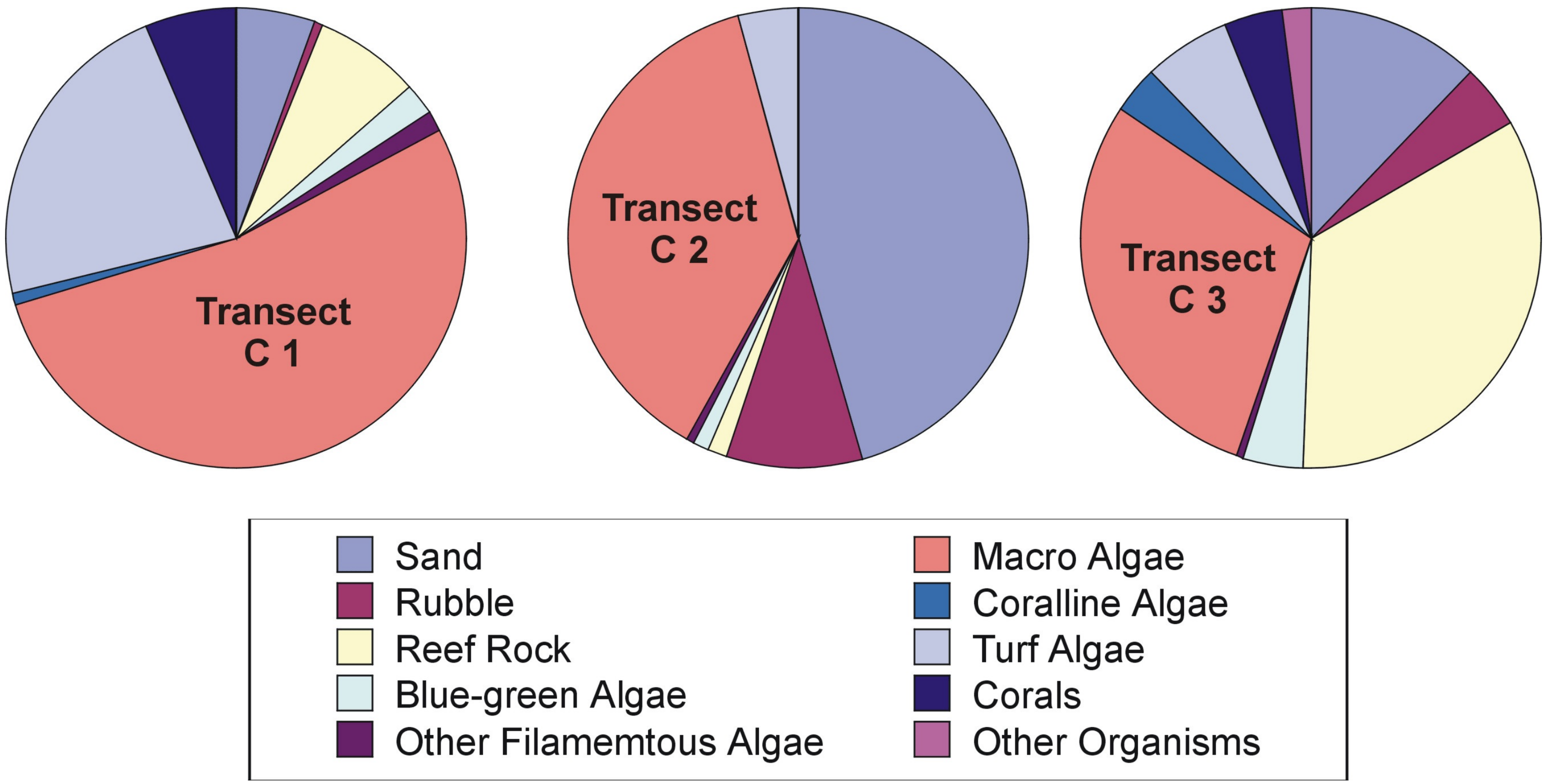

Figure 8. Surface coverage of the benthic community recorded along three transects on the floor of the Cooling Water Intake Channel at Tanguisson, expressed in percent.

Table 9. Species diversity of the algal community observed along the transects on the Tanguisson reef flat, channel, reef front, 20-ft contour, and the areas in the vicinity of the transects. The algal components of the turfs recorded along, and in the vicinity of, the transects are included.

	Transects											
Species	**E1**	**E2**	**E3**	**E4**	**E5**	**W1**	**W2**	**W3**	**W4**	**C1**	**C2**	**C3**
Cyanophyta												
Entophysalis deusta (Meneghini) Drouet & Daily	X					X						
Calothrix crustacea Thuret						X	X					
Microcoleus lyngbyaceus (Kützing) P. Crouan & H. Crouan	X	X	X	X	X	X	X		X	X	X	X
Schizothrix calcicola (C. Agardh) Gomont	X	X	X	X	X	X	X	X	X	X	X	X
Schizothrix mexicana Gomont	X	X			X	X	X					
Schizothrix sp.					X							
Chlorophyta												
Boergensenia forbesii (Harvey) Feldmann		X	X				X					
Boodlea composita (Harvey) Brand	X	X								X	X	X
Bryopsis pennata Lamouroux	X	X	X		X	X	X			X		X
Enteromorpha clathrata (Roth) Greville	X											
Caulerpa racemosa (Forsskål) J. Agardh	X			X	X			X	X	X		X
Caulerpa sertularoides (Gmelin) Howe				X						X		X
Caulerpa verticellata J. Agardh					X							
Chlorodesmis fastigiata (C. Agardh) Ducker				X	X			X	X		X	
Cladophora albida (Nees) Kützing		X							X			X
Cladophoropsis sudanensis Reinbold	X									X		
Codium edule P. Silva		X	X			X	X			X		X
Derbesia antennata Dawson					X				X			
Dictyosphaeria verluysii Weber-van Bosse			X							X		
Halimeda opuntia (Linnaeus) Lamouroux	X	X	X	X	X	X	X	X	X	X	X	X
Neomeris annulata Dickie	X	X						X				

Table 9. Continued.

Species	Transects											
	E1	E2	E3	E4	E5	W1	W2	W3	W4	C1	C2	C3
Phaeophyta												
Dictyota bartayresiana Lamouroux		X								X		
Dictyopteris repens (Okamura) Børgesen		X										
Hincksia indica (Sonder) J. Tanaka					X			X				
Lobophora variegata (Lamouroux) Womersley ex Oliveira		X	X	X						X	X	
Padina boryana Thivy			X	X		X	X			X	X	
Sargassum crisaefolium C. Agardh			X									
Sphacelaria rigidula Kützing										X		
Sphacelaria sp.		X			X							
Sphacelaria tribuloides Meneghini	X											
Turbinaria ornata (Turner) J. Agardh		X	X				X			X		
Rhodophyta												
Acanthophora spicifera (Vahl) Børgesen		X	X				X					
Acrochaetum sp.					X							
Actinotrichia fragilis (Forsskål) Børgesen		X	X	X				X	X			
Amphiroa fragilissima (Linnaeus) Lamouroux	X	X	X	X	X	X	X	X	X	X		X
Anotrichium sp.		X										
Antithamnion sp.					X							X
Antithamnionella elegans (Berthold) J. Price & D. John					X				X			
Bostrychia tenella (Lamouroux) J. Agardh				X					X			
Champia parvula (C. Agardh) Harvey		X				X				X	X	X
Cheilosporum culturatum (Harvey) Areschoug				X				X	X	X		
Centrocerus clavulatum (C. Agardh) Montagne		X	X	X	X	X					X	X
Ceramium macilentum J. Agardh		X		X						X		
Erythrotrichia sp.									X			

Table 9. Continued.

Species	Transects											
	E1	E2	E3	E4	E5	W1	W2	W3	W4	C1	C2	C3
Galaxaura fasciculata Kjellman		X	X		X			X				
Galaxaura marginata (Ellis & Solander) Lamouroux				X	X			X	X		X	X
Gelidiella acerosa (Forsskål) Feldmann & Hamel		X	X		X	X	X	X		X		
Gelidiella pannosa (J. Feldmann) J. Feldmann & G. Hamel		X	X									X
Gelidium pusillum (Stackhouse) Le Jolis		X	X	X	X			X	X	X		X
Gracilaria salicornia (C. Agardh) Dawson		X			X	X	X			X		X
Gracilaria tsudae (Abbott & Meneses) Abbott	X					X	X					X
Halymenia durvillei Bory				X	X		X	X	X			
Herposiphonia secunda (C. Aghard) Ambronn		X										
Hydrolithon reinboldii (Weber-van Bosse & Foslie) Foslie	X	X	X									X
Hypnea pannosa J. Agardh			X							X		
Hypoglossum attenuatum Gardner					X				X			
Jania decussatodichotoma (Yendo) Yendo	X											
Jania capillacea Harvey	X	X	X	X	X	X		X	X	X		X
Laurencia sp	X											
Leveillea jungermannioides (Hering & Martens) Harvey		X	X	X		X	X			X		X
Mastophora pacifica (C. Agardh) Setchell	X		X	X								
Mesophyllum mesomorphum (Foslie) Adey					X			X				
Neogoniolithon brassica-florida (Harvey) Setchell & Mason				X						X		
Peyssonnelia rubra (Greville) J. Agardh	X	X			X			X	X			
Polysiphonia triton P.C. Silva		X	X	X	X			X	X			
Porolithon spp.	X	X	X	X	X			X	X			X
Portieria hornemannii (Lyngbye) P. Silva					X			X	X		X	
Hapalospongidion pangoense (Setchell) P. Silva					X				X			

Table 9. Continued.

Species	Transects											
	E1	**E2**	**E3**	**E4**	**E5**	**W1**	**W2**	**W3**	**W4**	**C1**	**C2**	**C3**
Rhodymenia divericata Dawson		X	X			X	X		X	X		
Sporolithon sp.			X						X			
Symphyocladia marchantioides (Harvey) Falkenberg									X			
Tolypiocladia glomerulata (C. Aghard) Schmitz		X	X			X				X		X
Tricleocarpa fragilis (Linnaeus) Huisman & Townsend		X	X									
Total (72)	21	39	30	23	30	21	19	20	27	29	11	23

Macroinvertebrates

The distribution and abundance of conspicuous epibenthic macroinvertebrates observed along transects at Tanguisson are reported in Tables 10–12. The reef flat on either side of the intake channel at Tanguisson supports a macroinvertebrate community that is typical of other localities in Guam where spring low tides expose the reef pavement of the outer reef flat and produce temporal tide pools in depressions in the pavement. These depressions, described as pavement pools by Kerr and Smith (1993), may be subject to wide variations in temperature and salinity, depending upon both oceanic and atmospheric conditions. Despite this tendency for variability, the tide pools provide habitat for macroinvertebrates that would otherwise be at risk of dessication at low tide. As a consequence, the macroinvertebrates tend to aggregate in the depressions.

In terms of population density, echinoderms were the predominant taxon within that portion of the zone of influence on the reef flat at Tanguisson, although their numbers were considered to be low (Table 10). The most abundant species, the holothuroid *Actinopyga echinites*, was only slightly more than one-half as abundant as reported from pavement pools in nearby Tumon Bay (Kerr and Smith, 1993), where the population of this species gradually increased from 1977 to 1993 (Birkeland, 1978; Kerr and Smith, 1993). A similar relationship can be observed with the other holothuroids *Stichopus chloronotus*, *Holothuria atra*, and *Holothuria leucospilota* from similar habitats in Tumon Bay and Tanguisson.

Molluscs exhibited the greatest species richness, with ten species of gastropods observed on the reef flat transects. Seven of the ten species were carnivorous, with one each browsing herbivore, detritivore, and suspension feeder. Among the carnivorous species, some 71% were vermivores. The presence of abundant infaunal polychaete annelids can be inferred by the predominance of vermivorous gastropods, although only a single specimen of polychaete was observed on the reef flat transects. Similarly, the high motility and avoidance of humans by most crustaceans contribute to the paucity of observations of crabs and shrimps, and to the low estimations of their abundance on the reef flat.

Macroinvertebrate communities of the reef margin and upper reef slope in the zone of influence were dominated by echinoderms in both abundance and species richness (Table 11). However, unlike the reef flat, echinoids were more abundant than holothuroids. *Echinothrix*

Table 10. Densities of conspicuous epibenthic macroinvertrates along reef flat transects at Tanguisson. Densities are reported as means ± SD of counts in five 20-m^2 plots along 50-m belt transects. Transect locations are shown in Figure 4.

Species	Transect 1E	Transect 2E	Transect 3E	Transect 1W	Transect 2W
Phylum Annelida					
Class Polychaeta					
Eurythoe complanata (Pallas)			0.2 ± 0.4		
Phylum Mollusca					
Class Gastropoda					
Trochus niloticus Linnaeus	1.0 ± 1.7	0.2 ± 0.4	0.2 ± 0.4		
Cerithium nodulosum Bruguière	0.2 ± 0.4				
Dendropoma maxima Sowerby	0.2 ± 0.4	1.0 ± 2.2	0.2 ± 0.4	0.4 ± 0.9	
Chicoreus brunneus (Link)		0.2 ± 0.4			
Thais tuberosa (Röding)	0.2 ± 0.4				
Vasum turbinellus (Linnaeus)	1.6 ± 1.3			0.8 ± 1.3	1.8 ± 2.2
Conus ebraeus Linnaeus	0.6 ± 0.5		0.6 ± 0.9	0.2 ± 0.4	
Conus lividus Hwass		0.2 ± 0.4			
Conus sanguinolentus Quoy & Gaimard	0.2 ± 0.4	0.2 ± 0.4			
Conus sponsalis Hwass	0.2 ± 0.4			0.4 ± 0.9	
Phylum Arthropoda					
Class Crustacea					
Neaxius acanthus (A. Milne Edwards)	0.2 ± 0.4				
Calcinus sp.	0.4 ± 0.9				
Dardanus guttatus (Oliver)		0.2 ± 0.4			
Thalamita sp.	0.2 ± 0.4				
Atergatis floridus (Linnaeus)	0.2 ± 0.4				

Table 10. Continued.

Species	Transect 1E	2E	3E	1W	2W
Phylum Echinodermata					
Class Echinoidea					
Echinothrix diadema (Linnaeus)	0.4 ± 0.5		0.2 ± 0.4		
Echinometra mathaei (de Blainville)			1.0 ± 0.7		
Class Ophiuroidea					
Ophiocoma erinaceus Müller & Troschel				1.8 ± 1.6	0.4 ± 0.9
Ophiocoma scolopendrina (Lamarck)				5.2 ± 5.6	0.6 ± 0.5
Class Holothuroidea					
Stichopus chloronotus Brandt			0.8 ± 0.4		
Actinopyga echinites (Jaeger)	5.2 ± 4.8	1.4 ± 1.5			
Holothuria atra Jaeger	0.4 ± 0.5	1.0 ± 1.0	3.8 ± 3.1	5.0 ± 4.1	4.6 ± 4.8
Holothuria leucospilota Brandt	0.6 ± 0.9		0.8 ± 0.8	0.2 ± 0.4	0.2 ± 0.4

Table 11. Densities of conspicuous epibenthic macroinvertrates along reef margin and upper reef slope transects at Tanguisson. Densities are reported as means ± SD of counts in five 20-m^2 plots along 50-m belt transects. Transect locations are shown in Figure 4.

Species	Transect 4E	Transect 5E	Transect 3W	Transect 4W
Phylum Porifera				
Class Calcarea				
Leucetta sp.		0.2 ± 0.4		
Class Demospongiae				
Stylissa massa (Carter)		1.8 ± 1.3	0.2 ± 0.4	0.6 ± 0.9
Phylum Cnidaria				
Class Anthozoa				
Palythoa caesia Dana			0.4 ± 0.9	
Heteractis crispa (Ehrenberg)				0.4 ± 0.5
Cladiella krempfi (Hickson)		0.2 ± 0.4	2.0 ± 3.5	0.2 ± 0.4
Lobophytum batarum Moser		0.6 ± 1.3		0.2 ± 0.4
Lobophytum pauciflorum (Ehrenberg)				0.2 ± 0.4
Sinularia cf. *abrupta* Tixier-Durivault				0.8 ± 1.8
Sinularia sp.				1.0 ± 2.2
Phylum Annelida				
Class Polychaeta				
Spirobranchus corniculatus (Grube)		0.4 ± 0.5		
Phylum Mollusca				
Class Gastropoda				
Cypraea caputserpentis Linnaeus	0.2 ± 0.4			0.4 ± 0.5
Drupa morum Röding	0.4 ± 0.9			
Drupa ricinus (Linnaeus)	0.2 ± 0.4			
Vasum turbinellus (Linnaeus)	0.6 ± 1.3	0.2 ± 0.4		
Tridacna maxima (Röding)			0.2 ± 0.4	0.2 ± 0.4

Table 11. Continued.

Species	Transect			
	4E	5E	3W	4W
Phylum Arthropoda				
Class Crustacea				
Dardanus sp.			0.2 ± 0.4	
Phylum Echinodermata				
Class Echinoidea				
Diadema savignyi Michelin		0.2 ± 0.4		0.6 ± 0.5
Echinothrix diadema (Linnaeus)	4.2 ± 4.1		4.4 ± 2.9	0.4 ± 0.9
Echinometra mathaei (de Blainville)	0.2 ± 0.4	0.2 ± 0.4	0.2 ± 0.4	1.4 ± 1.1
Echinostrephus aciculatus A. Agassiz			1.0 ± 2.2	2.6 ± 2.3
Class Ophiuroidea				
Ophiocoma sp.				0.2 ± 0.4
Class Holothuroidea				
Stichopus chloronotus Brandt	0.2 ± 0.4	0.6 ± 0.9		0.4 ± 0.5
Actinopyga mauritiana (Quoy & Gaimard)	5.2 ± 3.7	1.0 ± 1.2	0.4 ± 0.5	1.0 ± 1.7
Holothuria atra Jaeger			0.2 ± 0.4	0.2 ± 0.4

diadema was predominant in the reef margin, where it inhabits crevices in the spur and groove zone. The boring echinoids *Echinometra mathaei* and *Echinostrephus aciculatus* were more numerous on the upper reef slope. *Actinopyga mauritiana* was the predominant holothuroid in this zone, where it can be found on most Guam reefs.

Fewer species of gastropod molluscs were observed in this zone, but this may be a function of the greater heterogeneity of the habitat in this zone, as well as greater exposure to highly motile predators such as fishes and crabs. In such an environment, the relatively sedentary gastropods tend to be more cryptic in behavior. Non-scleractinian corals were dispersed throughout this zone, but their abundance and diversity were considered to be low.

The Tanguisson intake channel supported a greater abundance and diversity of macroinvertebrates than either the reef flat or reef front (Table 12). Both holothuroids and echinoids were abundant, perhaps because the channel wall provides spatial heterogeneity required of echinoids, while the channel walls and floor provide protection from the effects of wave motion required of most holothuroids. *Echinothrix diadema* was the predominant echinoid of the channel walls, with *Diadema savignyi* and *Echinometra mathaei* being patchily distributed.

The relatively protected waters of the intake channel appeared to provide favorable habitat for the holothuroid *Stichopus chloronotus*, whose abundance reached a mean of more than 1 m^{-2} (24 per 20 m^2) and exceeded that reported for this species in Tumon Bay (Kerr and Smith, 1993) by several magnitudes. *Holothuria leucospilota*, another calm water species, similarly was very abundant on the channel walls.

Seven species of gastropods were recorded from the intake channel. Vermivorous species were predominant, as on the reef flat. In addition to entrainment of planktonic organisms, the intake current in the channel brings suspended organics to suspension-feeding organisms, such as the gastropod *Dendropoma maxima* and the infaunal polychaete *Loimia medusa*.

Table 12. Densities of conspicuous epibenthic macroinvertrates along transects in the intake canal at Tanguisson. Densities are reported as means ± SD of counts in five 20-m^2 plots along 50-m belt transects. Transect locations are shown in Figure 4.

Species	Transect 1C	Transect 2C	Transect 3C
Phylum Annelida			
Class Polychaeta			
Loimia medusa (Savigny)	0.2 ± 0.4		
Phylum Mollusca			
Class Gastropoda			
Trochus niloticus Linnaeus	0.2 ± 0.4		0.2 ± 0.4
Dendropoma maxima Sowerby	2.2 ± 3.9		1.0 ± 1.7
Cymatium nicobaricum (Röding)		0.2 ± 0.4	
Vasum turbinellus (Linnaeus)	2.6 ± 1.3		1.2 ± 1.3
Conus ebraeus Linnaeus	0.4 ± 0.9		0.4 ± 0.5
Conus flavidus Lamarck	0.2 ± 0.4		0.2 ± 0.4
Conus lividus Hwass	0.6 ± 0.9		
Phylum Arthropoda			
Class Crustacea			
Stenopus hispidus (Olivier)		0.4 ± 0.5	
Neaxius acanthus (A. Milne Edwards)		2.0 ± 2.1	
Calcinus sp.	0.4 ± 0.9		0.4 ± 0.9
Eriphia sebana (Shaw & Nodder)			0.2 ± 0.4
Phylum Echinodermata			
Class Echinoidea			
Diadema savignyi Michelin	3.2 ± 4.0	0.2 ± 0.4	0.6 ± 0.5
Echinothrix diadema (Linnaeus)	10.0 ± 8.0	0.2 ± 0.4	13.6 ± 9.6
Tripneustes gratilla (Linnaeus)	0.2 ± 0.4		
Echinometra mathaei (de Blainville)	0.6 ± 0.5	2.6 ± 2.6	3.0 ± 5.6
Echinostrephus aciculatus A. Agassiz	0.2 ± 0.4	0.2 ± 0.4	
Class Holothuroidea			
Stichopus chloronotus Brandt	24.0 ± 6.9	1.0 ± 1.4	13.8± 7.8
Actinopyga echinites (Jaeger)	0.6 ± 0.5	1.2 ± 2.2	0.6 ± 0.5
Actinopyga mauritiana (Quoy & Gaimard)	0.8 ± 1.8		1.0 ± 1.2
Holothuria atra Jaeger	0.4 ± 0.5	1.2 ± 0.8	4.8 ± 4.3
Holothuria leucospilota Brandt	6.4 ± 9.0		3.4 ± 1.3
Holothuria nobilis (Selenka)			0.2 ± 0.4

Fishes

Fish species observed at all transect sites (81 species in 22 families) are given in Table 13. Diversity measures are given in Table 14. Species richness (S) and species diversity (H') were greatest at transect site 1C and least at transect site 2W. The number of individuals of all species (N) was greatest at transect site 2W and least (N = 0) at 1W. Evenness (J') was greatest at transect site 2W but also at 5E and 1E; the lowest value of J' was from transect site 2E. Higher values of S, H' and N may be explained by the degree of complexity in habitat structure. At sites 1–3E and 1–2W, habitat structure consists primarily of pavement with a few boulders and some benthic algae, mainly sargassum, that offer little structure for fishes to utilize. The spur and groove zone (3W and 4E) offered a greater degree of habitat complexity but the number of species living in this zone seemed restricted to those specialized for this zone, whereas the channel sites (1–3C) had spur and groove species (resident along the walls of the channel) plus those associated with reef flats, rocks, rubble, and sand, or in the adjacent water column. Species richness was directly proportional to the number of individuals (Figure 9), and species diversity (Figure 10) was proportional to the number of individuals observed at each site.

The matrix of similarity in fish assemblage structure between transect sites is given in Table 15 (site 1W had no fishes and was eliminated from further analyses). Over the reef margin, the greatest similarity in assemblage structure was between sites 4E–4W while the least similarity was between sites 5E–3W. On the reef flat, the greatest similarity was between sites 2E–2W and the least was between 2W–3E. In the channel, sites 1C–2C were most similar and 2C–3C were the least similar. Overall relationships between sites are depicted in the cluster analysis dendrogram given in Figure 11. Channel sites were more allied with inshore reef flat sites (1E–2E) and, in succession, those beyond or below the reef margin (sub-marginal sites: 4E–4W, 3W and 5E) followed by reef flat (3E and 2W) sites. MDS analysis (Figure 12) indicated that channel sites were positioned between both reef flat and sub-reef marginal sites, but that the channel sites were separated into either reef flat or sub-reef marginal sites. The stress value of 0.06 indicated a high degree of reliability in this result.

Table 13. Checklist of fishes observed at control and treatment transect sites at Tanguisson. Numbers refer to the number of fishes observed.

Species	Family	Transect											
		1C	2C	3C	1E	2E	3E	4E	5E	1W	2W	3W	4W
Myrpristis amaena	Holocentridae	5								0			
Neoniphon sammara	Holocentridae				2								
Sargocentron diadema	Holocentridae	5		2	2								
Sargocentron spiniferum	Holocentridae												
Fistularis commersoni	Fistularidae	1											
Cirrhitus pinnulatus	Cirrhitidae							6	1			1	
Paracirrhites forsteri	Cirrhitidae								1				
Apogon novemfasciatus	Apogonidae				6								
Caranx melampygus	Carangidae			4									
Monotaxis grandoculis	Lethrinidae	1											
Scolopis bilineata	Nemipteridae								2				
Mulloidichthys flavolinneatus	Mullidae	1	3										
Parupenus cyclostoma	Mullidae							1					
Parupenus multifasciata	Mullidae	1			1				1				1
Pempheris oualensis	Pempheridae							2					
Chaetodon auriga	Chaetodontidae	2				4							
Chaetodon bennetti	Chaetodontidae			1		1							
Chaetodon citrinellus	Chaetodontidae	3		4		5			2				
Chaetodon ephippium	Chaetodontidae								2				
Chaetodon lunula	Chaetodontidae	3										1	
Chaetodon ornatissimus	Chaetodontidae							2	2				
Chaetodon reticulatus	Chaetodontidae							2	2			3	1
Chaetodon ulietensis	Chaetodontidae								3				
Forcipinger flavissimus	Chaetodontidae							3					
Heniochus chrysostomus	Chaetodontidae	1							2				

Table 13. Continued.

Species	Family	Transect											
		1C	2C	3C	1E	2E	3E	4E	5E	1W	2W	3W	4W
Pomacanthus imperator	Pomacanthidae											1	
Pygoplites diacanthus	Pomacanthidae											1	
Abudefduf sordidus	Pomacentridae	3		1									
Chrysiptera biocellata	Pomacentridae				3	12							
Chrysiptera brownriggi	Pomacentridae	43	31	16		37	102	3	1		3		
Chrysiptera glauca	Pomacentridae				15	18	6				1		
Plectroglyphididon dickii	Pomacentridae								18				13
Plectroglyphididon johnstonianus	Pomacentridae								1				
Plectroglyphididon lacrymatus	Pomacentridae												3
Plectroglyphididon leucozona	Pomacentridae	1	1					22				11	
Plectroglyphididon phoenixensis	Pomacentridae	1		1				20				2	
Pomacentrus vaiuli	Pomacentridae			4									
Stegastes albifasciatus	Pomacentridae	12	12	9	12								
Stegastes fasciatus	Pomacentridae							6	15			39	2
Anampses caeruleopunctatus	Labridae	1						6	4			5	
Gomphosus varius	Labridae							2	1				
Halichoeres margaritaceus	Labridae	9	4	2	23	65	21						
Halichoeres richmondi	Labridae											1	
Halichoeres scapularis	Labridae	2		1	1			1					
Halichoeres trimaculatus	Labridae	17	6	1	16	3							
Hemigymnus melapterus	Labridae	2		1									
Labroides dimidiatus	Labridae	3	2	1					1			1	2
Oxycheilinus unifasciatus	Labridae								1				1
Stethojulis bandanensis	Labridae	3	5	4	14	1		1			1	1	2
Stethojulis strigiventer	Labridae				5								
Thalassoma amblycephalum	Labridae	1		1				26				10	27
Thalassoma hardwicke	Labridae	4		1									

Table 13. Continued.

Species	Family	Transect											
		1C	2C	3C	1E	2E	3E	4E	5E	1W	2W	3W	4W
Thalassoma purpureum	Labridae	1											
Thalassoma quinquevittatum	Labridae	3						22	6			14	14
Chlorurus sordidus	Scaridae	5	5					4	8			20	2
Calatomus carolinus	Scaridae		1										
Scarus niger	Scaridae											1	
Scarus psittacus	Scaridae	1	16									1	
Cirripectes variolusus	Blenniidae							4	4				3
Ecsenius bicolor	Blenniidae												8
Exalias brevis	Blenniidae			1				2					1
Salarias fasciatus	Blenniidae	1				1							
Zanclus cornutus	Zanclidae	5		2	1							3	2
Siganus spinus	Siganidae				1		2						
Acanthurus guttatus	Acanthuridae											1	
Acanthurus lineatus	Acanthuridae	8				1	1	17	10			67	20
Acanthurus nigricans	Acanthuridae			1				4				4	2
Acanthurus nigrofuscus	Acanthuridae	24	2	9		1		15	4			16	3
Acanthurus triostegus	Acanthuridae	1										10	2
Ctenochaetus striatus	Acanthuridae	2	1					3	9			1	11
Naso annulatus	Acanthuridae			4					4				
Naso literatus	Acanthuridae		2	10				2				2	
Balistapus undulatus	Balistidae			1					1				
Pseudobalistes flavimarginatus	Balistidae			1									
Rhinecanthus aculeatus	Balistidae	7		2	8		1						
Rhinecanthus rectangularis	Balistidae	2		1			6						
Sufflamen chrysoptera	Balistidae		1	1									
Amanses scopas	Monacanthidae					1			1				1
Ostracion cubicus	Ostracionidae											1	

Table 13. Continued.

Species	Family	Transect											
		1C	2C	3C	1E	2E	3E	4E	5E	1W	2W	3W	4W
Canthigaster janthinaoptera	Tetraodontidae											1	
Canthigaster solandri	Tetraodontidae		1		12	8							
Total number of individuals		185	93	87	122	158	139	176	107	0	5	219	121

Table 14. Measures of fish species richness (S), species diversity (H'), evenness (J') and numbers of individuals of all species (N) from reef flat transect sites at Tanguisson.

	Measure			
Transect	S	N	J'	H'($\log_e$)
1E	16	122	0.86002	2.38447
2E	14	158	0.67051	1.76950
3E	5	31	0.60894	0.98006
4E	22	170	0.84336	2.60687
5E	27	107	0.86023	2.83518
2W	3	5	0.86497	0.95027
3W	27	219	0.71905	2.36989
4W	20	122	0.81818	2.45104
1C	36	185	0.80746	2.89354
2C	16	93	0.77973	2.16186
3C	28	87	0.85659	2.85432

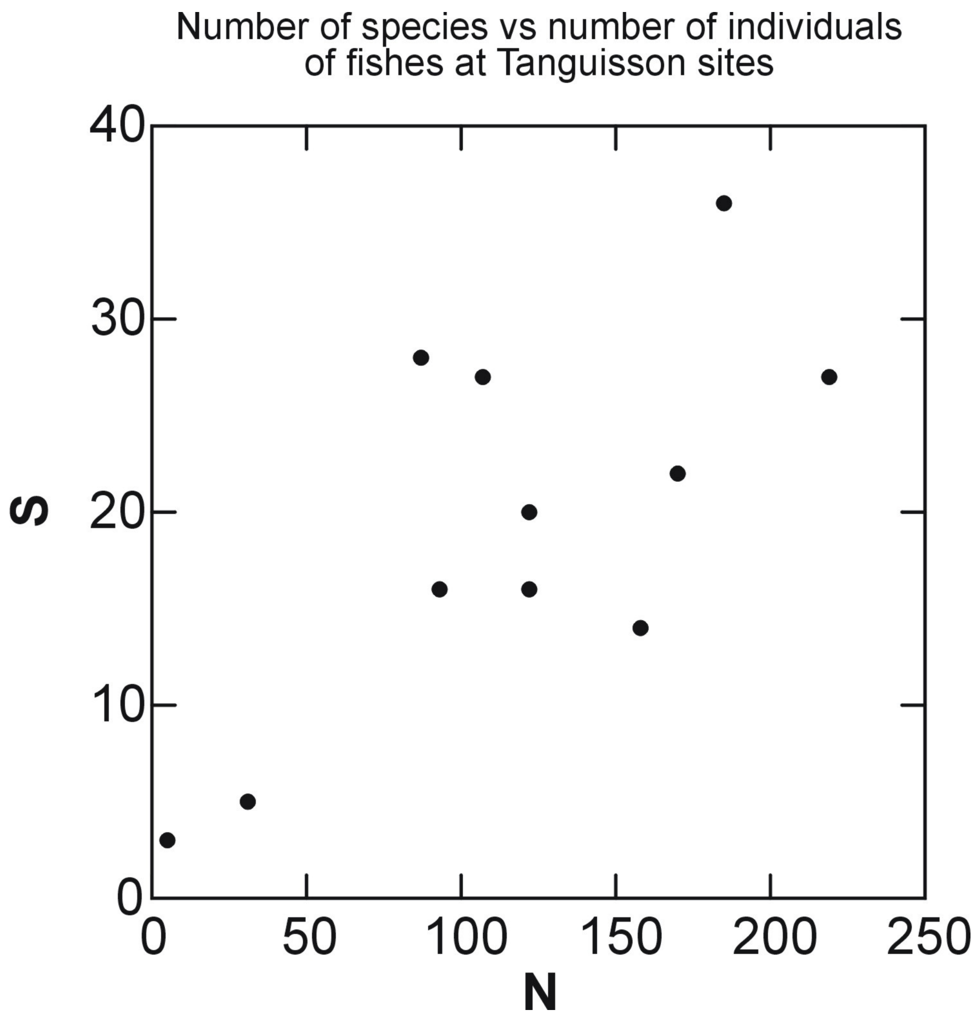

Figure 9. Relationship between the number of individuals observed (N) and species richness (S) on fish survey transects at Tanguisson.

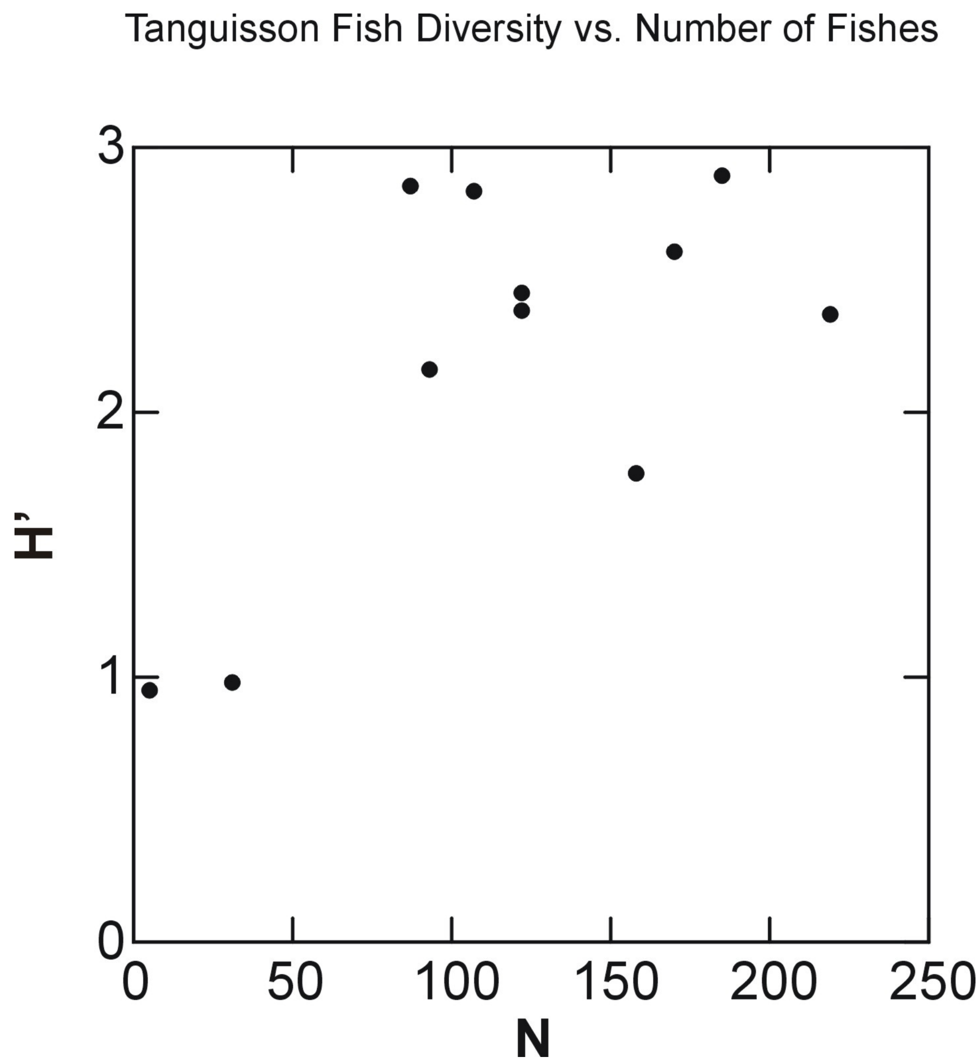

Figure 10. Relationship between the number of individuals observed (N) and species diversity (H') on fish survey transects at Tanguisson.

Table 15. Matrix of Bray-Curtis similarity index values for pairwise comparisons between control and treatment transects at Tanguisson. Higher values indicate a greater similarity.

	Transect										
Transect	1E	2E	3E	4E	5E	2W	3W	4W	1C	2C	3C
1E	0	0	0	0	0	0	0	0	0	0	0
2E	41.970	0	0	0	0	0	0	0	0	0	0
3E	26.405	23.708	0	0	0	0	0	0	0	0	0
4E	4.304	6.655	3.127	0	0	0	0	0	0	0	0
5E	2.294	12.827	3.435	44.669	0	0	0	0	0	0	0
2W	9.271	18.484	0.000	3.494	3.883	0	0	0	0	0	0
3W	11.013	6.220	2.847	55.936	31.332	3.147	0	0	0	0	0
4W	8.322	10.090	3.768	58.512	49.796	4.313	49.083	0	0	0	0
1C	32.937	34.026	16.162	29.154	28.492	7.520	38.827	31.381	0	0	0
2C	30.825	35.356	9.222	18.113	16.481	14.905	29.175	17.619	47.672	0	0
3C	26.020	30.855	14.110	24.378	22.740	11.491	22.828	25.050	45.602	39.722	0

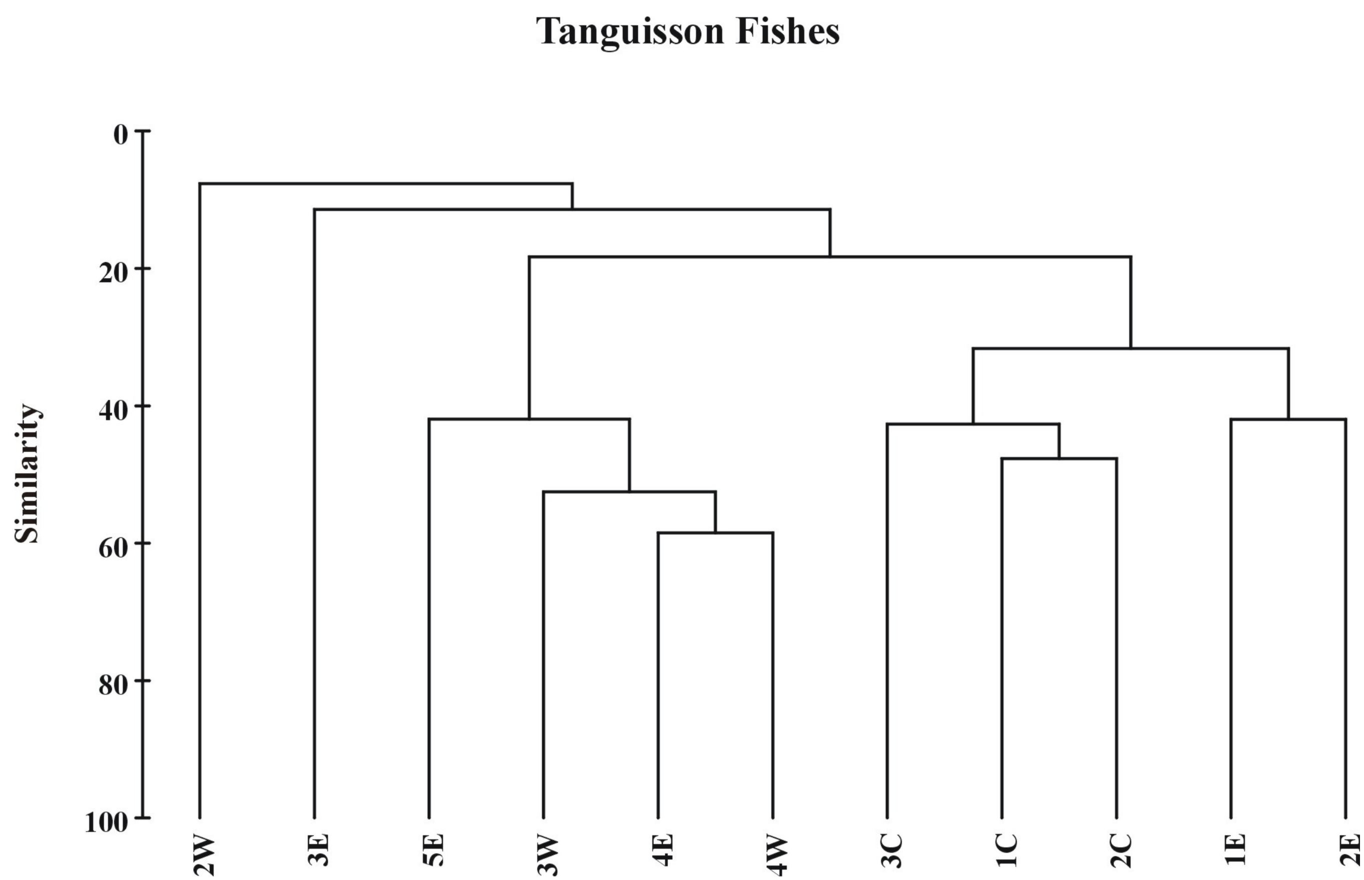

Figure 11. Cluster analysis of Bray-Curtis similarity index values from pair-wise comparisons of fish assemblages on transects at Tanguisson.

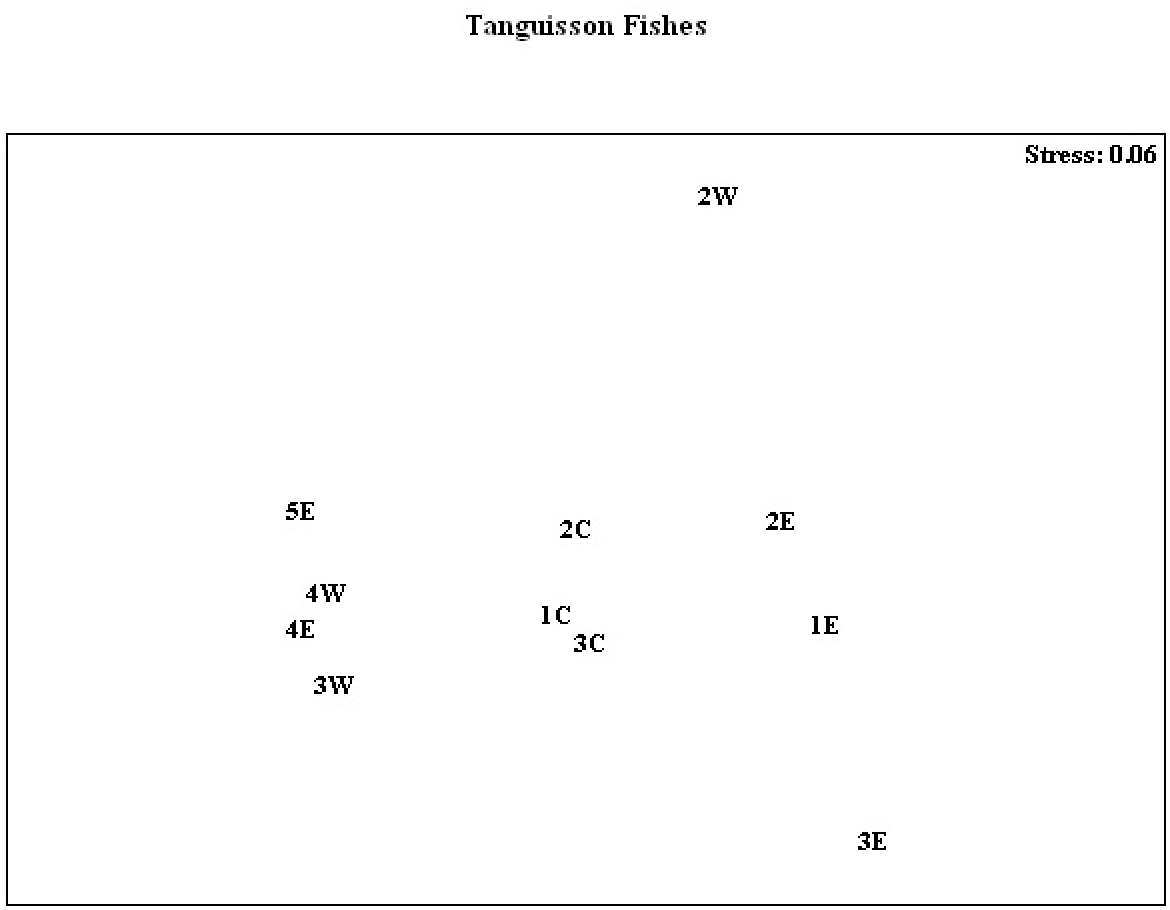

Figure 12. Multi-dimensional scaling (MDS) analysis of fish assemblages on transects at Tanguisson.

Threatened and Endangered Species

No threatened or endangered species were observed within the zone of influence of the Tanguisson Cooling Water Intake System during this study. The beaches in the vicinity of the CWIS could potentially serve as nesting sites for marine turtles inhabiting the seas around Guam. The hawksbill turtle *Eretmochelys imbricata* is protected as an endangered species by the U.S. Endangered Species Act, and the green sea turtle *Chelonia mydas* is listed as a threatened species. However, the prolonged disturbance of the Tanguisson coastal area by the power plant and the frequent use of the beach and reef areas by island residents would likely preclude successful nesting at Tanguisson by either species. The third species of marine turtle reported from Guam's waters, the leatherback turtle *Dermochelys coriacea*, is observed at sea (Eldredge, 2003), but there are no records of this species coming ashore in Guam.

Of the seven species of marine mammals protected by the U.S. Endangered Species Act, three have been reported from the waters of Guam and the Mariana Islands. The sperm whale *Physeter macrocephalus*, the sei whale *Balaenoptera borealis*, and the humpback whale *Megaptera novaeangliae* have been sighted in the past 30 yr (Eldredge, 1991, 2003). None of the three species was observed during this study, but one species of marine mammal was noted offshore of the Tanguisson intake channel entrance. On the morning of September 13, 2002, we observed a pod of eight to ten long-snouted spinner dolphins, *Stenella longirostris*, swimming about 200 m beyond the reef margin. Although not federally listed as endangered, these animals are protected under the Marine Mammal Protection Act of 1972.

REFERENCES

Beck, R.W. 1995. Tanguisson Intake, 316(B) Analysis. Prepared for the Guam Power Authority. 20 pages.

Birkeland, C., R.H. Randall, and G. Grimm. 1974. Three Methods of Coral Transplantation for the Purpose of Reestablishing a Coral Community in the Thermal Effluent Area at Tanguisson Power Plant. University of Guam Marine Laboratory, Technical Report 60:1–30.

Birkeland, C.E. 1978. Other macroinvertebrates. Pages 77–90 in R.H. Randall, editor. Guam's Reefs and Beaches. Part II. Transect Studies. University of Guam Marine Laboratory, Technical Report 48.

Bonito, V. 2002. Tanguisson Reef: Changes in Coral Community Structure Driven by *Acanthaster planci* Predation? Master of Science Thesis, University of Guam. 82 pages.

Clarke, K.R., and R.N. Gorley. 2001. PRIMER, v5. PRIMER-E, Ltd, Plymouth, England, 91 pages + software.

Colgan, M.W. 1981. Long-term Recovery Processes of a Coral Community after a Catastrophic Disturbance. University of Guam Marine Laboratory, Technical Report 76:1–69.

Colgan, M.W. 1982. Succession and recovery of a coral reef after predation by *Acanthaster planci* (L.). Proceedings of the Fourth International Coral Reef Symposium, Manila 2:333–338.

Colgan, W. 1987. Coral reef recovery on Guam (Micronesia) after catastrophic predation by *Acanthaster planci*. Ecology 68:1592–1605.

Duwel, J.T. 2002. Tanguisson Power Plant Oil Recovery System Report of Activities for July 1– September 30, 2002. Prepared for Mirant Guam (Tanguisson) Corp. 126 pages.

Division of Aquatic and Wildlife Resources, Guam Department of Agriculture. 2003. Top 10 Sampled Species Listed by Weight, Year 1990 - 2000. Unpublished list. 4 pages.

Eldredge, L.G. 1991. Annotated checklist of the marine mammals of Micronesia. Micronesica 24:217-230.

Eldredge, L.G. 2003. The marine reptiles and mammals of Guam. Micronesica 35-36:653–660.

English, S., C. Wilkinson, and V. Baker, eds. 1997. Survey Manual for Tropical Marine Resources, 2nd Edition. Australian Institute of Marine Science, Townsville. 400 pages.

Heslinga, G.A., and A. Hillmann. 1981. Hatchery culture of the commercial top snail *Trochus niloticus* in Palau, Caroline Islands. Aquaculture 22:25–43.

Jones, R.S., and R.H. Randall. 1973a. A Study of Biological Impact Caused by Natural and Man- Induced Changes on a Tropical Reef. University of Guam Marine Laboratory Technical Report 7:1–184.

Jones, R.S., and R.H. Randall. 1973b. A Preliminary Marine Survey for the Northern District Sewage System. University of Guam Marine Laboratory, Environmental Survey Report 8:1–15.

Kerr, A.M., and B.D. Smith. 1993. Macroinvertebrates. Pages 55–61 in S.S. Amesbury, R.T. Tsuda, R.H. Randall, A.M. Kerr, and B.D. Smith. Biological Communities in Tumon Bay, 1977–1991. University of Guam Marine Laboratory, Technical Report 99.

Kohn, A.J., and J.K. White. 1977. Polychaete annelids of an intertidal reef limestone platform at Tanguisson, Guam. Micronesica 13:199–215.

Myers, R.F. 1999. Micronesian Reef Fishes, 3rd ed. Coral Graphics, Barrigada, Guam. 330 pages + 192 plates.

Neudecker, S. 1976. Effects of Thermal Effluent on the Coral Reef Community at Tanguisson. University of Guam Marine Laboratory, Technical Report 30:1–55.

Neudecker, S. 1977. Development and Environmental Quality of Coral Reef Communities near the Tanguisson Power Plant. University of Guam Marine Laboratory, Technical Report 41:1–68.

Neudecker, S. 1977. Transplant experiments to test the effect of fish grazing on coral distribution. Proceedings of the Third International Symposium on Coral Reefs, Miami 1:317–323.

Randall, R.H. 1971. Tanguisson-tumon, Guam Reef Corals Before, During and after the Crown-of-thorns Starfish (*Acanthaster planci*) Predation. Master of Science Thesis, University of Guam. 119 pages.

Randall, R.H. 1973a. Coral reef recovery following extensive damage by the “crown-of-thorns” starfish, *Acanthaster planci* (L.). Publications of the Seto Marine Biological Laboratory 20:469–489.

Randall, R.H.. 1973b. Distribution of corals after *Acanthaster planci* (L.) infestation at Tanguisson Point. Micronesica 9:213–222.

Randall, R.S., and J. Holloman. 1974. Coastal Survey of Guam. University of Guam Marine Laboratory Technical Report 14:1–422.

Randall, R.H., R.T. Tsuda, and R.G. Bowman. 1992. A Reassessment of Reef-building Corals, an Assessment of Framework Bioerosion, and a Reassessment of Marine Benthic Algae in the Reef Area Affected by Thermal Effluent at Tanguisson Point, Guam. University of Guam Marine Laboratory Technical Report 98:1-45 + 107-page Appendix + vi.

Richmond, R.H. 1997. Reproduction and recruitment in corals: Critical links in the persistence of reefs. Pages 175–197 in C. Birkeland, editor. Life and Death of Coral Reefs. Chapman & Hall, New York.

Richmond, R.H., and C.L. Hunter. 1990. Reproduction and recruitment of corals: Comparisons among the Caribbean, the tropical Pacific, and the Red Sea. Marine Ecology Progress Series 60:185–203.

Rowley, D.M. 1980. Analysis of Biofouling Communities on Settling Plates at the Proposed Ocean Thermal Energy Conversion Site off Guam. University of Guam Marine Laboratory Technical Report 64:1–89.

Science Application International Corporation. 1999. Technical Review of Guam Power Authority's Section 316(b) Analysis for Tanguisson Power Plant. Prepared for EPA, Contract No. 68-4-0034, WA No. IM-5-36(P). 17 pages.

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

SPSS, Inc. 1999. SigmaScan Pro 5.0 image analysis software. Chicago, Illinois.

Tsuda, R.T. 1972. Morphological, zonational, and seasonal studies on two species of *Sargassum* on the reefs of Guam. Proceedings of the Seventh International Seaweed Symposium, Sapporo, Japan:40–44.