BIOLOGICAL MONITORING OF THE CHEVRON DIFFUSER BARBERS POINT, O‘AHU --- 2009

Evelyn F. Cox, Ku‘ulei Rodgers, Regina Kawamoto
University of Hawai‘i
Honolulu, Hawai‘i 96822

Summary

Surveys of corals, micromollusks and fishes were conducted at permanent monitoring areas on 26 August 2009 in compliance with the requirements of a Zone of Mixing Permit issued by the Hawai‘i State Department of Health to the Chevron Oil Refinery. We report the following:

- Coral saddle-top population mortality averaged 20%. Nine additional colonies, primarily on the sides of the saddles were measured for additional growth estimates in the coming years. Average growth for *Pocillopora meandrina* colonies from 2008 to 2009 was 101 cm^2.

- The micromollusk abundance and species numbers for 2009 were similar to numbers from 2002-2008. In 2009, a total of 4,244 micromollusks belonging to 139 mollusk taxa were collected. Species indicative of habitat degradation were not found or present in very low numbers in the vicinity of the pipeline. *Isognomon*, a genus characteristic of lowered salinity conditions, were not present at the Control site, but present in extremely low numbers at Pipeline (T1), T2, and T3 sites. At all four sites, pyramidellids and infaunal bivalves (indicators of enriched conditions) were present but in low numbers.

- The total number of individual fishes was higher at the Pipeline and T3 sites and lower at T2 and the Control sites as compared to the previous year. The richness or number of species recorded was higher at all sites as compared to 2008 except at the Control site where the same number of species was observed in both years (Appendix 3). A considerably higher number of fishes were quantified at the Pipeline (234) as compared to the Control site (63). This pattern was also observed with the number of species recorded at the Pipeline (23) and the Control (10) sites. An ordination analysis suggests that T2 and the Control sites are most similar to one another based on number of fish species, numerical abundance and biomass densities. These sites had fewer fish of smaller size than recorded at the other two sites. T3 is similar to these two sites in number of fishes although biomass was considerably higher due to many large acanthurids. The number of species found at T3 was also slightly higher than at T2 and the Control site. The Pipeline is clearly separated in ordination space from the other three sites. This is due to the large differences in all fish community factors included in the Principal Components Analysis (numerical abundance, biomass, and richness). As in previous years, fish factors were considerably higher at the Pipeline. No evidence of negative impacts to fish populations due to the Pipeline or effluent was found.

Introduction

The Chevron monitoring program at Barbers Point, Oʻahu, was initiated in 1982 to comply with the requirements of a Zone of Mixing Permit issued by the Hawaiʻi State Department of Health. Censuses of corals on the pipeline saddle, micromollusks from sediments near the discharge pipe, and fishes in the vicinity of the pipeline have been conducted yearly with the exception of an 18-month (1983-1984) and 16-month (1999-2000) hiatus. In 1996 the zone of mixing was expanded, and two additional sites within the zone and an outside control site were added to the surveys (Figure 1). We report here measured parameters of coral growth and population dynamics for pipeline saddle-top populations, and micromollusk and fish counts for all surveyed sites for the year 2009.

Pipeline

The pipeline (T1, Figure 1) carrying the effluent discharge extends a distance of 364 m (1200 ft) from the shore to a depth of 7 m (23 ft). The discharge consists of process effluent and cooling water with temperatures 3° to 4° above ambient, and DO and pH slightly different from ambient (Kay and Smalley 1982). The discharge is rapidly diffused, and the receiving water falls well within ambient limits within a few seconds of discharge (Kay 1981).

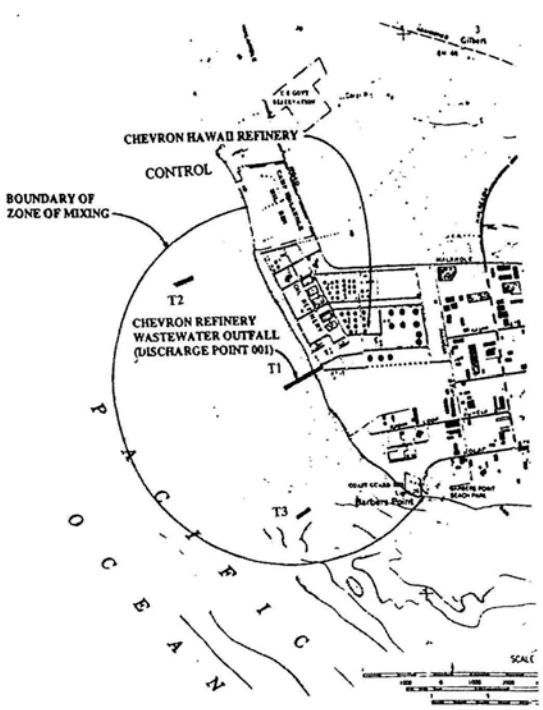

Figure 1: Biological monitoring sitess for the Chevron Refinery wastewater outfall.

The pipeline sits on a topographically homogeneous limestone shelf which experiences continuous surge, varying in intensity relative to surf conditions, and a long-shore current that frequently changes speed and direction. The shelf is subject to continual sand abrasion and the water to relatively high turbidity, with visibility typically from 1.5-6 m due to the sediment load in the water column.

The diffuser is anchored by eight large concrete saddles (approximately 1.5 m x 1.5 m x 1.5 m) though which the pipeline passes. The seaward-most saddle is in 7 m (23 ft) of water, and the other saddles are in progressively shallower water as the pipe approaches shore. Approximately 50 m shoreward of the end of the diffuser several bags of concrete (ca 75 lb) have been dumped under and around the pipe. The pipe, saddles, and concrete bags significantly increase the structural complexity of an otherwise two-dimensional habitat.

The macrobiota reflects the physical conditions of the environment. The limestone shelf is interrupted by pockets and crevices, some with sand, and is covered by a sparse algal turf. Scattered encrusting *Porites* and *Montipora* corals are present, along with low-level branching colonies of *Pocillopora meandrina*. Corals are present on the pipeline itself, with the dominant species being *P. meandrina*. Other obvious components of the biota are several species of fish and sea urchins (*Echinometra*) that are found around the pipeline.

Experimental Sites

In 1996, two additional experimental sites (T2 and T3, Figure 1) within an expanded zone of mixing (ZID) were designated. Location, proximity and greatest similarity to the pipeline in terms of topographic relief and macrobiota were the basis for the selection (Kay et al. 1996). T2 is approximately 600 m northwest of the pipeline and roughly 250 m southeast of the Barbers Point Harbor. It consists of approximately 40-70% living coral cover in the form of large colonies of *Porites lobata* (and some *P. evermanni*) along with *P. compressa* and various *Montipora* spp. Massive three-dimensional colonies and accretions provide complex habitat for fish that is reasonably comparable to the saddle structures of the diffuser pipeline, given the limitations of habitat within the ZID.

The second site, T3, is approximately 600 m south of the diffuser pipeline in 9-11 m of water and consists of fractured and contoured limestone shelf with an abrupt 2 m drop and gradual rise, and several large apparently carbonate boulders. Coral cover, although estimated at less than 20%, is greater than that found in the inshore area surrounding the pipeline. *P. lobata* (included server large heads) and *P. meandrina* are the most common species. Numerous encrusting corals, including *Montipora patula*, *M. flabellata*, *M capitata* and *Pavona varians*, are also present. The area appears impacted by occasional heavy swell that may serve to limit expansion of coral cover and upright growth of all but the *P. meandrina* and *P. lobata* heads.

Control Site

A control site (Figure 1), outside the ZID, was also established in 1996. The site is approximately 600-700 m north of the Barbers Point Harbor entrance and 400-500 m south of the Ko‘Olina Resort, at a fairly consistent depth of about 8 m. The bench is topographically complex, with numerous caves, crevices, and an apparent spur and groove network. The grooves are estimated to be 2-4 m wide, with an abruptly vertical northernmost wall approaching 3 m in height and a southernmost wall sloping more gradually to the bench above. Each groove contains scattered sand deposits. Live coral cover in the area is estimated to be less than 10%. Dominant species include *P. meandrina* and *P. lobata* (including both encrusting and large heads). Other scleractinians include *P. varians*, *M. capitata*, *M. flabellata* and *Cyphastrea ocellina* (all encrusting).

Methods

Transects

The permanent monitoring locations (Pipeline [T1], T2, T3 and Control) were relocated using GPS and surveyed on 26 August 2009. Fish surveys and sediment collections occurred along a 50 m transect laid perpendicular to shore at T2, T3 and the Control site. The pipeline between and including the 4 outermost (makai) saddles served as the permanent transect for surveys of coral and fish and sediment sampling at T1.

Corals

Length (the longest curved dimensions of live coral colony skeleton structure in a direction perpendicular to the pipeline) and width (longest curved width of live coral colony skeletal structure in a direction parallel to the pipeline) measurements were made using a flexible measuring tape on colonies of *P. meandrina* on the tops of the 4 outermost saddles of the diffuser pipeline. These included previously measured colonies and new colonies to replace those suffering from high levels of partial or total mortality. Coral recruits and the position of all live and dead colonies on each saddle-top were mapped.

Micromollusks

Micromollusks (mollusks with shells less than 10 mm in greatest dimension) were sorted from sediments collected from sand-accumulations within 3 m of each of the four saddles on limestone bench adjacent to the Pipeline. Sediments were also collected within 3 m of the 0, 17, 34 and 50 m marks on the transect lines at T2, T3, and Control sites. The sediments were put through two 95% alcohol washes, air dried, and only fresh shells were removed from aliquots of 25 ml by sorting under a dissecting microscope. The shells were identified to the lowest taxonomic level possible using Kay (1979). The shells were counted and counts were analyzed for abundance, habitat and trophic information (Kay 1979, Beesley et al. 1998).

Fish

Visual fish transects were conducted on 26 August 09 at the four sites previously established. For each transect, fishes were counted within 2 m on either side of a 50 m transect line. At the pipeline site, this included the areas under the pipeline and within the concrete stanchions.

Results

Corals

A map of the colonies measured in August 2009 and summary data are shown in Appendix 1. Mortality of colonies occurred primarily on saddles 1 and 4, but was on average low (20%). There has been continued mortality to colonies on the tops of these saddles over time, which is probably attributable to the determinate growth of *P. meandrina*. Growth rates, calculated in 2009, are similar to past recorded growth rates (average 101 cm^2, standard error 27.1 cm^2, n = 14). They are slightly lower as the new colonies added in 2008 were flat colonies that had not begun to grow in an upright, branching pattern. Nine additional colonies, mostly on the sides of the saddles, were measured for additional growth measurements.

Micromollusks

The micromollusks in the Chevron biomonitoring samples for 2009 were representative of various habitats and trophic structure (Kay, 1979; Beesley et al., 1998). A total of 4,244 micromollusks belonging to 139 mollusk taxa were counted (Appendix 2). For all sites, gastropods made up 93.8% of the total number of specimens, while bivalves (6.0%) and Polyplacophora (0.2%) made up the remainder. The high value of the ratio of gastropods to bivalves has been reported to be a result of the lack of expanses of nutrient-rich, silty-sand ocean substrata (Kay 1967). The dominant taxa in 2009 belonged to the families Rissoidae (1446) and Cerithiidae (540). *Rissoina cerithiiformis* (833) was the dominant species, followed by *Tricolia variabilis* (438).

The overall abundance in 2009 was 4,244 micromollusks. The highest abundance of micromollusks in 2009 was at T2 (2,229), followed by T3 (1,214), Pipeline (T1)(515), and Control (286) [Figure 1, Appendix 2].

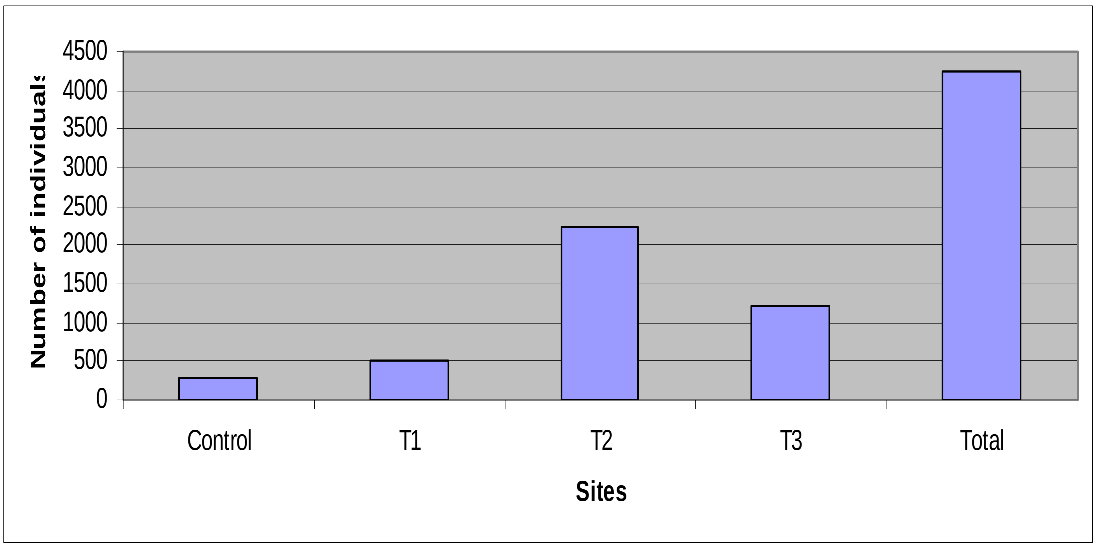

Figure 1: Abundance of all micromollusks at the 4 sites in 2009.

The total abundance for 2009 (4,244) was similar to abundances in 2002 (3,266), 2003 (4,763), 2004 (4,772), 2005 (5,781), 2006 (4,798), 2007 (4,589) and 2008 (4,377). In 2005, there was an increase in abundance at the Control site. In 2006, the abundance at the Control site exhibited a major decrease, and then in 2007, the abundance returned to the ranges observed between the years 2002-2005 and continued in this range in 2008 and 2009 [Figure 2].

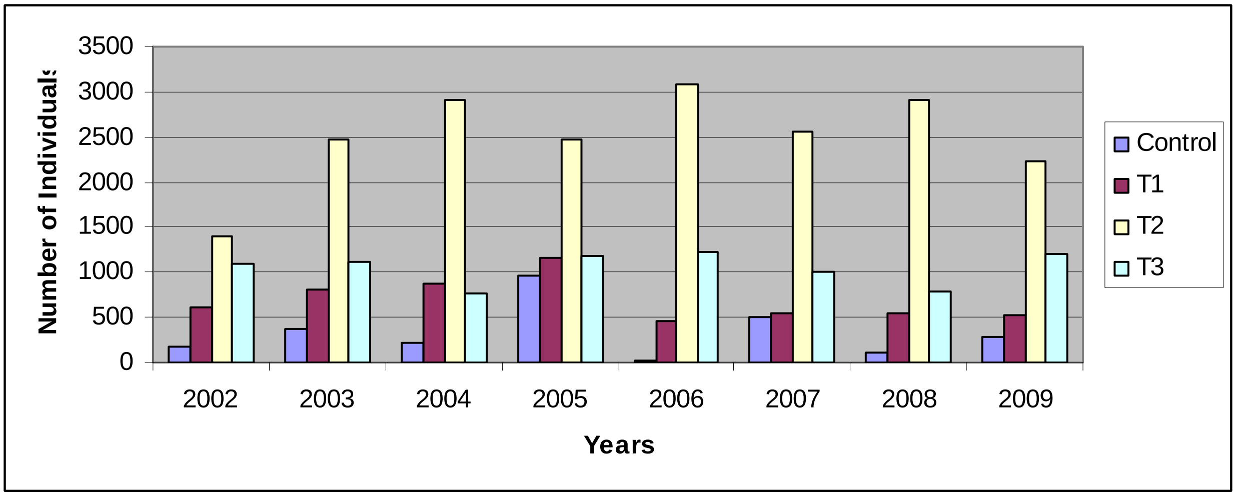

Figure 2: Abundance of all micromollusks at the 4 sites over 2002-2009.

The distribution of micromollusks for 2009 among sites [Figure 3] was similar to the pattern seen in previous years. Abundance and species composition are given in Appendix 2.

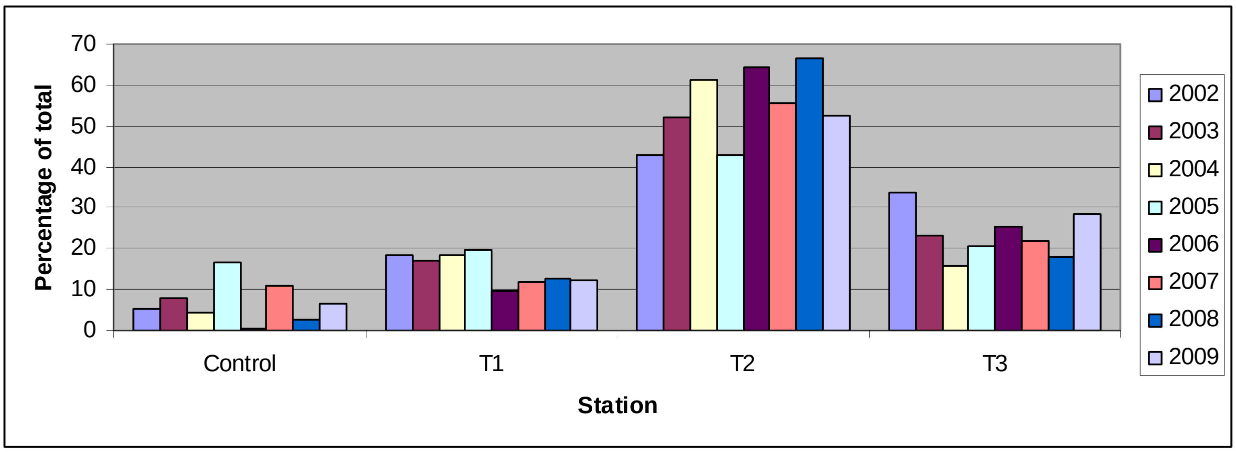

Figure 3: Distribution of micromollusks at the 4 sites over the years 2002-2009 (percentage of total samples).

There were 139 taxa in 2009 [Figure 4], which was slightly lower than the numbers of taxa in 2003 (171), 2004 (151), and 2005 (156), but similar to 2002 (144), 2006 (130), 2007 (144), and 2008 (135). There were noticeable decreases in the number of taxa in the 2006 Control site data and the data from 2007 at site T3, but the total numbers were within the range of 130 to 171 taxa [Figure 5].

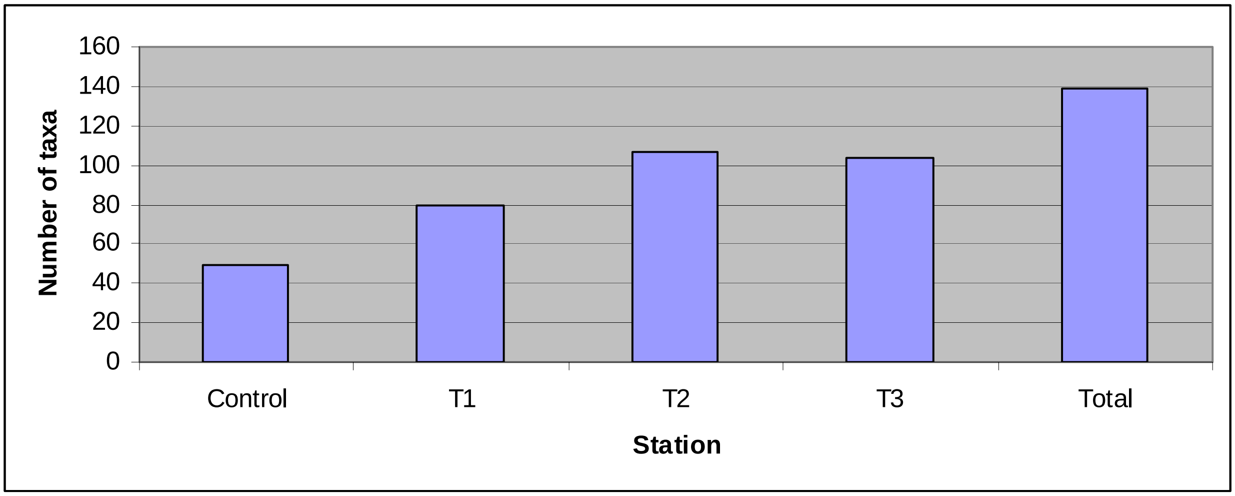

Figure 4: Number of taxa at the 4 sites in 2009.

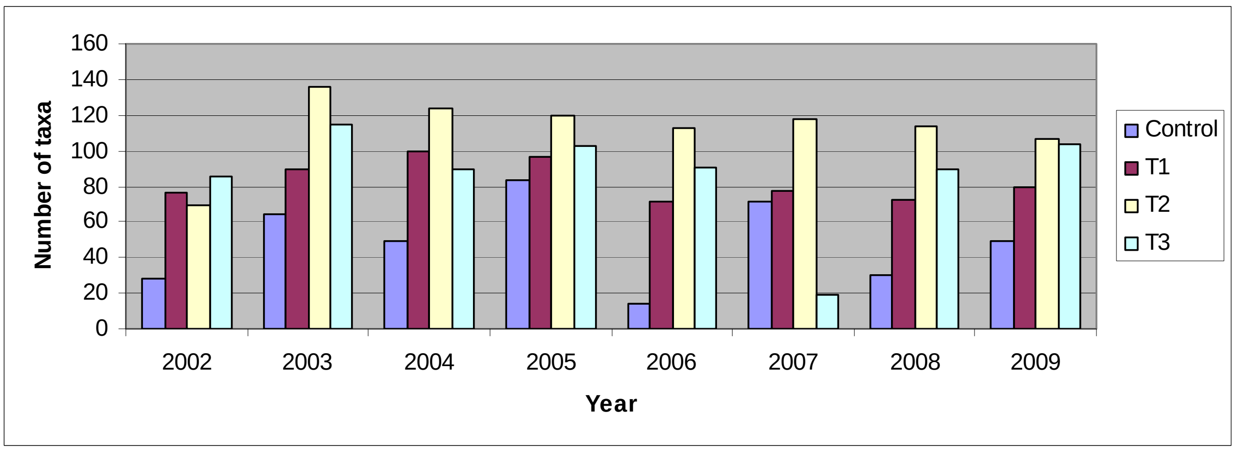

Figure 5: Number of taxa at the 4 sites over the years 2002-2009.

For all taxa present at the 4 sites in 2009, epifaunal species (i.e. species associated with rocks, gravel, or other hard substrates) made up 88.3% of the total. Epifaunal species comprise 93.0% of micromollusk individuals observed at the Control site, 89.8% at T2, 85.6 % at Pipeline (T1), and 85.6% at T3. Infaunal species (i.e. those that burrow or live in bottom deposits of the ocean) comprise 5.7% of the micromollusk individuals, parasitic species 4.2%, commensal species 1.5%, and unknown 0.3% micromollusks comprise the habitat types at all sites in 2009 [Figure 6].

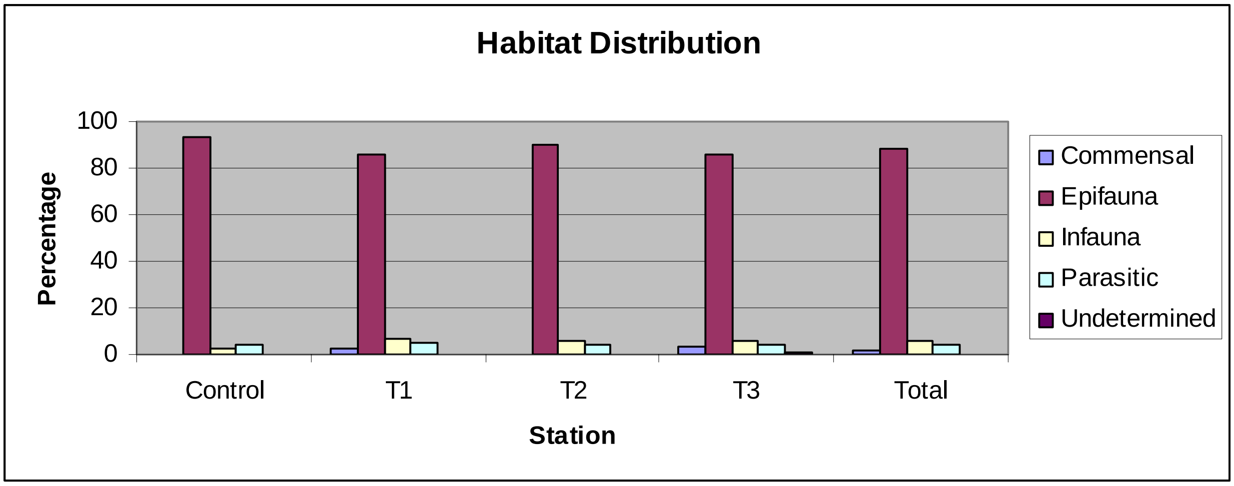

Figure 6: Habitat distribution at the 4 sites in 2009.

At the Control site, for all taxa enumerated detritivores were most common (50.7% of all individuals), followed by herbivores (25.2%), filter feeders (14.4%), parasitic mollusks (5.8%), carnivores (3.7%), and unknown (0.2%). At Pipeline (T1), herbivores (46.7%) were followed by detritivores (35.4%), carnivores (8.9%), filter feeders (4.6%), parasitic mollusks (4.3%) and unknown (0.1%). At the T2 site, detritivores (45.4%) were more abundant than herbivores (31.3%). They were followed by filter feeders (14.3%), parasitic mollusks (4.4%), carnivores (3.9%), and unknown (0.7%). Finally at the T3 site, detritivores (65.7%) were followed by filter feeders (14.7%), herbivores (12.6%), parasitic mollusks (3.8%), carnivores (2.8%) and unknown (0.3%) [Figure 7].

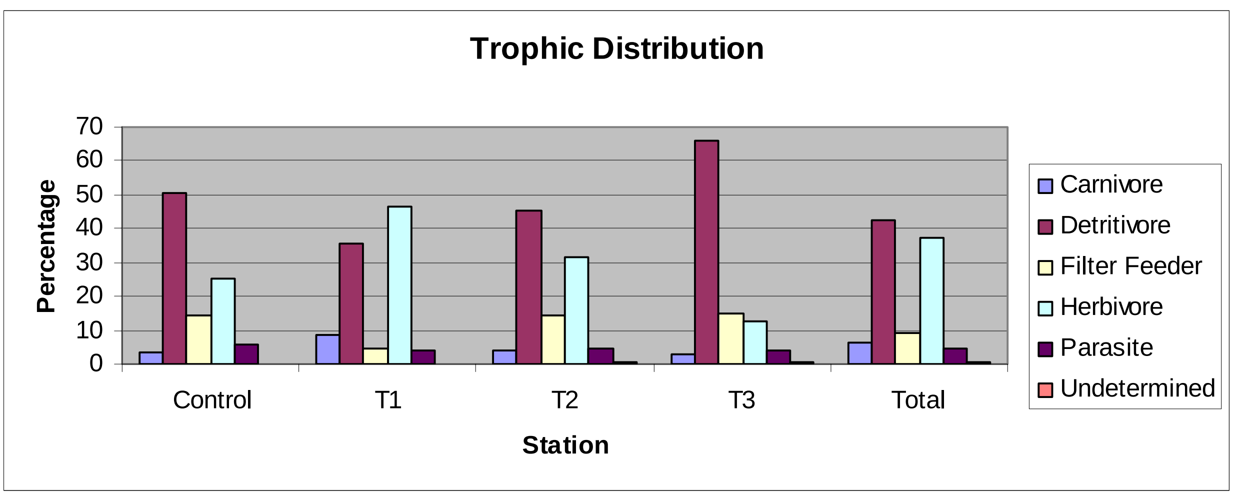

Figure 7: Trophic distribution of micromollusks for all 4 sites in 2009.

In the 2009 samples, herbivores (45.6%) made up a major portion of the epifauna: Pipeline (T1)(31.3%), T2 (51.3%), T3 (36.5%), and Control (26.2%). For the epifauna, herbivores were closely followed by detritivores (42.3%), carnivores (7.0%), filter feeders (4.9%), and parasites (0.1%) [Figure 8].

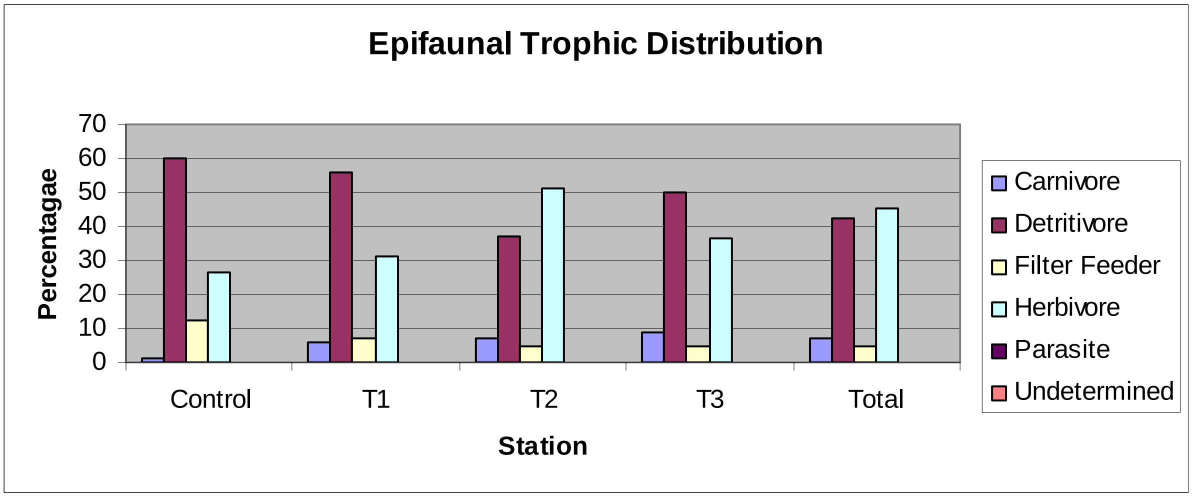

Figure 8: Epifaunal trophic types at the 4 sites in 2009.

Individuals in the family Rissoidae (1,446) which feed on diatoms and algal filaments were the most abundant type present: Pipeline (T1) (98), T2 (984), T3 (285), and Control (79). The rissoid, *Rissoina cerithiiformis* (833), was the most abundant species present: Pipeline (T1)(28), T2 (685), T3 (107), and Control (13). The herbivore, *Tricolia variabilis* (438), was the third most abundant: Pipeline (T)(194), T2 (163), T3 (9), and Control (72). The sponge feeding triphorids were most abundant at Pipeline (T1)(87), followed by T2 (17), Control (5), and T3 (2). Pyramidellids and infaunal bivalves, indicative of enriched conditions, were present in low percentages – pyramidellids: Pipeline (T1) (4.9%), T2 (3.4%), T3 (3.7%), Control (3.8%); infaunal bivalves: Pipeline (T1)(3.7%), T2 (1.1%), T3 (2.6%), Control (0.7%). No *Finella pupoides*, characteristic of anaerobic conditions was recorded for this study. Bivalves in the family Lucinidae, indicative of anoxic conditions (i.e. low nutrients and often high sulphide content environments, Reid & Slack-Smith, 1998), were present at low percentages: Control (1.0%), Pipeline (T1)(0.4%), and T2 (0.1%). No lucinid bivalves were recorded for T3 [Figure 9].

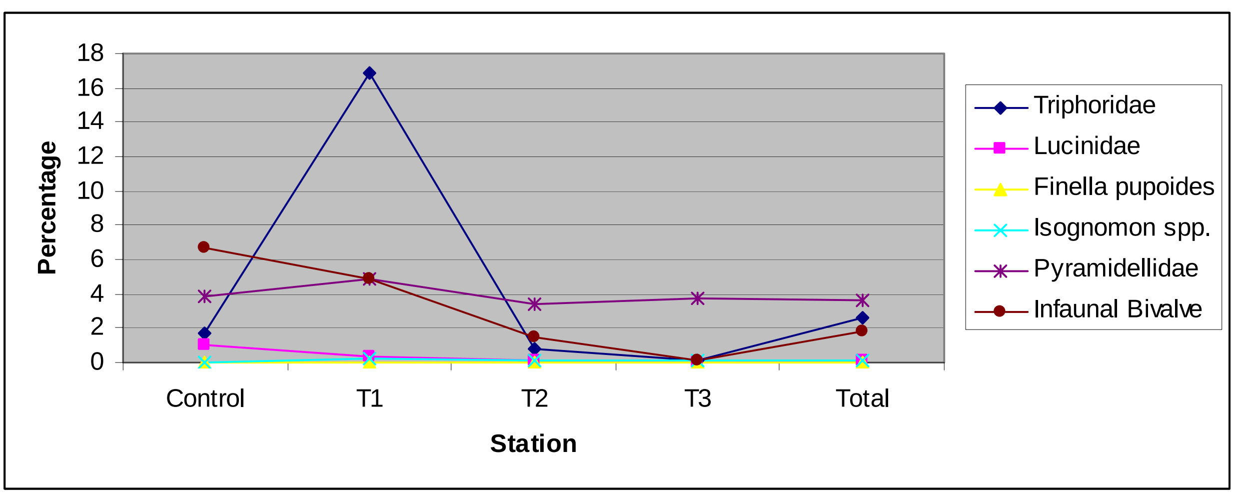

Figure 9: Indicator species at the 4 sites for 2009.

The classic model of pollution or deleterious effects of land-based outfalls predicts a decline in species richness at the impact site and/or an increase in abundance of pollution tolerant organisms. The Pipeline (T1) site has a species richness value of 79, which is higher than the Control (49**).** No individuals of *Finella pupoides*, a species characteristic of anaerobic conditions, were recorded in this study**.** Pyramidellids and infaunal bivalves, indicative of enriched conditions, were recorded but at very low percentages. Mollusk species in the genus *Planaxis*, characteristic of lowered salinity, were not present. Four juvenile shells in the genus *Isognomon*, also characteristic of lowered salinity conditions, were present at sites Pipeline (T1, 1 individual), T2 (2), and T3 (1), with none present at the Control site. Lucinid bivalves, indicative of anoxic conditions, were present at very low percentages at 3 sites: Control (1.0%), Pipeline (T1)(0.4%) and T2 (0.1%). None were recorded at the T3 site.

Fish

Numbers of individual species are shown in Appendix 3. Total numbers of individual fishes were higher in 2009 (399) when compared to previously measured transects in 2008 (247). Fish numerical abundances in 2009 were not statistically different from the prior 12 years of census data at any of the four sites (Single Specimen Compared to a Sample, $P > 0.05$, Table 1). Species richness average across sites was lower than the average for the previous 11 years (16 versus 21.3 across all sites; Appendix 3, Table 1). This may be due to high variability. However, species richness was not significantly different from previous surveys.

Table 1: Comparison of 2009 data with earlier data.
Total number of individuals:

date	Pipeline	T3	T2	Control
Aug 96	369	229	246	134
Aug 97	386	174	209	126
Aug 98	364	82	134	86
Sep 99	274	143	81	290
Apr 01	197	121	97	113
Apr 02	344	228	172	128
Average – Mohlmann data	322	163	156	146
Aug 03	142	56	116	87
Nov 04	202	201	131	94
Aug 05	170	175	129	71
Aug 06	184	105	111	73
July 07	168	19	64	63
Aug 08	53	32	95	67
Aug 09	**234**	**50**	**52**	**63**

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Aug 96	369	229	246	134
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Nov 04	202	201	131	94
Aug 05	170	175	129	71
Aug 06	184	105	111	73
July 07	168	19	64	63
Aug 08	53	32	95	67
Aug 09	**23**	**17**	**14**	**10**

As in all previous years since 1996 except for 2008, there were a considerably higher number of fishes at the Pipeline than at the Control site. The 2008 anomaly was due to poor visibility at the Pipeline. Species richness also followed the same trend in 2009, with a larger number of fish species recorded at the Pipeline than at the Control site in all previous years since 1996 with the exception of 2004. Fish biomass at the Pipeline (46.98 Kg) and at T3 (34.30 Kg) was higher than at the Control site (6.62 Kg) and at T2 (4.00 Kg). The arrangement of the four sites in multi-dimensional space for the 2009 survey show a clustering of T2 and the Control sites based on species richness, numerical abundances and biomass densities combined (Figure 10). As in the majority of previous years, the Pipeline site is remote in ordination space from the other three sites due to high fish numbers, biomass, and species quantified.

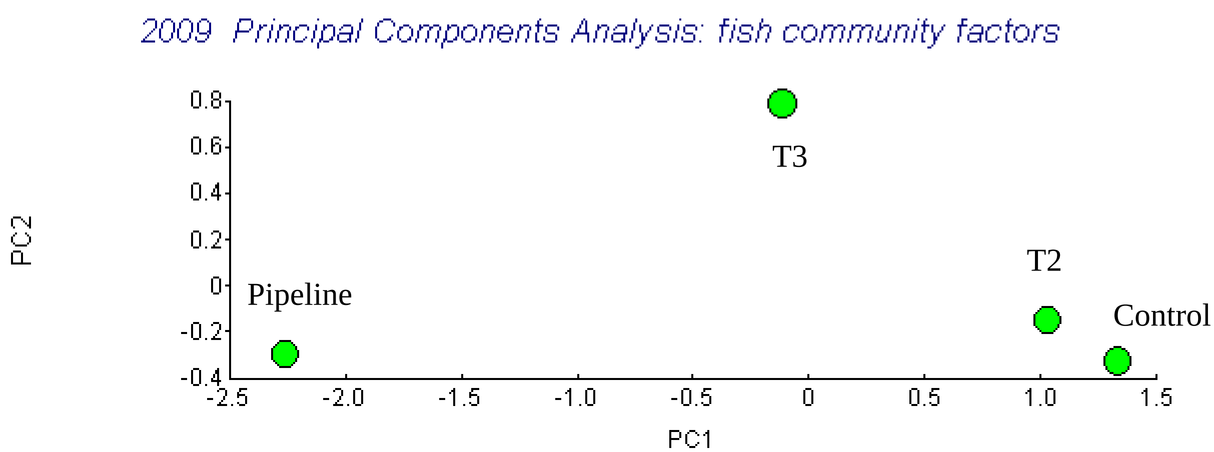

Figure 10: Multivariate ordination of fish assemblage characteristics for 4 sites.

Fifteen species counted during 2009 were not seen on previous 2008 transects. This was most likely due to the poor visibility at the pipeline in 2008. Five species that were recorded in 2008 were not seen in 2009. All of the fish species recorded (36) are either endemic or indigenous. No introduced species were recorded in 2009. Unusual species not usually recorded on transects included *Caranx ignobilis*, the giant trevally, seen at the Pipeline site.

Total numbers of individuals and number of species were higher than the previous survey in 2008 at the Pipeline due to poor visibility in 2008. The Pipeline site had considerably higher number of individuals and species as compared to all other sites. Numbers of individuals were slightly higher in 2009 at T3 and lower at T2 and the Control site as compared to numbers in 2008. Number of species of fishes observed was higher at all sites in 2009 as compared to 2008 except at the Control site where it remained constant.

Higher topographic relief is positively correlated with these fish community characteristics. The pipeline and stanchions and sites with large coral colonies provide additional substrate for fishes. Fishes are normally concentrated around and within the stanchions providing protection, shelter, and food. Prior research has recognized the importance of topographic relief in the structure of fish assemblages throughout the world and in Hawaiʻi. It is evident that fish populations are highly associated with spatial relief for several reasons.

- Increased substrate provides habitat for benthic invertebrates, which serve as the main diet of many species of fishes, which in turn are utilized at other trophic levels.
- Increase in coral cover associated with rugosity feed obligate corallivores.
- Spatial complexity increases habitat heterogeneity, providing increased areas of refuge for fish populations from predation and competition.
- Topographical relief can expand the availability of resources and their production rate.
- Increased relief results in higher heterogeneity, creating habitat complexity that increases fish diversity.

Fish populations are highly variable, requiring numerous transects to quantify absolute values of fish communities. A large sample size is necessary due to the high variability among fish assemblages. Many rare, cryptic or mobile species can be under reported and the power to accurately detect absolute fish abundances can be extremely low. Although fish populations vary considerably both spatially and temporally, relative comparisons can be made between sites with few transects over time. This dataset currently includes 13 years of fish data increasing the statistical power to detect differences when present.

Discussion

Corals

The continuing decline in the coral population on the saddles reflects the age of the colonies on these saddles. Many of these colonies are close to the maximum size of colonies of *Pocillopora meandrina* (Grigg and Maragos 1974, Kolinski and Cox, personal observations). Although there was no recruitment to the saddles during 2008 to 2009, recruitment of corals in Hawaiʻi is highly variable in both time and space (Kolinski 2004, Coles and Brown 2007, Brown and Friedlander 2008, Basch et al. 2008). Coles and Brown (2007) followed coral coverage around the Kahe Power Plant (to the west of this study area) over a long time span and reported that irregular recruitment had the greatest impact on recovery of coral coverage following hurricanes.

Remaining colonies on these saddles are showing fairly consistent rates of growth, indicating that this environment is suitable for growth.

Micromollusks

Several indicators - the high species richness value at the impact site Pipeline (T1), no individuals of the species of *Finella pupoides* (indicative of nutrient rich conditions), the very low abundances of species indicative of anoxic conditions, and the high ratio of gastropods to bivalves - strongly suggest that effluent released at the Pipeline (T1) is not negatively impacting or shifting micromollusk communities in the region. High species numbers and abundances at T2, T3 and Pipeline (T1), in comparison to the Control populations, also support this conclusion.

The classic model of pollution or deleterious effects of land-based outfalls predicts a decline in species richness at the impact site and/or an increase in abundance of pollution tolerant organisms. The Pipeline (T1) has a species richness value of 79, which is higher than the Control (49**).** *Finella pupoides,* a species characteristic of anaerobic conditions, was not recorded in this study**.** Pyramidellids and infaunal bivalves, indicative of enriched conditions, were recorded but at very low percentages. Mollusk species in the genus *Planaxis*, characteristic of lowered salinity, were not present. Four juvenile shells in the genus *Isognomon*, also characteristic of lowered salinity conditions, were present at the Pipeline (T1), T2 and T3 sites, with none present at the Control site. Lucinid bivalves, indicative of anoxic conditions, were present at 3 of the 4 sites; Control, Pipeline (T1), and T2; but at very low percentages. None were recorded at T3.

Fish

Total numbers of fishes, biomass, and species varied, but did not differ statistically from estimates made over the past 12 years. Variation in numbers can be attributed to differences in visibility and natural fluctuations that are typically observed in temporally spaced censuses of highly mobile reef organisms. Species richness and fish numerical and biomass abundance at the Pipeline were much higher than at the Control site. The results of this survey do not indicate that the Pipeline or effluent negatively impact fish populations (as measured) within the zone of mixing (ZID).

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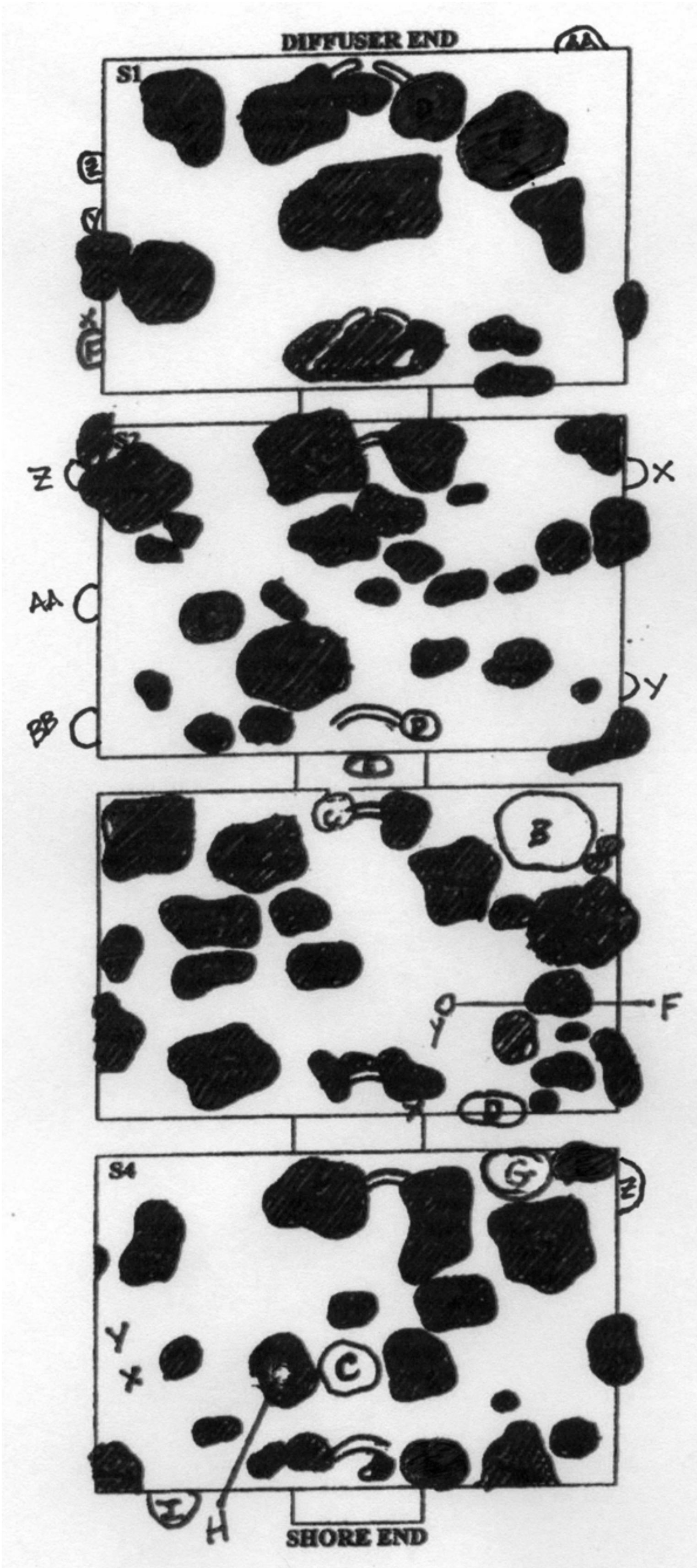

Saddle 1

F 12 x 7	growth 16 cm^2
X 3.5	growth 6.5 cm^2
new	
Y 4.5 x 3.5	
Z 7 x 7.5	
AA 43 x 48	

Saddle 2

C 32 x 26	growth 187 cm^2
D 125 x 15	growth 70 cm^2
new	
X 7.5 x 7.0	
Y 5.0 x 4.0	
Z 18 x 29	
AA 20 x 17	
BB 16 x 12	

Saddle 3

B 58 x 58	growth 46 cm^2
C 27 x 26	growth 287 cm^2
D 54 x 33	growth 78 cm^2
F 14 x 11	growth 83 cm^2
X 6	growth 16 cm^2
Y 4	growth 9.4 cm^2

Saddle 4

C 32 x 35	growth 50 cm^2
G 42 x 47	growth 198 cm^2
H 16 x 19	growth 104 cm^2
I 41 x 39	growth 268 cm^2
X 5	growth 15 cm^2
Y 5	growth 15 cm^2
new	
Z 34 x 34	

Appendix 2: micromollusk abundance data								
Family	Species	Habit	Trophic	Control	Pipeline (T1)	T2	T3	Total
	BIVALVIA							
Arcidae	*Barbatia divaricata*	Epifaunal	Filter		10	7	9	26
Arcidae	*Barbatia nuttingi*	Epifaunal	Filter	3	11	21	22	57
Condylocardiidae	*Carditella hawaiensis*	Infaunal	Filter		1		1	2
Propeamusiidae	*Chlamydella* sp. A	Epifaunal	Filter				3	3
Philobryidae	*Cosa waikikia*	Epifaunal	Filter			1		1
Mytilidae	*Crenella* spp.	Epifaunal	Filter				6	6
Lucinidae	*Ctena bella*	Infaunal	Symbiotic/ Filter		3		1	4
Lucinidae	*Epicodakia* spp.	Infaunal	Filter			2	1	3
Cardiidae	*Fragum mundum*	Infaunal	Filter		6	7	4	17
Hiatellidae	*Hiatella arctica*	Infaunal	UNDETER				1	1
Isognomonidae	*Isognomon* spp.	Epifaunal	Filter		1	2	1	4
Galeommatidae	*Kellia hawaiensis*	Commensal	Filter		14	2	44	60
Galeommatidae	Galeommatidae spp.	Commensal	Commensal	1			1	2
Nuculidae	*Nucula hawaiensis*	Infaunal	Filter	1	2	6	7	16
Ostreidae	Ostreidae spp.	Epifaunal	Filter	1	1	7	4	13
Mesodesmatidae	*Rochefortina sandwichensis*	Infaunal	Filter	1	4	2	13	20
Semelidae	*Semelangulus crebrimaculatus*	Infaunal	Detritus				1	1
Mytilidae	*Septifer bryanae*	Infaunal	Filter		3	8	3	14
Bivalvia	Bivalvia spp.	UNDETER	UNDETER				3	3
	GASTROPODA							
Scaphandridae	*Acteocina hawaiensis*	Infaunal	Carnivore				1	1
Scaphandridae	*Acteocina sandwicensis*	Epifaunal	Herbivore			1		1
Trochidae	*Alcyna ocellata*	Epifaunal	Detritus	4	3	39	10	56
Trochidae	*Alcyna subangulata*	Epifaunal	Detritus	5	6	2	5	18
Rissoidae	*Alvania isolata*	Epifaunal	Detritus	1	3		9	13
Hipponicidae	*Antisabia foliacea*	Epifaunal	Filter	25	8	16	27	76
Muricidae	*Aspella producta*				1			1
Atyididae	*Atys semistriata*	Infaunal	Herbivore			2		2
Eulimidae	*Balcis brunnimaculata*	Parasitic	Parasitic			1	3	4
Eulimidae	*Balcis* spp.	Parasitic	Parasitic		1	15	5	21
Barleeidae	*Barleeia labiosa*	Epifaunal	Detritus	2	4	8	1	15
Barleeidae	*Barleeia* spp.	Epifaunal	Detritus		2			2
Cerithiidae	*Bittium impendens*	Epifaunal	Detritus	1	6	80	8	95
Bullidae	*Bulla vernicosa*	Infaunal	Herbivore			1		1
Caecidae	*Caecum arcuatum*	Infaunal	Detritus		6	43	16	65
Turridae	*Carinapex minutissima*	Infaunal	Carnivore			1	2	3
Turridae	*Carinapex papillosa*	Epifaunal	Carnivore		7	68	20	95
Cephalaspidea	*Cephalaspidea* spp.	Epifaunal	Carnivore			1		1
Dialidae	*Cerithidium diplax*	Infaunal	Detritus			2	1	3
Dialidae	*Cerithidium perparvulum*	Epifaunal	Detritus		3	45	9	57
Cerithiopsidae	*Cerithiopsis* spp.	Epifaunal	Carnivore	5	2	14	3	24
Cerithiidae	*Cerithium atromarginatum*	Epifaunal	Detritus	1				1
Cerithiidae	*Cerithium columna*	Epifaunal	Detritus			8		8
Cerithiidae	*Cerithium egenum*	Epifaunal	Detritus			15		15
Cerithiidae	*Cerithium interstriatum*	Epifaunal	Detritus			23	2	25
Cerithiidae	*Cerithium nesioticum*	Infaunal	Detritus	5	8	37	14	64
Cerithiidae	*Cerithium rostratum*	Infaunal	Detritus			1		1
Cerithiidae	*Cerithium zebrum*	Epifaunal	Detritus	19	37	52	37	145
Cerithiidae	*Cerithium* spp.	Epifaunal	Detritus		6		12	18
Turridae	*Clavus mighelsi*	Epifaunal	Carnivore			4		4
Turbinidae	*Collonista candida*	Epifaunal	Forage	8	5	7	19	39
Conidae	*Conus* spp.	Epifaunal	Carnivore				1	1
Calyptraeidae	*Crepidula aculeata*	Epifaunal	Filter			1		1
Skeneidae	*Cyclostremiscus emeryi*	Epifaunal	Detritus		7	15	28	50
Vermetidae	*Dendropoma* spp.	Epifaunal	Filter	10	8	13	22	53
Dialidae	*Diala semistriata*	Epifaunal	Detritus		3	8	3	14
Aytididae	*Diniatys dentifer*	Infaunal	Herbivore			1		1
Fissurellidae	*Diodora granifera*	Epifaunal	Herbivore	1	1	2	3	7
Triviidae	*Erato sandwicensis*	Epifaunal	Carnivore				1	1
Turridae	*Etrema acricula*	Epifaunal	Carnivore			1		1
Trochidae	*Euchelus* spp.	Epifaunal	Herbivore	1	5	3	10	19
Pyramidellidae	*Evalea peasei*	Epifaunal	Detritus				3	3
Trochidae	*Gibbula marmorea*	Epifaunal	Herbivore	1		10	5	16
Marginellidae	*Granula sandwicensis*	Epifaunal	Forage	6	5	5	9	25
Marginellidae	*Granulina vitrea*	Epifaunal	Forage			1	1	2

Architectonicidae	*Heliacus implexus*	Epifaunal	Carnivore			3		3
Pyramidellidae	*Herviera gliriella*	Parasitic	Parasitic	1	7	39	9	56
Pyramidellidae	*Herviera patricia*	Parasitic	Parasitic			4	2	6
Pyramidellidae	*Hinemoa indica*	Parasitic	Parasitic			1		1
Hipponicidae	*Hipponix australis*	Epifaunal	Detritus			3	1	4
Hipponicidae	*Hipponix pilosus*	Epifaunal	Filter		5	1	2	8
Cerithiidae	*Ittibittium parcum*	Epifaunal	Detritus	7	27	68	66	168
Juliidae	*Julia exquisita*	Epifaunal	Herbivore		1	5	8	14
Turridae	*Kermia aniani*	Epifaunal	Carnivore		1	3	1	5
Turridae	*Kermia pumila*	Epifaunal	Carnivore		1	1		2
Turbinidae	*Leptothyra rubricincta*	Epifaunal	Detritus	52	12	4	29	97
Turbinidae	*Leptothyra verruca*	Epifaunal	Detritus	8	26	38	34	106
Turridae	*Lienardia mighelsi*	Epifaunal	Carnivore			2		2
Skeneidae	*Lophocochlias minutissimus*	Epifaunal	Detritus	1	9	35	23	68
Skeneidae	*Lophocochlias* sp. A	Epifaunal	Detritus		14	22	41	77
Rissoidae	*Merelina granulosa*	Epifaunal	Detritus		1		2	3
Rissoidae	*Merelina hewa*	Epifaunal	Detritus	3	2	75	14	94
Rissoidae	*Merelina wanawana*	Epifaunal	Detritus	1	2	14	23	40
Pyramidellidae	*Miralda paulbartschi*	Parasitic	Parasitic		3	6	8	17
Pyramidellidae	*Miralda scopulorum*	Parasitic	Parasitic	6	6	5	13	30
Columbellidae	*Mitrella* spp.	Epifaunal	Carnivore		1	2	1	4
Turridae	*Mitrolumna* spp.	Epifaunal	Detritus			1		1
Modulidae	*Modulus tectum*	Epifaunal	Detritus				1	1
Thaididae	*Morula* spp.	Epifaunal	Carnivore			2		2
Muricidae	Muricidae spp.	Epifaunal	Carnivore	1				1
Naticidae	Naticidae spp.	Infaunal	Carnivore			2		2
Pyramidellidae	*Odostomia gulicki*	Parasitic	Parasitic		1	2	1	4
Pyramidellidae	*Odostomia stearnsiella*	Parasitic	Parasitic	3	7	10	7	27
Pyramidellidae	*Odostomia* spp.	Parasitic	Parasitic	1	1	5	2	9
Orbitestellidae	*Orbitestella regina*	Epifaunal	Detritus	1	1	9	23	34
Orbitestellidae	*Orbitestella* spp.	Epifaunal	Detritus				1	1
Rissoidae	*Parashiela beetsi*	Epifaunal	Detritus		2	19	13	34
Littorinidae	*Peasiella tantilla*	Epifaunal	Herbivore/Detritus		1			1
Fasciolariidae	*Peristernia chlorostoma*	Epifaunal	Detritus	1	1		1	3
Rissoidae	*Pusillina marmorata*	Epifaunal	Herbivore		6	101	38	145
Pyramidellidae	Pyramidellidae spp.	Parasitic	Parasitic			2		2
Eulimidae	*Pyramidelloides gracilis*	Epifaunal	Parasitic		1	3	1	5
Eulimidae	*Pyramidelloides suta*	Epifaunal	Parasitic				1	1
Rissoellidae	*Rissoella* spp.	Epifaunal	Parasitic			1		1
Rissoidae	Rissoidae spp.	Epifaunal	Detritus				1	1
Rissoidae	*Rissoina ambigua*	Epifaunal	Detritus	1	28	28	25	82
Rissoidae	*Rissoina cerithiiformis*	Epifaunal	Herbivore	13	28	685	107	833
Rissoidae	*Rissoina costata*	Epifaunal	Detritus	14	12	13	20	59
Cingulopsidae	*Rufodardanula* spp.	Epifaunal	Detritus			3		3
Rissoidae	*Sansonia kenneyi*	Epifaunal	Filter			6	4	10
Scaliolidae	*Scaliola* spp.	Epifaunal	Detritus			1		1
Rissoidae	*Schwartziella ephamilla*	Epifaunal	Detritus			21	3	24
Rissoidae	*Schwartziella triticea*	Epifaunal	Detritus	27	12	18	22	79
Scissurellidae	*Scissurella pseudoequatoria*	Epifaunal	Detritus		1	3	9	13
Columbellidae	*Seminella peasei*	Epifaunal	Detritus		3	1	1	5
Columbellidae	*Seminella smithi*	Epifaunal	Detritus			4	2	6
Columbellidae	*Seminella* spp.	Epifaunal	Detritus	1				1
Scissurellidae	*Sinezona insignis*	Epifaunal	Herbivore		3	2	15	20
Siphonariidae	*Siphonaria normalis*	Epifaunal	Herbivore	1				1
Rissoidae	*Stosicia hiloense*	Epifaunal	Detritus	19	2	4	4	29
Caecidae	*Strebloceras subannulatum*	Infaunal	Herbivore				3	3
Dialidae	*Styliferina goniochila*	Infaunal	Detritus			15	1	16
Stomatellidae	*Synaptocochlea concinna*	Epifaunal	Herbivore	2	2	3	2	9
Costellariidae	*Thala* spp.	Infaunal	Carnivore			1		1
Phasianellidae	*Tricolia variabilis*	Epifaunal	Herbivore	9	72	194	163	438
Triphoridae	*Triphora* spp.	Epifaunal	Carnivore	2	5	87	17	111
Trochidae	*Trochus intextus*	Epifaunal	Herbivore		1	5	2	8
Turbinidae	*Turbo sandwicensis*	Epifaunal	Herbivore	1	5	8	10	24
Pyramidellidae	*Turbonilla cornelliana*	Parasitic	Parasitic			1		1
Turridae	Turridae spp.	Parasitic	Forage				2	2
Vanikoridae	*Vanikoro* spp.	Epifaunal	Detritus		2		1	3
Costellariidae	*Vexillum tusum*	Epifaunal	Carnivore			3		3
Costellariidae	*Vexillum* spp.	Epifaunal	Carnivore		1	2		3
Marginellidae	*Volvarina* spp.	Epifaunal	Carnivore			1		1

Siphonariidae	*Williamia radiata*	Epifaunal	Herbivore		1	6	2	9
Rissoinidae	*Zebina bidentata*	Epifaunal	Herbivore	3	1	10	2	16
Rissoinidae	*Zebina tridentata*	Epifaunal	Herbivore	3	1	2	2	8
Rissoinidae	*Zebina* spp.	Epifaunal	Herbivore				1	1
Gastropoda	Gastropoda sp. A	UNDETER	UNDETER	1	1	3	5	10
	POLYPLACOPHORA							
Polyplacophora	Polyplacophora spp.	Epifaunal	Herbivore	1	2		7	10
	Total No. of Individuals			286	515	2229	1214	4244
	Total No. of Individuals/cm3			2.86	5.15	22.29	12.14	10.61
	Total No. of Taxa			49	79	107	104	139

APPENDIX 3: Numbers of individuals by species at T-1 – T-3 and Control sites, 2009.

Species	Pipeline (T1)	T2	T3	Control
Acanthuridae				
A. blochii	4		4	
A. leucopareus	3		6	
A. nigrofuscus	43	4	1	25
A olivaceous	6		4	
A. triostegus	40		10	2
Ctenochaetus hawaiiensis			1	
C. strigosus		14		2
Zebrasoma flavescens		11		
Balistidae				
Melichthys niger			2	
M. vidua			1	
Rhinecanthus rectangulus	1		1	
Sufflamen bursa		2		
Carangidae				
Caranx ignobilis	2			
Chaetodontidae				
C. lunula	4		2	
C. miliaris	2			
Cirrhitidae				
Cirrites pinnulatus	1		1	
Labridae				
Gomphosus varius		1		2
Labroides phthirophagus	1			
Macropharyngodon geoffroy		1		
Stethojulis balteata		3	4	3
Thalassoma duperrey	21	9	8	18
T. purpureum		1		
Mullidae				
M. vanicolensis	22			
Parupeneus multifasciatus	1	1	1	
P. bifasciatus	2	1	1	3
P. cyclostomus	1			
Pomacentridae				
Abudefduf abdominalis	22			
Abudefduf vaigiensis	2			
Chromis hanui		2		
Chromis vanderbiliti	30			
Coris gaimard		1		
Plectroglyphidodon imparipenis	3		1	2
Stegastes fasciolatus				3
Scaridae				
Scarus juveniles	5			
Tetraodontidae				

Canthigaster jactator	7	1	2	3
Zanclidae				
Zanclus cornutus	1			
Total per site	224	52	50	63
Number of species	23	14	17	10