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SHORT-TERM ASSESSMENT OF AN OIL SPILL AT BAHIA LAS MINAS, PANAMA

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SHORT-TERM ASSESSMENT OF AN OIL SPILL AT BAHIA LAS MINAS, PANAMA

Contents

An Oil Spill Affecting Coral Reefs and Mangroves on the Caribbean Coast of Panama. John J. Cubit, Charles D. Getter, Jeremy B. C. Jackson, Stephen D. Garrity, Hugh M. Caffey, Ricardo C. Thompson, Ernesto Weil, Michael J. Marshall........................Page 1

Observations on Oiled Reefs. Ernesto Weil...............Page 7

Hydrocarbon Analysis Report. Kathy Burns................Page 20

The Effects of the Bahia Las Minas Oil Spill on Thalassia Meadow Communities. Michael J. Marshall........................Page 43

Mangrove Canopy and Seedling Survival at Different Forests Following a Major Oil Spill in Panama. Charles D. Getter...........Page 66

Effects of the April 1986 Oil Spill at Isla Payardi on Mangrove Root Communities. Stephen D. Garrity...................Page 93

Effects of May, 1986 Oil Spill on Gonodactylid Stomatopods Near Galeta Point. Roy Caldwell and Rick Steger.....................Page 113

Effects of the April 1986 Oil Spill on Intertidal Reef-Flat Gastropods. Stephen D. Garrity....................................Page 129

Oil Spill Project: Reef Flat Studies through December 1986. John D. Cubit..Page 151

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AN OIL SPILL AFFECTING CORAL REEFS AND MANGROVES ON THE CARIBBEAN COAST OF PANAMA

John D. Cubit, Charles D. Getter,[1]
Jeremy B. C. Jackson, Stephen D. Garrity,[2]
Hugh M. Caffey, Ricardo C. Thompson,
Ernesto Weil, Michael J. Marshall
Smithsonian Tropical Research Institute
Apartado 2072, Balboa, Republic of Panama

ABSTRACT: *In April 1986, more than 50,000 barrels of medium weight crude oil were spilled into the largest complex of coral reefs and mangroves on the central Caribbean coast of Panama. Considerable amounts of oil came ashore at Punta Galeta, where a long-term environmental sciences program of the Smithsonian Tropical Research Institute provided extensive baseline information for investigating the effects of the oil spill. Immediate mortality was most apparent for organisms living at the seaward edge of the reef flats and on drying substrata above mean water level. By June 1986, a number of reef species were reduced in abundance, and a bloom of microalgae grew over much of the reef flat that had been directly exposed to the oil at low tide. The abundances of some fast-growing algae appeared to have recovered by September 1986, but the slower-growing corals, zoanthids, and calcareous algae were at the lowest abundances recorded. Defoliation and mortality of mangroves, particularly* Rhizophora mangle, *was severe on windward coasts, and other areas where the oil penetrated into sediments around the mangrove roots. Oysters and other organisms living on mangrove roots also suffered severe mortality. The types of habitats and organisms affected were obviously dependent on the particular weather conditions during the oil spill. Studies are continuing to follow succession and other changes in seagrass meadows, coral reefs, mangrove forests, and associated habitats that were affected by the oil.*

On April 27, 1986, an estimated 50,000 barrels of medium-weight crude oil spilled into the sea on the Caribbean coast of Panama. By September 1986, the oil had contaminated coral reefs, algal flats, seagrass beds, mangrove forests, small estuaries, and sand beaches. The biological reserve and research areas at the Smithsonian Tropical Research Institute's laboratory at Punta Galeta received substantial amounts of oil. Extensive environmental monitoring data and other detailed information about the area before the spill provided a rare opportunity for examining the ecological effects of the oil. In this paper we briefly describe the spill and give a preliminary account of its effects.

The spill occurred at Refineria Panamá (a subsidiary of Texaco, Inc.), located on Payardi Island (Lat. 9° 24′ N, Long. 79° 49′ W), about 12 km northeast of the City of Colón (Figure 1). About 240,000 barrels (1 barrel = 159.6 liters = 42 gal) of oil drained from a ruptured storage tank into a surrounding impoundment. About 140,000 barrels broke through a containment dike and overwhelmed separators and a retaining lagoon. Refinery personnel originally estimated that about 35,000 to 50,000 barrels escaped into Bahia Cativá, the bay on the west side of Isla Payardi (quantities from R. Morales and A. Lasday, Texaco, Inc.). The recovery of more than 48,000 barrels of cleaned oil from the sea (R. Morales, pers. comm.), plus the probable losses from evaporation, suggest the initial spill was at least 55,000 to 60,000 barrels. An undetermined amount of oil continued to escape into the sea from seepage through the porous, coral landfill beneath the refinery. The oil type was 70 percent Venezuelan crude and 30 percent Mexican Isthmus crude, with a specific gravity of 27° API at 15.6° C (≈0.89 gm/cm^3 (R. Morales, pers. comm.)).

For six days, onshore (northerly) winds pushed the oil into the head of an adjacent bay, Bahia Cativá. On May 4, 1986, refinery personnel reported that rainfall and shifting winds moved a large quantity of oil out to sea, where it could not be controlled by means that were available locally (R. Morales, pers. comm.). For the next two weeks, onshore winds concentrated the oil along the coast, at the heads of the bays, and in estuaries where land-based crews could contain and collect it. Lack of rain minimized flushing from the estuaries. Refinery officials estimate that more than 50 percent of the oil lost to sea was recovered during these favorable conditions. Eventually, shifts of winds moved part of the unrecovered oil out to sea and along the coast. Oil sheen extending from the spill was observed on the open sea over the region from Bahia Limón to the town of Nombre de Dios, a distance of about 60 km.

Except for the areas of deeper water in Las Minas Bay and Cativá Bay, collection of the oil was mostly limited to areas that are accessible by road. Much of this region is roadless, and pockets of oil remained in lagoons and mangrove inlets that were too shallow to be reached by conventional boats. A Hercules C130 transport plane and a Cessna crop duster also sprayed the dispersant Corexit 9527 (Exxon Chemical Americas, Houston, Texas) on oil slicks. The total amount of Corexit sprayed has not yet been determined, but refinery officials estimated the quantity at less than 21,000 liters (A. Lasday, pers. comm.).

In surveys on foot, in small boats, and from low-flying aircraft, we have seen oiled shoreline from the Chagres River to the north shore of Isla Grande, a distance of about 85 km (Figure 1). The most heavily oiled shoreline was between Isla Margarita and the Islas Naranjos; as of August 1986, only two areas within this region appeared not to be contaminated with oil. Both were mangrove-lined lagoons, one between Isla Margarita and Isla Galeta, and the other in the uppermost reaches of the unnamed bay south of Isla Peña Guapa. Natural barriers, augmented by floating booms at Isla Margarita, protected these areas.

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1. Also, 915 Academy Street N.E., Salem, Oregon 97303
2. Also, Department of Zoology, University of Rhode Island, Kingston, Rhode Island 02881

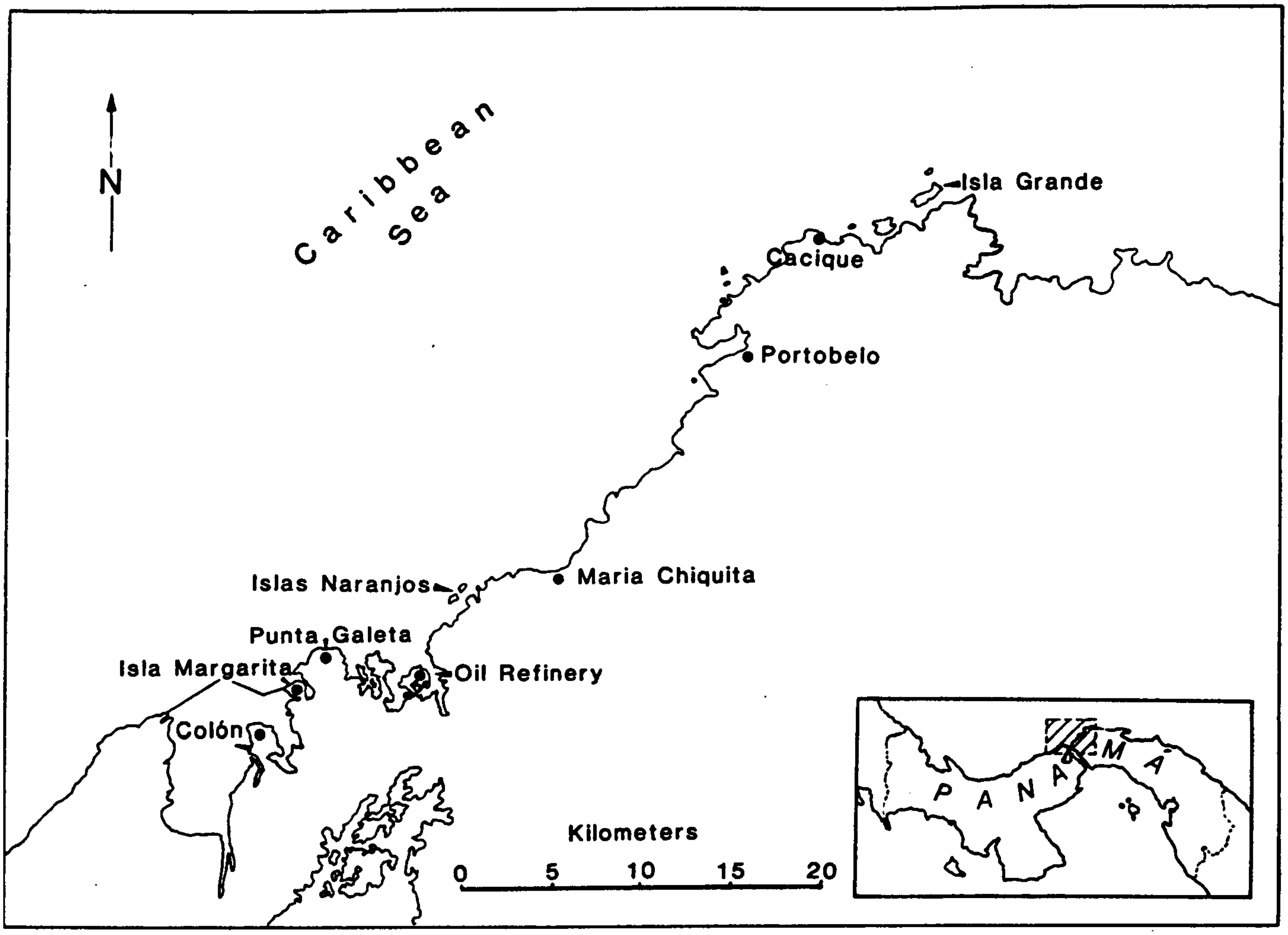

Figure 1. Map of the Caribbean Coast of Panamá, between the City of Colón and Isla Grande—On April 27, 1986, crude oil spilled from a ruptured storage tank at Refineria Panama, S. A. The Smithsonian Tropical Research Institute marine laboratory is at Punta Galeta.

Habitats and species affected

The oil refinery is located within a complex maze of coral reefs and coral islands with shallow lagoons, sand beaches, coconut groves, and mangrove forests. Small estuaries exist along the shore. Much of the shoreline is drying (intertidal) reef flat. This is the largest area of mangrove-reef complex on the central Caribbean coast of Panama. The total area of land and water encompassed by the oil spill was about 40 km^2, which includes about 16 km^2 of mangroves and 8 km^2 of coral reefs. The actual area or length of coastline covered by oil is difficult to determine precisely because of the intricate channels and shorelines, and the undetermined penetration of oil into the mangrove forests.

Mangroves. Of the four common mangrove species that occur in the area of the oil spill, the red mangrove (*Rhizophora mangle*) is the most seaward in occurrence, and makes up nearly all of the fringing forest. The prop roots of these trees form thickets that line much of the shoreline within the range of the spill. Overflights in June and July 1986 showed that more than 15 km of this shoreline between Isla Margarita and Maria Chiquita was oiled. On the open coast, a tarry residue coated the roots and lower leaves of these trees between lowest low water and the upper reaches of the splash zone (about 60 cm vertical extent). White mangroves were also exposed to oil, especially where the oil penetrated deeper into the forests. Our studies have concentrated on two aspects of the mangroves: the communities of plants and animals that inhabit the roots of the red mangroves and the mangrove trees themselves.

Sessile organisms on mangrove roots. The labyrinthine prop roots of the red mangroves serve as firm substrata or refugia that support a number of plants and animals. For example, at Punta Galeta, the prop roots of the red mangrove are the habitat for 127 species of animals and 43 species of algae, some of which are specialized for this habitat.[1] Before the oil spill the abundances of oysters, mussels, algae, and other organisms living on mangrove roots had been surveyed in three types of habitats (open coast, channel/lagoon, and riverine), each with a distinctive biotic community. In each habitat, approximately 100 roots (submerged but not firmly anchored to the bottom) were randomly chosen and the relative cover of organisms estimated. After the spill, the surveys were repeated in both oiled and unoiled sites.

Before the spill (1981–1982), the mussel *Mytilopsis domingensis* covered about 50 percent of the root surface in the riverine habitats (Table 1). The barnacle, *Balanus improvisus*, was present in each survey, but varied in mean cover from a low of 2 percent in June 1982 to a high of 18 percent in January 1981. The overall mean of algal coverage was 6–9 percent, which was formed of 3 to 10 species. Bare space averaged 20–40 percent. In unoiled sites after the spill (July 1986), the average space occupancy in most categories was roughly similar to that of 1981–1982. Only *Mytilopsis* was less abundant (mean cover = 32 percent) than in 1981 or 1982. In oiled sites, the amount of bare space (microbial slime and oil are included in this category) averaged 85 percent. The rest of the space was occupied by dead and decomposing organisms (Table 1).

On channel roots before the spill, *Mytilopsis* formed a mean cover of 8–12 percent and the edible oyster *Crassostrea rhizophorae* covered most space (mean cover = 46–62 percent). Two other bivalves (the

Table 1. Abundances of major organisms on *Rhizophora* prop roots before and after the oil spill (N is the number of roots sampled.)

Habitat and organism	Percent coverage: mean (range)				
				July 86	
	Sep 81	Jan 82	Jun 82	Unoiled	Oiled
Riverine					
Mytilopsis					
alive	53 (0–86)	47 (0–80)	49 (0–81)	32 (0–90)	0
dead				1 (0–12)	11 (0–75)
Balanus					
alive	6 (0–75)	18 (0–90)	2 (0–18)	11 (0–82)	0
dead				0	3 (0–33)
Algae	7 (0–22)	9 (0–41)	6 (0–14)	10 (0–62)	0
Bare	30 (0–99)	20 (0–95)	40 (7–89)	25 (0–95)	85 (5–100)
N	51	49	25	92	100
Channel					
Crassostrea					
alive	46 (0–80)	56 (0–96)	62 (0–100)	36 (0–100)	0
dead				0	21 (0–100)
Isognomon					
alive	6 (0–20)	5 (0–16)	3 (0–12)	2 (0–16)	6 (0–63)
dead				0	2 (0–18)
Mytilopsis	12 (0–30)	11 (0–28)	8 (0–24)	6 (0–82)	4 (0–35)
Brachidontes	2 (0–15)	2 (0–12)	3 (0–12)	6 (0–53)	1 (0–6)
Balanus	15 (0–30)	10 (0–32)	9 (0–36)	6 (0–26)	1 (0–21)
Algae	1 (0–10)	2 (0–8)	3 (0–12)	8 (0–87)	7 (0–71)
Bare	13 (0–100)	10 (0–100)	10 (0–10)	14 (0–81)	6 (0–45)
Diatoms				11 (0–100)	29 (0–100)
N	48	46	25	100	100
Open coast					
Diatoms	25 (0–100)	5 (0–55)		—	70 (8–100)
Sponges	5 (0–40)	6 (0–54)		—	1 (0–78)
Hydroids					
alive	5 (0–45)	3 (0–22)		—	2 (0–80)
dead				—	3 (0–55)
Foliose					
algae	29 (0–100)	47 (0–100)		—	21 (0–100)
Bare	32 (0–100)	31 (0–100)		—	2 (0–25)
N	50	50			100

oyster, *Isognomon alatus* and the mussel, *Brachidontes exustus*) were always present in relatively low abundance (Table 1). *Balanus improvisus* averaged from 9–15 percent cover, and the smaller barnacle, *Chthamalus* sp., covered an average of 2–5 percent space on roots. Other sessile organisms (sponges, bryozoans, hydroids, algae) averaged only 1–3 percent cover. Prior to the oil spill, the bare space on roots in this habitat averaged 10–13 percent of the total area. Postspill changes were less obvious on channel roots. *Crassostrea*'s cover decreased from 1981–1982 levels in both oiled and unoiled areas, but more so where roots were oiled. Most other invertebrates also declined from 1981–1982 levels of abundance (Table 1). Algae increased in relative cover in both oiled and unoiled areas, compared with 1981–1982 data.

Before the oil spill, open coast mangrove roots had about 30 percent bare space on their roots (Table 1). These differed from roots in other habitats by the absence of a dominant bivalve; instead, a diverse array of foliose algae covered a mean of 29–47 percent cover. Several species of hydroids and sponges averaged from 3–5 percent and 5–6 percent cover respectively. Open coast mangroves are presently being monitored. No unoiled roots have yet been examined; however, data from 100 oiled roots suggest a diatom bloom and a concomitant decrease in sponges and in some species of algae and hydroids (Table 1). The shells of the mangrove snail *Littorina angulifera* were coated with oil, but the snails moved out of the oily areas and into the higher parts of the mangrove trees. Additional measurements are being made of size-frequency distributions and ash-free dry weights of the species living on the roots in all mangrove habitats.

Mangrove trees. Aerial surveys in June and July of 1986 showed defoliated mangrove trees and trees with yellowing leaves along the borders of Bahia Cativá and on the northern portions of the islands and headlands between Punta Muerto and Punta Galeta. The stress and defoliation of the mangroves tended to be concentrated where the trees were rooted in a berm of intertidal sediments. In most places, the berm apparently intercepted and partially absorbed the oil, blocking further movement of oil into the forests.

Monthly surveys are being made of mangroves in oiled and unoiled habitats. The variables used to quantitatively describe the structural characteristics of the mangrove communities are individual tree location, species composition, diameter at breast height (DBH), tree height, leaf area index (LAI), phenology, canopy density, growth of respiratory organs, and rate of litter fall. In addition, the leaves from randomly chosen trees are evaluated for phenology, longevity, structure, herbivory, and deformities. Groups of red mangrove propagules also have been planted and are being monitored monthly for sprouting success, height, leaf number, phenology, and leaf structure.

Transect surveys were made of the mangrove forests in September 1986. In heavily oiled sites, there was complete defoliation of trees in inner fringe and outer fringe forests that were rooted in the intertidal sediments. Trees of the inner fringe, but not the outer fringe, that were rooted in subtidal sediments suffered less defoliation. As of September 1986, the trees rooted in the supralittoral sediments of the oiled region had suffered less defoliation than the trees rooted at lower levels (Table 2).

Reef flats. In the heavily oiled region, platforms of fringing reefs form extensive shallow habitats covered with algae, seagrasses, and invertebrates. In the early days of the oil spill, between 10 and 19 May, extreme low tides exposed the reef flats above water level during warm, sunny weather. Driven by onshore winds, the oil accumulated able 2. Leaf area indices and percent defoliated trees in three mangrove transects

	Forest type in transect		
	Lightly oiled	Heavily oiled	
	Reference forest	Inner fringe	Outer fringe
f area index			
ubtidal	2.4	1.2	0
ntertidal	1.7	0	0
upratidal	1.2	2.9	0.9
cent defoliated trees			
ubtidal	0	27	100
ntertidal	0	100	100
Supratidal	8	0	0

iinst the seaward borders of the reef flats where it remained for duration of the low tides. By early June, a band of substratum o 3 m wide at the reef edge was nearly barren of the normal emblage of sessile invertebrates and algae, which contributed to lower abundances of organisms in the quantitative sampling de- ibed below.

As part of a larger-scale monitoring program, we have surveyed the verage of organisms at the seaward edge of the reef 16 times in the riod between March 1983 and December 1984. These surveys were peated to compare changes before and after the oil spill. The sur- ys consisted of 10 transects, 9 to 22 m long (average length, 18 m), iich were perpendicular to the reef edge and spaced randomly with- 20 m intervals. Using point sample methods, we determined the atial coverage of organisms on the substrate. (The method used ndom points in sets of 5 per 0.5 m interval.) The number of points mpled per survey ranged between 1,510 and 1,560.

By the first week of June 1986, visual inspection of the reef edge ne showed that it was being colonized by a thin, transparent mat algae. In a microscopic examination of a systematic collection of iese algae, the mat was mainly *Cladophora* sp., *Enteromorpha* sp., nd (mostly epiphytic) diatoms. By the last week of June, the mat ad become a thicker assemblage of *Cladophora, Centroceras*, and iatoms, overgrowing both the vacated substrata and the sessile or- anisms that had survived the oil spill. At this time, this algal mat overed more than 54 percent of the hard substratum—more than 4 times the average abundance, and almost twice the maximum abun- 4
dance, measured in pre-spill surveys (Table 3).

The two common species of zoanthids on the reef flat, *Palythoa caribaeorum* and *Zoanthus sociatus* were less abundant after the oil spill. The reef flat population of *Palythoa caribaeorum* was concentrated in the area where the oil accumulated at low tide. Before the oil spill, its coverage ranged between 1 and 2 percent averaged over the whole transects, or 10 to 12 percent in a band 2 m wide at the seaward fringe of the reef flat. In June 1986, the overall spatial coverage of this colonial cnidarian was about 0.12 percent, or less than one tenth the average pre-spill abundance. By September 1986, the coverage had increased to 0.25 percent, still less than at any time before the spill. The population of *Zoanthus sociatus* extended landward of the *Palythoa* population, but was not entirely outside the zone of direct oiling. In the post-spill censuses, the abundances of *Zoanthus* were also below the minimum recorded before the spill (Table 3).

Within the areas of the surveys, most of the *Porites* spp. (scleractinian corals) were found in the same habitats as *Palythoa*. Averaged over the whole length of the transects, the percent coverage of *Porites* spp. in aggregate was less than 1 percent of what it had been in the pre-spill surveys, but the corals were always present. No *Porites* were found in the post-spill surveys.

The abundance of crustose coralline algae, the main reef builders at the reef crest,[10] also decreased in the aftermath of the oil spill. Like the *Palythoa* and *Porites*, the peak abundance of these algae was at the seaward border of the reef flat, forming an average cover of more than 25 percent before the spill; this corresponds to 8–9 percent cover averaged over the whole length of the transects. In June 1986, the overall cover was measured as 2.24 percent cover overall, which increased by September 1986 to 5.7 percent cover. Both post-spill measurements were lower than any made in the 16 surveys before the oil spill.

In June 1986, the percent coverage of the calcareous green alga *Halimeda opuntia* was lower than average, but within the range of values recorded in the pre-spill surveys; however, in September 1986 the coverage was about half that measured in June, which was the lowest abundance ever recorded (Table 3). Besides the possibility of delayed mortality, this may have been the result of the time it takes for this tough alga to slough off the substratum after dying. Overgrowth by fleshy red algae also may have reduced the actual or apparent coverage of *Halimeda opuntia*.

The fleshy red alga *Laurencia papillosa* was the predominant alga at the edge of the reef, where it formed extensive mats ranging between 22 to 62 percent average overall coverage, and 1 to 4 cm in average overall thickness, depending on the season. In June 1986, the overall cover was 19.9 percent, and the thickness was 0.77 cm, each

Table 3. Comparisons of spatial coverage, algal thickness, and species counts at the seaward edge of the Galeta reef flat, before and after the oil spill

	Pre-spill																Post-spill	
	1983						1984										1986	
Organism	Mar	Apr	May	Jun	Sep	Oct	Feb	Mar	Apr	May	Jun	Jul	Sep	Oct	Nov	Dec	Jun	Sep
Percent cover																		
Palythoa	1.50	1.31	1.37	1.05	1.19	1.47	1.73	1.41	1.67	1.47	1.67	1.73	1.47	1.80	1.67	1.86	0.13	0.26
Zoanthus	5.37	4.29	4.41	5.23	4.91	4.44	4.19	4.51	4.89	5.07	4.73	5.65	5.79	6.08	5.25	5.18	3.93	3.75
Porites	0.81	0.58	0.31	0.48	0.27	0.27	0.16	0.30	0.31	0.11	0.32	0.41	0.31	0.42	0.22	0.41	0	0
Crustose corallines	6.99	6.33	8.49	7.58	8.01	6.60	8.40	9.29	11.03	11.28	8.01	10.06	10.83	10.70	7.69	6.47	2.24	5.70
Halimeda	7.11	8.71	9.11	8.32	3.82	7.04	7.48	5.91	5.53	4.92	4.23	4.75	3.91	4.95	4.66	4.54	4.05	2.02
Microalgal mat	3.20	6.01	5.29	5.36	7.15	3.65	3.14	2.24	6.86	14.23	28.27	16.28	14.42	12.05	11.15	9.36	54.17	18.40
Acanthophora	1.75	1.23	0.96	0	2.44	1.80	3.08	2.26	0	0.18	0.23	1.11	1.61	0.14	3.82	2.00	2.18	2.47
Laurencia	45.49	36.41	43.40	30.85	55.70	61.86	48.65	45.58	22.31	28.08	29.29	33.53	40.06	39.42	48.27	57.24	19.94	54.23
Thickness of *Laurencia* mat	3.06	2.01	2.15	1.37	3.50	3.76	2.33	1.87	1.14	1.17	1.06	1.30	1.34	1.30	1.85	2.50	0.77	2.24
Total species	23	21	23	13	20	21	21	20	19	25	21	20	23	21	23	21	14	19
Sample size (total points)	1530	1530	1530	1530	1510	1560	1560	1560	1560	1560	1560	1560	1560	1560	1560	1560	1560	1560

measure lower than in any previous survey. However, by September 1986, the coverage of the mat had increased to 54 percent and the thickness to 2.24 cm, both of which were higher than the pre-spill averages. The coverage of a similar fleshy red alga *Acanthophora spicifera* was also higher than average in the post-spill surveys.

Before the oil spill, the counts of sessile species that could be recognized in the field ranged between 13 and 25 total species per survey and averaged 23 species per survey. In June 1986, the count was 14 species; in September 1986, 19 species (Table 3).

The abundances of sea urchins at the reef edge also declined immediately after the spill. As part of a larger monitoring program, censuses of all species of sea urchins are made approximately once per month at the reef edge. *Echinometra lucunter* and *E. viridis* are the predominant species in this zone. In nine years of surveys, these urchins were generally most abundant between March and June, when *E. lucunter* may reach population densities of 1,000–2,000 individuals per 20 m^2 according to Cubit, et al.[5] As the oil began coming ashore at Punta Galeta in early May 1986, the population densities of *E. lucunter* and *E. viridis* had reached 308 and 56 urchins per 20 m^2, respectively. By the end of May, the densities were 54 and 8 urchins per 20 m^2, respectively. The numbers of urchins increased in the following months (Table 4), but were less than the seasonal average for previous years.[5]

Table 4. Population densities of *Echinometra lucunter* and *E. viridis* in censuses at the seaward edge of the Punta Galeta reef flat—Densities are in number of animals per 20 m^2. Heavy oiling of Punta Galeta began on May 8, 1986.

	Date of census (1986)								
Species	Feb 19	Mar 12	Apr 9	May 8	May 31	Jun 20	Jul 21	Aug 22	Sep 22
Echinometra lucunter	20	68	127	308	54	132	137	138	160
Echinometra viridis	1	1	5	56	8	20	23	21	21

In addition to the studies reported above, we are continuing surveys of spatial coverage of algae, seagrasses, and sessile invertebrates on the whole reef flat, together with various types of population surveys of sea urchins, stomatopods (mantis shrimp), and gastropods.

Subtidal reefs. As of August 1986, numerous colonies of shallow water corals were dead or dying in depths of 1 to 2 m in the heavily oiled areas. In quadrat sampling, the proportion of dead or dying colonies averaged between 17 and 30 percent on oiled reefs, and was 0 percent on unoiled reefs (see Table 5). Surveys of corals are continuing and include repetitions of surveys that were first made along the coast before the oil spill. These will provide data about coral abundances before and after the spill in areas inside and outside the oiled region.

Table 5. Percentage of the colonies of the coral *Siderastrea siderea* showing recent partial mortality of tissue in habitats exposed to different amounts of oil—The number of corals observed is shown in parentheses. 5

Amount of oiling in habitat[1]	Number of reefs	Percentage of partially dead colonies[2] Depth <1 m	1–2 m
Very heavy	4	30 (331)	17 (155)
Heavy	2	25 (145)	22 (23)
Moderate/light	2	17 (166)	17 (133)
None	4	0 (354)	0 (138)

1. Arbitrary ranking based on observations from overflights, photographs, visits to sites, early path of the oil, and distance from the refinery

2. The criterion for recent mortality of tissue was growth of a microbial film over obviously decaying coral tissue

Discussion

The oil spill has affected several different tropical marine communities, each of which is dominated by a group of organisms, such as corals, mangrove trees, and algae, that provide the primary local structure of their habitat. The relevant questions are: what will happen to these communities following disturbance by oil, and how long (if ever) will it take them to recover? Answers will depend on the species affected as well as on the nature of the disturbance. For example, corals are very long-lived and rates of recruitment and recovery in disturbed areas may require decades.[8] In contrast, mangrove roots are relatively short-lived habitats whose inhabitants routinely recruit, grow, and mature within a few years,[13] so that recovery from disturbance should be more rapid than for corals unless the roots themselves are too severely altered or destroyed, or widespread mortality of the epibionts has eliminated the source of recruits.

Chronic, long-term, contamination also may affect biological changes in the aftermath of this spill. The heavily oiled mangroves and the coral fill beneath the oil refinery may leak oil to adjacent environments for years to come. At the end of September 1986, five months after the initial oil spill, black oil slick was still present around the mangroves in Bahia Cativá, and translucent oil sheen was present daily at Punta Galeta.

In following the course of the spill, it was apparent that the spatial pattern of oil contamination and the types of organisms affected were very much dependent on the peculiar weather at the time of the spill. The usual rains and shifting winds for the season when the spill occurred would have carried more oil out of the bays and along the coast; instead, aseasonal northerly winds held the oil relatively near the refinery. Higher water levels, such as those normal for November through February, would have protected organisms at the seaward edge of the reef, but would have allowed the oil to penetrate more deeply into the basin habitats of the mangrove forests, causing mangrove death over a greater area. Because of the season, we have seen few oiled birds to date. Most of the migratory shorebirds and ospreys that forage around the reefs had departed northwards a few weeks before the spill. Few swimming and diving birds are resident in this area; however, as of September 1986, considerable oil remained in habitats that are winter feeding grounds for North American shorebirds, which may cause chronic oiling of wading and swimming species when they return. Thus, applying the information gained from this oil spill to others must take into account the circumstances of weather and season.

If mortality follows stress and defoliation of the red mangroves, the impact may be much wider than loss of the trees themselves. The thickets of prop roots of this species serve as breeding and nursery areas for many marine species, and as substrata and shelter for a diverse group of others,[1,4,12,13] including economically important species of fish, molluscs, and crustaceans.[12] Sediment now retained by the root masses could be released if the roots decompose, which is a potential threat to nearby corals and other organisms that are intolerant of siltation.

Although mangroves are ecologically important and ranked among the coastal environments most sensitive to oiling,[7] there has been little research involving the effects of oil on mangrove root communities. Cairns and Buikema[2] define mangroves as one of the research areas for which the fewest data on oil effects exist.

The state of knowledge for the effects of oil on shallow beds of algae and seagrass flats is worse. The National Research Council[11] describes the situation as "totally neglected," even though these habitats are "highly vulnerable to oiling," a ranking with which Gundlach and Hayes[7] concur. The beds of seagrasses and algae in warm, shallow water typically exhibit rates of primary productivity per unit area that are among the highest of all ecosystems measured.[9] In situ measurements with flow respirometry at Punta Galeta show that such rates of productivity are maintained even through seasons of stressful conditions.[6] Like mangroves, seagrasses and rhizophytic algae are effective in controlling erosion.[14]

The data base accumulated at the Galeta Marine Laboratory includes extensive information about the marine biota, as well as meteorological and hydrographic factors. Estimating the effect of oil spills often hampered by the lack of any ecological baseline information it allows scientists to make before-and-after comparisons or put eir shorter-term findings into longer-term contexts. The data base Galeta provides both a measure of what organisms were in the allow marine environments before the spill, as well as estimates of eir natural variations in distribution, abundance, and growth rate—ta that are necessary to distinguish changes caused by oil from the anges that occur naturally.

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6

OBSERVATIONS ON OILED REEFS

Most of the shallow water scleractinian corals and other groups of organisms showed signs of "strees". In fact a great number of corals were dying in areas close to the refinery by the time these sampling took place.

The common shallow water scleractinians in the area are : Siderastrea siderea, S. radians, Porites astreoides, P. furcata, P. porites, Diploria strigosa, and D. clivosa. From these, S. siderea and D. strigosa are the more abundant species and the ones that showed more frequency of recently dead areas and/or actually bleaching zones.

1.- Bleached area:

Generally the upper (closest to the water surface) area of the coral colony showed signs of recently death, clean areas devoid of coral tissue or covered by a thin layer of filamentous algae and diatoms. Microarchitectural features appear intact or in very good conditions, no signs of bioerosion or physical decay means recent mortality. Some of the colonies showed the common black halo around the bleached area that characterizes bacterial infection (Muscatine, 1981). Whether this "infection" is the consequence of oil-related tissue stress, is unknown but, the high frequency, the distribution pattern and the characteristics of the colonies affected, points to a recent shallow and wide spread external factor producing the stress. No sick or bleached colonies were found in the control areas. Other colonies do not showed the black ring, specially the ones that start to die more recently in the shallow area and almost none of the deep ones had any of these signs.

In some areas, extense patches of the calcareous algae Halimeda were recently lost or were actually peeling off. Bleached areas were common among the patches observed in the sampling areas.

2.- Unusual high production of mucus:

Specially in Siderastrea siderea, Diploria strigosa, D. clivosa and the zoanthids Zoanthus sociatus and Palythoa caribbaea. Thick layers of mucus were specially conspicuous on the borders of the bleached areas. Although there was a strong surge during the survey dates, water was clear on shallow areas and sedimentation effects were apparently normal. In any case I wouldn't rule this possibility out.

3.- Swollen tissues in scleractinians and zoanthids:

In almost all shallow colonies of S. siderea, D. strigosa and D. clivosa, the whole colony showed swollen tissues (probably by inhalation of water by stressed polyps) which gave them a peculiar popped-out funny looking aspect. Similar patterns were observed upper areas of large colonies of P. caribbaea.

4.- Day activity of typically nocturnal species:

Most shallow colonies of Diploria spp, showed polyp and tentacle activity all day long (diurnal activity). No nocturnal observations were done. In some colonies of P. caribbaea, portions with all polyps retracted and others with all polyps swollen were observed.

5.- Oiled colonies:

The proportions of affected colonies were always higher in the shallow areas than in the intermediate and deep areas. Colonies of S. siderea with dead areas covered with filamentous algae were carefully removed and transported to the lab. where, they were placed in recently cleaned plastic tanks with running sea water. # out of ten colonies released "oil" when the layer of filamentous algae was squeezed (an oily film appeared on the water surface)

Neither one of these signs was observed in any of the reefs sampled in the control areas (Isla Grande and Portoleone). This could be the only evidence that the symptoms observed on the reef organisms along the oil-affected area are the consequence of stress produced by the oil. Experimental tests should be done to confirm these observations and rule out possible effects of sedimentation, low salinity, other efluents etc. or particular combination of them.

III. DESCRIPTION OF AREAS AND REEFS STUDIED :

The areas are described below in sequence from west to east. Reefs and other characteristics (i.e. closeness to river mouths) are given in Table 1. The complete list of coral species found at each reef is given in appendix 1.

1.- Galeta :

This area is dominated by mangrove with no high elevations closeby. Beyond the mangrove, the shore is bordered bi alternating areas of fringing reefs and meadows of the sea grass Thalassia testudinum with high diversity of algae. The majority of the coast is exposed to strong wave action and high turbidity during the dry season (December-May). The reefs sampled here were (Fig.2) :

Margarita reef : The east coast of Isla Margarita, is bordered by a semiprotected fringing reef with a wide Thalassia-algal platform and an extended mangrove shore. The gently sloping back reef is dominated by fleshy and coralline algae, sponges, the hydrozoan Millepora complanata, zoanthids and corals of which, Porites astreoides, P.porites, Agaricia spp., Diploria strigosa, D.clivosa and Siderastrea siderea are the main species. The fore reef drops from 2 to 8 m with a gentle slope (Fig.3a). The upper part is covered primarly by P.furcata, S.siderea, A.agaricites danae and the coralline algae Halimeda opuntia. The deeper part is characterized by platty forms of Leptoseris cucullata, A.agaricites purpurea, A.agaricites humilis, and scattered colonies of Montastraea cavernosa, P.furcata, P.divaricata, Stephanocoenia michelini and Colpophyllia natans. beyond the reef is a muddy bottom covered with fleshy algae, sparse coral heads of S.michelinii and M.cavernosa with sponges and the sea grass Halophylla sp. covers extensive areas. A total of 36 scleractinians were identified in this reef.

Galeta : Two exposed reefs were sampled at Isla Galeta close to the STRI lab. The first, located to the north of the lab is a fringing reef that runs from south to north-west with a wide plant-dominated shallow platform (Birkeland et.al, 1973; Macintyre & Glynn, 1974, 1976). The fore reef drops gently to a muddy bottom at 8 m depth (Fig.3b). The upper part of the reef presented wide areas covered by M. complanata and coralline and fleshy algae. D. clivosa, D. strigosa, S. siderea, A. agaricites danae, P. furcata and M. cavernosa are the common scleractinians. The deep zone is characterized by plate forms of A. agaricites purpurea, A. agaricites humilis and the domical M. cavernosa, S. michelini and C. natans. Fleshy algae and rubble are dispersed over the muddy bottom. Most of the alcionarians in the front reef were dead.

The second reef is located across a channel to the east and is generally similar except that the drop off with depth is steeper. A total of 45 Scleractinians from the two reefs were identified in this area, but they are widely scattered and apparently they are not contributing significantly to reef growth (Macintyre & Glynn, 1974, 1976).

2.-Portobello :

The area is dominated by high, recently deforested basalt mountains close to shore and numerous rivers. During the rainy season the rivers are brown and discharge extensive amounts of fine sediment along the coast. Much of the protected zone is lined by mangroves and Thalassia beds whereas the exposed to waves is primarly basalt. Corals commonly grow scattered directly on the rocks and only locally accumulate sufficient framework to form fringing reefs, of which we studied four.

Buenaventura : The exposed reef located to the north of Isla Buenaventura begins as a wide (70 m) platform that slopes gently to 8 m and then steeply (45 degrees) to about 22 m (Fig.3.c). The platform is igneous at the shore line with big rocks and scattered colonies of Favia fragum, P. astreoides, P. porites, S. radians, and D. clivosa. Sponges, coralline and macro algae, and zoanthids are common on the northern shore and Thalassia on the lee shore towards the south. Bordering the Thalassia beds is a shallow back reef dominated by A. palmata and various massive corals. At the edge of the platform the coral cover is high, particularly A. tenuifolia, A. agaricites danai and M. annularis.

The wall is covered mainly by plate forms of Mycetophyllia spp., A. agaricites formas danai, purpurea and humilis, M. meandrites, M. annularis, and encrusting forms of S. michelini, C. natans, and M. decactis. Hydrocorals, other hidrozoans gorgonians and esponges are common in the deeper parts of the reef. The reef ends over a muddy bottom. It is frequently exposed to heavy sedimentation and high turbidity by the run off from the river located 1-2 miles to the south-west and the one at the Portobello bay.

A total of 50 scleractinians were found.

Drake : Located to the south west of Isla Drake at the mouth of Portobello bay, is a fringing reef growing over basalt with a slope of 25 degrees and reaching a maximum depth of 12 m (Fig. 3d).

Acropora palmata, D. clivosa, D. strigosa, A. agaricites, A. tenuifolia, S. siderea and M. annularis are the common scleractinians. Sponges hydrocorals and other hydrozoans are very common in the deeper areas of the reef. The reef bottom is a mixture of coarse (calcareous) and fine sediment. Many long reef buttress run parallel to the bay mouth. Those are covered by calcareous and macro algae and a rich fauna of scleractinians and sponges. In front of the reef sampled, two buttresses are found at 10 m depth, they are separated by a sandy bottom and the southern most one reach 30 m depth. A total of 40 Scleractinians were found .

Portoleone : Located at the north shore of the Portobello peninsula, this is a fringing reef running from southwest to northeast with a broad calcareous platform separated from the mangrove coast-line by a wide Thalassia bed. The reef platform is mainly covered by fleshy and coralline algae, sparse colonies of A.palmata, D.clivosa, D.strigosa, M.cavernosa, P.porites, P.astreoides, P.furcata, and by sponges. The edge of the platform (2 m depth) is formed by large colonies, partially dead of M.annularis, M.cavernosa, C.natans, and the hydrocoral M.complanata. The reef drops gently (Fig.3-e) to a maximum depth of 15 m, and is covered by platty forms of A.agaricites formas humilis, purpurea and danae, M.meandrites, P.astreoides, and Mycetophyllia spp. There is also a series of deep patch reefs parallel to the shore line that were not studied. 41 scleractinians were found.

Tres Marias : Three Islands (Duarte Cays) lie 2 km northeast of the Portobello peninsula. The western shore of the central island is fringed by a short semiexposed reef. The shore line is mainly igneous rock covered by fleshy algae and scattered colonies of F.fragum, D.clivosa, D.strigosa, P.astreoides and A.agaricites. There are large colonies of A.palmata at 2 m. The reef slopes gently (Fig. 3-f) and ends on a calcareous, muddy bottom at 18 m Siderastrea.siderea, M.meandrites, M.annularis, M.cavernosa, A.agaricites cf. danae, cf purpurea and humilis, I.rigida, I.sinuosa, and sponges are very common. 32 Scleractinians were identified.

3.- Isla Grande :

This is the northern most area of Panama, located 50 km to the east of the canal and conformed by 14 high basaltic islands surrounded by fringing reefs, extense Thalassia beds, patch reefs and algal ridges. The main coast area is dominated by recently deforested high mountains and the shore line by mangrove. Four reefs were sampled and 3 were surveyed :

Mamey : located on the east area of Isla Grande, is a fringing reef bordering the mangrove shore of Mamey cay. The reef runs in a northeast direction from the shore, forming a cone-shaped submersed reef for several hundred meters. It has a broad flat shallow platform dominated by macro algae, crustose algae and sponges with A.palmata, D.strigosa, D.clivosa, A.agaricites, A.danai and F.fragum as the most common scleractinians. The platform slopes gently to approximately 6 m (Fig.3g), where channels and buttresses up to 3 m high are characteristic at the edge zone. The top of the buttresses are dominated by algae with sparse colonies of A.agaricites, A.danai, C.natans, C.breviserialis, and S.siderea. The sides are mainly covered with sponges, algae, and A.danai, I.sinuosa, I.rigida, D.strigosa, M.annularis, M.cavernosa, M.ferox, M.aliciae and C.natans. Then, the reef drops steeply to 17 m ending in a sand platform with sparse colonies of M.cavernosa, S.siderea, S.hyades and sponges. The drop off is mainly covered by sponges and M.annularis, A.tenuifolia, M.cavernosa, M.ferox, M.aliciae, and M.asperula. Calcareous pinnacles with burrows and small caves covered by Bryozoans, Hidrozoans (S.roseus), sponges and ahermatipic scleractinians characterize the deep part of the reef. A total of 48 scleractinians were found.

Juan Joaquin : Is a protected patch reef located in the channel between Juan Juaquin cay and the mangrove dominated main shoreline. The reef is almost circular in shape with a very shallow platform covered by T.testudinum, P.porites, M.complanata, and M.alcicornis being common at the borders. Transects were done on the northern area. The slope is steep (fig.3h), and dominated by A.tenuifolia up to 10 m, where M.cavernosa, S.siderea, S.bournoni, S.michelini and C.natans are the dominant scleractinians up to 16 m deep. The reef ends on a muddy bottom that goes down to 20 m. High sponge abundance is found in this zone covering the dead coral skeletons. A total of 31 scleractinians were identified.

Bastimentos : A semiexposed patch reef located to the south of La Guaira town. Is aproximately 150 m in diameter with a wide shallow platform dominated by A.palmata and M.annularis that slopes down gently to 9 m depth (Fig.3i). Broad areas of A.tenuifolia, M.mirabilis, A.cervicornis and large colonies of S.siderea are characteristic from 4 m to the end of the reef. A great portion of the corals is dead and covered with fine sediment. The muddy bottom continues down to 12m and scattered patches of T.testudinum with isolated colonies of S.siderea and S.michelinii may be found. 41 scleractinians were identified.

Tambor : The semi-exposed fringing reef is located at the extreme south-west of Isla Tambor, north of Isla Grande. It runs from east to west and is separated from the basaltic coast line by a sandy area (20 m wide) covered by gorgonians. Flat and encrusting colonies of A.palmata, D.clivosa, D.strigosa, S.siderea, S.radians, F.fragum, P.astreoides and M.annularis are common in the rocky shore that drops to 1.5 m deep steeply. Then, more coral growth mixed with gorgonians and zoanthids is found up to 3 m where a sandy platform dominated by gorgonias and scattered small coral patches that extends 45 m from the shore line with a gentle slope (fig. 3j) to 4-5 m deep. Here, the reef frame is continuous and goes up to 2.5 - 3.5 m deep forming a short platform mainly covered by P.furcata, A.danai, A.purpurea, M.annularis, C.natans, and S.siderea. Sponges are common, covering wide areas of the drop-off. The reef slope is steep and ends at 12 m depth on a coarse calcareous sandy bottom. M.cavernosa, M.annularis, A.purpurea, A.danai, P.astreoides, S.michelinii, and D.strigosa are abundant in this area.
40 scleractinians were found.

Los Naranjos area:

<u>Wreck Reef</u> (site 1): Located to the east of the refinery at the mouth of the bay. Is a fringing reef with a wide platform(25-40 m). The platform drops down gently to 3 m and then steeply up to 6 m ending on a muddy-fine sediment bottom. Traces of oil were observed on calcareous exposed rocks in the intertidal zone, also aerial mangrove rots on the shore line were covered with oil. Approximately 10% of the colonies of <u>D. clivosa</u>, 12% of <u>S. siderea</u>, 10 % of <u>P. porites</u> showed "stress" symptoms. Zoanthids, calcareous algae, sponges and other organisms looked in good conditions. No affected colonies were observed at intermediate and deep areas with the exception of one big colony of <u>Colpophylia natans</u> which had a bleached area. 17 scleractinian species were identified.

<u>Los Naranjos West</u> (site 2): Western reef of Los Naranjos Island separated from the shore line by extense <u>Thallasia</u> beds. Wide intertidal platform covered by macro algae, coralline and crustose algae, <u>Millepora complanata</u> and zoanthids. The platform drops gently to the south west ending on a sandy substrate at 5 m depth. To the west, it drops from .20 to 4 m over a 50 m length and then, steeply down to 12 m on the fore reef ending on a muddy bottom.

Shallow platform and reef edges well covered by macro algae, <u>Millepora complanata</u>, calcareous and crustose algae. High cover of corals and sponges below 1 m and at the edges of the slope. The fore reef is characterized by buttresses at the edge (4 m) and forming deep canyons with high platy corals and sponge cover on the sides but poor coral cover at the bottom due possibly to high sedimentation. Bleaching colonies of <u>D. strigosa</u>, <u>D. clivosa</u>, <u>P. astreoides</u> and <u>S. siderea</u> were observed in a low frequency on the shallow area. 30 scleractinian species were identified.

REFINERY AREA:

The refinery is located at the entrance area of two small bays. All shore lanes to the east and west are formed by mangrove, sea grass beds and fringing reefs. The bays are shallow with mangrove communities conforming the shore line extensively covered by oil in the intertidal zone, and Thallasia communities with no apparent signs of oil effect characterizing the marine substrata.

Refinery Reef (site 1): Located at some 200 m inside the bay, to the west and same coast of the refinery. It is a shallow not-to- well developed reef area interrupted by sandy areas until it gets to 4 m depth where a fringing reef is well developed. The intertidal zone and up to 1 m depth is covered by a dense and tall macroalgae "forest" (Laurencia spp., Halimeda spp etc).

Scattered colonies of S.siderea, S.radians, D.clivosa and P.astreoides most of which showed recently dead areas covered by filamentous algae. Oil was detected on surface areas of exposed carbonate substrate in the intertidal zone and over the sandy beach closeby. Some pieces of a wreck on the sea grass bed were also partially covered with oil. The back reef area is dominated by Thallasia and algae and showed no apparent signs of oil stress and in general looked in good conditions. Area seems to be affected by frequent high sedimentation events judging from the fine sediment substrate, the sediment accumulation in crevices and holes and the scarcity of scleractinian species and other organisms susceptible to this environmental effect. Deep areas with higher coral and sponge cover and surprisingly, high numbers of the sea urchin D.antillarum were seeing in this area. 19 scleractiniab species were identified in this reef.

Largo Remo area: (Sites 2 and 3): Located in front of the reef and to the north west. Mangrove shore lines that were extensive affected by the oil-spill, showed all intertidal root

inside of the root system after heavy rains or during strong windy days thus, after two months, small an located sources of oil were still affecting reef areas when particular environmental conditions occurred. Two reefs were sampled, one in front of the other at both sides of the entrance to the inside shallow lagoon of isla Largo Remo. Site 2, to the southwest, is a poor developed reef in the shallow area and up to 4 m depth. This area is characterized by clusters of small patch reefs with sandy areas in between, mainly S. siderea, M. annularis, D. strigosa and Agaricia tenuifolia. Large patches of P. furcata were found at intermediate depths. The shallow area is mostly coarse gravel accumulated by strong wave action and scattered clusters of S. siderea, P. astreoides and D. strigosa with a high percentage of the colonies with recently dead areas covered by filamentous green algae and/or diatoms. More recently bleaching zones were still white and calices showed no signs of bioerosion. Wide Thallasia bed separates the reef from the coast line. Maximum depth reached by the reef is 8 m and the fore reef is dominated by A. tenuifolia and a variety of sponges.
20 scleractinian species were identified in this reef.

In site 3, only the shallow back reef area was surveyed. It is a mixture of coarse and big carbonate rocks, Thallasia zones and large S. siderea and small crustose colonies of D. clivosa, D. strigosa and P. astreoides all over the area. 50 % of all S. siderea colonies chequed were ill with same patterns explained in topic 2. High % of the other species were also dying at the time of these sampling.

Patch Reef (site 4): A large patch reef with an extense shallow intertidal and submerged platform area is located right in front of the refinery. Poor coral cover on these areas was observed and zoanthids , macroalgae and crustose algae are the dominant organisms. This is a high energy reef with steep

droop off on the back area (southwest) with low coral cover.

bottom areas, no signs of mass mortalities were observed and some colonies of S. siderea and D. clivosa showed signs of stress with small bleaching areas.

Punta Muerto (site 5): Located in front and to the east of the refinery (200-400 m), is a well developed semi-circular fringing reef separated from the shore line by a seagrass-bed dominated by T. testudinum. Wide (30 m) platform slopping gently to 4 m and dropping steeply to 8 m on the fore reef, ending on a fine sediment and muddy bottom. Shore line conformed by mangrove (Rhyzophora mangle) some of which were dead and lots of oil were detected covering the intertidal areas of the aerial roots and part of the sandy shore line. The sea grass showed some cleared areas but no other signs of being affected. The community (crustaceans, snails, anemones etc) associated with it could be affected but no data was collected and no dead organisms were observed. Some mats of Laurencia and Halimeda were chequed and some crustaceans (small crabs, isopods, shrimps and stomatopods) were observed.

The shallow reef platform is widely covered by zoanthids (Zoanthus spp), calcareous algae (Halimeda spp), crustose algae and patches of P. porites that showed no signs of oil stress. Colonies of F. fragum, D. clivosa, D. strigosa, S. siderea and M. complanata showed partial mortality on the top and some bleaching on the sides. High densities of the sea urchin Echinomtra sp were observed in the crevices and small holes of the reef frame. Deep areas with high cover of scleractinians, sponges and macroalgae and no signs of ill colonies were observed.

Bermuda Biological Station for Research, Inc.
Ferry Reach 1-15, Bermuda (809) 297-1880 Telex BA 3246

19 December 1986

Dr. Jeremy Jackson
Marine Coordinator
Smithsonian Tropical Research Institute
Panama
C/O APO Miami 34002-0011

Dear Jeremy,

Enclosed you will find results of analyses of the coral, sediment and seawater samples collected from the Galeta oil spill site in September, 1986. Generally, I am pleased with the success we had in replicate analyses of the Siderastrea corals, especially at the extremely low levels of oil seen in most tissue samples. (Table 1). It took much more effort than I had anticipated due to the carbonate matrix. So having satisfactorily established our techniques on the first set, being then short of time, and having more limited material to work with for Agaricia corals, I elected to analyze the second set of corals as composite samples from each station.

In addition to documenting the presence of oil in coral tissues, we have discovered an interesting modification in the lipid composition of corals stressed by oil. We measured a depression in the percentage of non-saponifiable lipids and a change in the protein to lipid ratios. Although the sample size is too small to make a strong statement, this observation is consistent with some of the past tank experiments conducted at BBS. We would like to put together a small proposal to investigate the effects of oil on lipid synthesis in corals. This alteration in lipid content is evident in the tabulated results as follows. Expression of petroleum hydrocarbon results as ug/mg lipid shows a difference between the Refinery reef as heavily oiled and the Galeta reef as less heavily oiled; but this difference is not obvious if the results are expressed as ug/mg protein. (Table 2).

Sediments do not show the same ranking of oil levels but this is due to the physical composition of the samples (Table 3). Los Narangos had a much larger percentage of fine sediments which hold oil, while Galeta was mostly course coral rubble.

Water samples showed oil is still present in the water column as expected in the two sites sampled (Table 4). We did not differentiate between "particulate" and "dissolved" residues.

The original oil appears to be a medium range crude oil and I am characterizing it as I write this. Density is 0.87 and I will tabulate the percentage composition which comes out in our saturated and aromatic hydrocarbon fractions. I could tell by the color of the column that some portion is more polar than we usually elute(F1 through F3).

The composition of oil residues in all of these field samples is relatively degraded showing the expected unresolved mixture of saturated hydrocarbons with very little of the discrete n-alkane peaks visible, and very few of the more volatile components remaining. Corals showed a suite of biogenic hydrocarbons typical of a contribution from algae (n-C15, C17, C19, Pristane). Except for corals from the refinery area it was not practical to quantify the oil signal in the unresolved hydrocarbons in the aromatic fractions by gc due to the large biogenic signal (alkenes, etc). But UV Fluorescence measurements confirm the content of aromatic hydrocarbons with spectra similar to the spilled oil. I am including copies of representative chromatograms. You will need to decide what detail is necessary to support the biology for the manuscript.

Analytical methods were described in the section of the proposal we sent you last September. We adhered to them, except that we did not sieve the sediments before extraction. For coral analysis we used the referenced procedure of blowing the tissue off the coral matrix with compressed air. There is always a question of tissue recovery using this approach. However we noted that the *Agaricia* is thin enough to crush in total and in future would use this method to obtain total extracts. I determined protein content by the standard Lowry procedure.

We have found these initial results quite interesting and are hopeful of funding for further collaborative efforts. Keep us informed of progress on funding for the long term study. If further analytical support for the short term study is desired, we will be quite happy to do them. The mangrove sediments should be useful to Getter's work. We have quite a set in our freezer. I trust you are satisfied with this data set and we'll look forward to the contribution to our operating expenses as agreed.

I will be in the USA over Christmas but Tony will be resident at BBS. We look forward to seeing a draft manuscript, maybe in January? Have a happy holiday season.

Sincerely,

Kathy Burns

Kathy Burns

Table 1. Concentration of saturated hydrocarbons in corals from Galeta Panama area September 1986 expressed as ug/mg lipid extracted as determined by gas chromatographic analysis and oil units determined by UVF analysis of aromatic hydrocarbon fractions.

Sample	Protein mg	Lipid mg	Fl URE[1] ug/mg	Alkanes[2] ug/mg	Biogenics[3] ug/mg	Oil Units ug/mg
Mamey Reef						
	93	22	1.7	0.5	1.4	0.18
	296	52	0.6	0.2	0.3	0.05
	205	50	0.6	0.2	0.2	0.03
Siderastrea			1.0 ± 0.6 (3)			0.08 ± 0.08 (3)
Agaricia	497	190	0.3	<0.1	<0.1	0.04
Los Narangos Reef:						
	86	17	1.5	0.7	2.7	1.7
	169	35	1.4	0.5	1.7	1.1
	138	43	1.3	0.3	1.1	1.0
Siderastrea			1.4 ± 0.1 (3)			1.3 ± 0.3 (3)
Agaricia	700	235	0.4	<0.1	<0.1	0.4
Galeta Reef:						
	358	73	4.0	0.2	0.1	8.9
	267	77	2.0	0.2	0.5	3.6
	454	161	2.0	0.1	0.3	2.2
Siderastrea			2.7 ± 1.1 (3)			5.0 ± 3.4 (3)
Agaricia	730	171	2.6	<0.1	<0.1	3.1
Refinery Patch Reef:						
	486	76	4.6	0.3	0.5	23.6
	476	120	3.7	0.1	0.3	20.4
	834	102	5.2	0.3	0.4	32.0
Siderastrea			4.5 ± 0.8 (3)			25.5 ± 6.0 (3)
Agaricia	709	118	7.0	0.4	<0.1	49.7

1. URE is the signal generated by the complex mixture of hydrocarbon residues that cannot be resolved into individual peaks in the gas chromatographic analysis. This is a conservative estimate of petroleum content.
2. Alkanes are the sum of concentrations of individual n-alkanes in then C12 to C36 elution range.
3. Biogenics are the sum of C15, C17, C19 and pristane peaks which are common biogenic hydrocarbons.

Table 2. Petroleum hydrocarbons in coral tissues as determined by gas chromatography expressed as ug/ mg lipid or as ug/ mg protein. %NSL is the percent non-saponifiable lipid of total lipid extracted.

Sample	ug/mg Lipid	Protein/ Lipid	% NSL	ug/mg Protein
Mamey S.s. (PC 61-65)	1.0 ± 0.6 (3)	4.7 ± 0.9 (3)	24 ± 3 (3)	0.22 ± 0.15 (3)
Mamey A.t. (PC 66-70)	0.3	2.6	24	0.07
Los Nar. S.s. (PC 41-45)	1.4 ± 0.1 (3)	4.4 ± 0.9 (3)	26 ± 1 (3)	0.32 ± 0.05 (3)
Los Nar. A.t. (PC 46-50)	0.4	3.0	33	0.14
Galeta S.s. (PC 01-5)	2.7 ± 1.1 (3)	3.7 ± 1.1 (3)	24 ± 4 (3)	0.71 ± 0.11 (3)
Galeta A.t. (PC 06-10)	2.6	4.3	19	0.99
Refinery S.s. (PC 21-25)	4.5 ± 0.8 (3)	6.2 ± 2.1 (3)	22 ± 5 (3)	0.78 ± 0.17 (3)
Refinery A.t. (PC 26-30)	7.0	6.0	3	1.16

Table 3. Hydrocarbons in surface sediments collected from coral reefs in the Galeta oil spill area plus associated physical composition data.

Sample	dry/wet	ug Lipid/g wet wt.	% size composition[1]	Saturates[2]			Unsaturates[2]		
				URE	n-Alkanes	Biogenics	URE	Biogenics	UVF[3]
Mamey Reef (P2-30)	0.73	74	77/ 23/ 0.1	1	0.3	0.9	<1	0.2	0.1
Los Narangos (P2-83)	0.47	29	13/ 33/ 53	85	0.6	nd	48	6.4	393.3
Galeta Reef (P2-86)	0.67	95	52/ 47/ 0.3	4	1.1	0.4	2	0.5	2.7
Refinery Reef (P2-42)	0.61	32	49/ 28/ 22	110	0.6	nd	53	0.2	343.4

1. Size composition determined by seiving the residue left after KOH-MeOH extraction of 100 g wet sediment; Sizes are: > 1 mm/ > 125 um/ < 125 um.

2. Hydrocarbons are expressed as ug/g dry wt based on gc analysis in the C12 to C36 n-alkane elution range. Petroleum content is conservatively estimated as the sum of saturated plus unsaturated unresolved hydrocarbons (URE).

3. UVF oil units determined by using the spilled oil as the calibration standard and measuring fluorescence at 360 nm emission with 310 nm excitation.

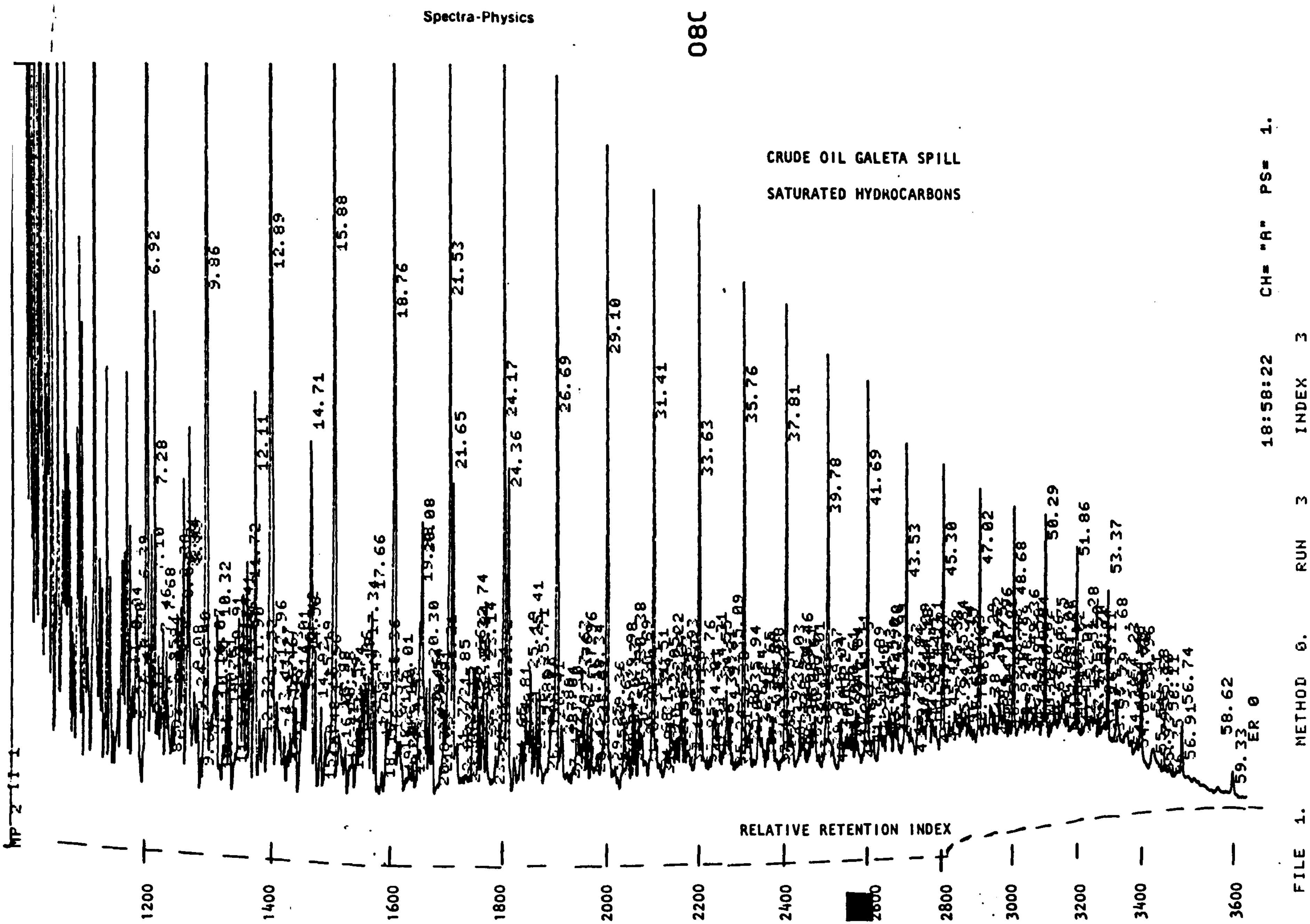
Table 4. Concentrations of petroleum hydrocarbons in water samples from Galeta oil spill area as determined by gc analysis of saturated fractions and UVF analysis of aromatic fractions.

Sample	Volume 1	URE ug/1	UVF ug/1
Largo Remo			
PX 8	53	4.5	15.1
PX 10	45	6.7	29.1
Galeta			
PX 9	115	1.9	4.8
PX1	88	0.3	2.0

1. Samples collected by pumping seawater through glass columns filled with Amberlite XAD2 resin. Columns were tied to the roots of mangrove trees with intakes approximately 0.5 m below the water surface. Columns were sealed and stored on ice during return to the lab. Hydrocarbons were eluted from columns in a custom designed continuous extraction apparatus.

Table 5. Percent composition of oil spilled at Galeta eluting in fractions from the column chromatography procedure using alumina and silica gel.

F1	Hexane	Saturates	47.4%
F2	10% Ether/Hexane	Light Aromatics	6.4%
F3	20% MeCl /Hexane	Heavy Aromatics	4.8%
F4	MeCl	Polar Fraction	18.9%
	Left on column	Not Recovered	22.5%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SATURATED HYDROCARBONS
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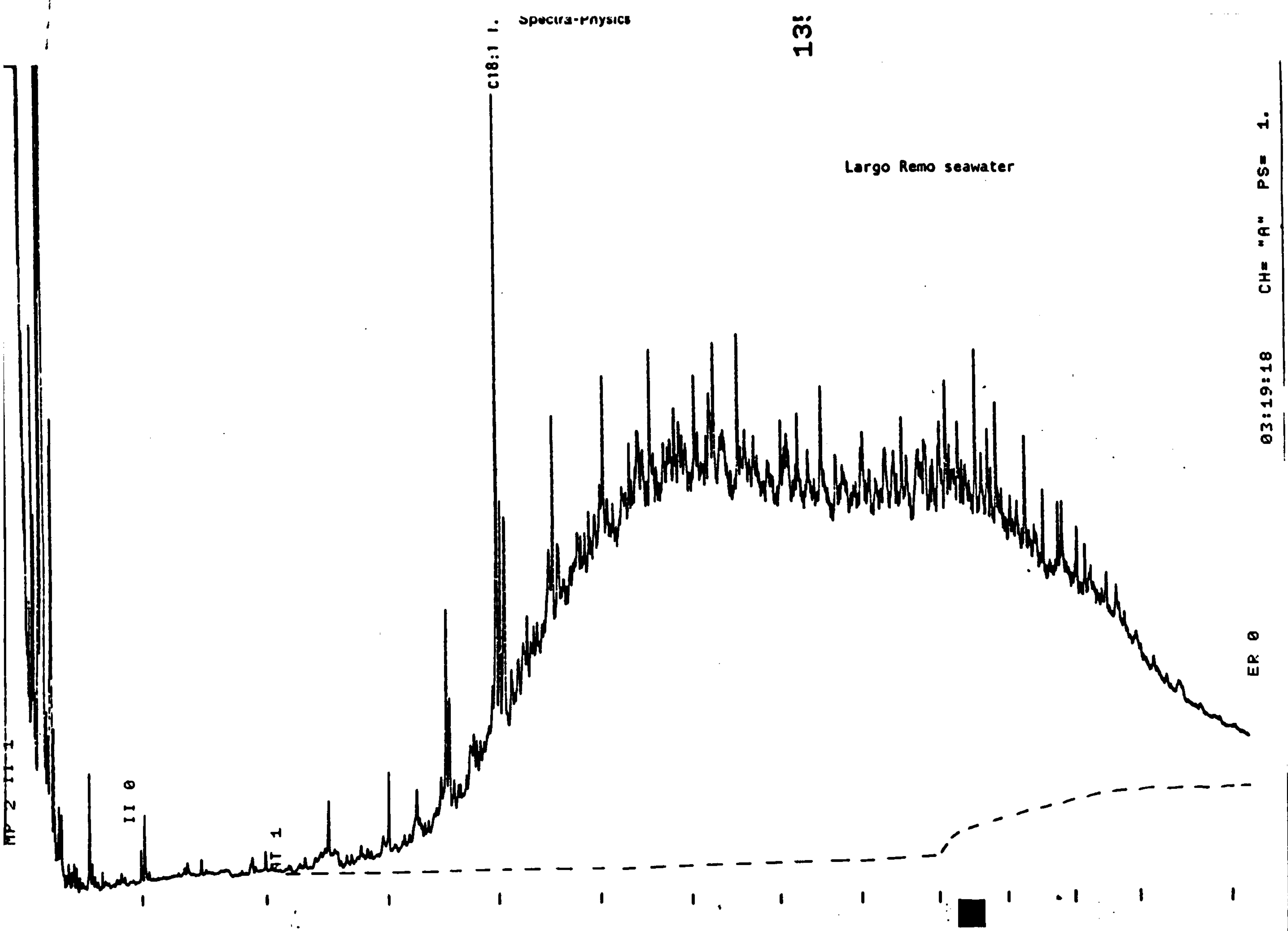
27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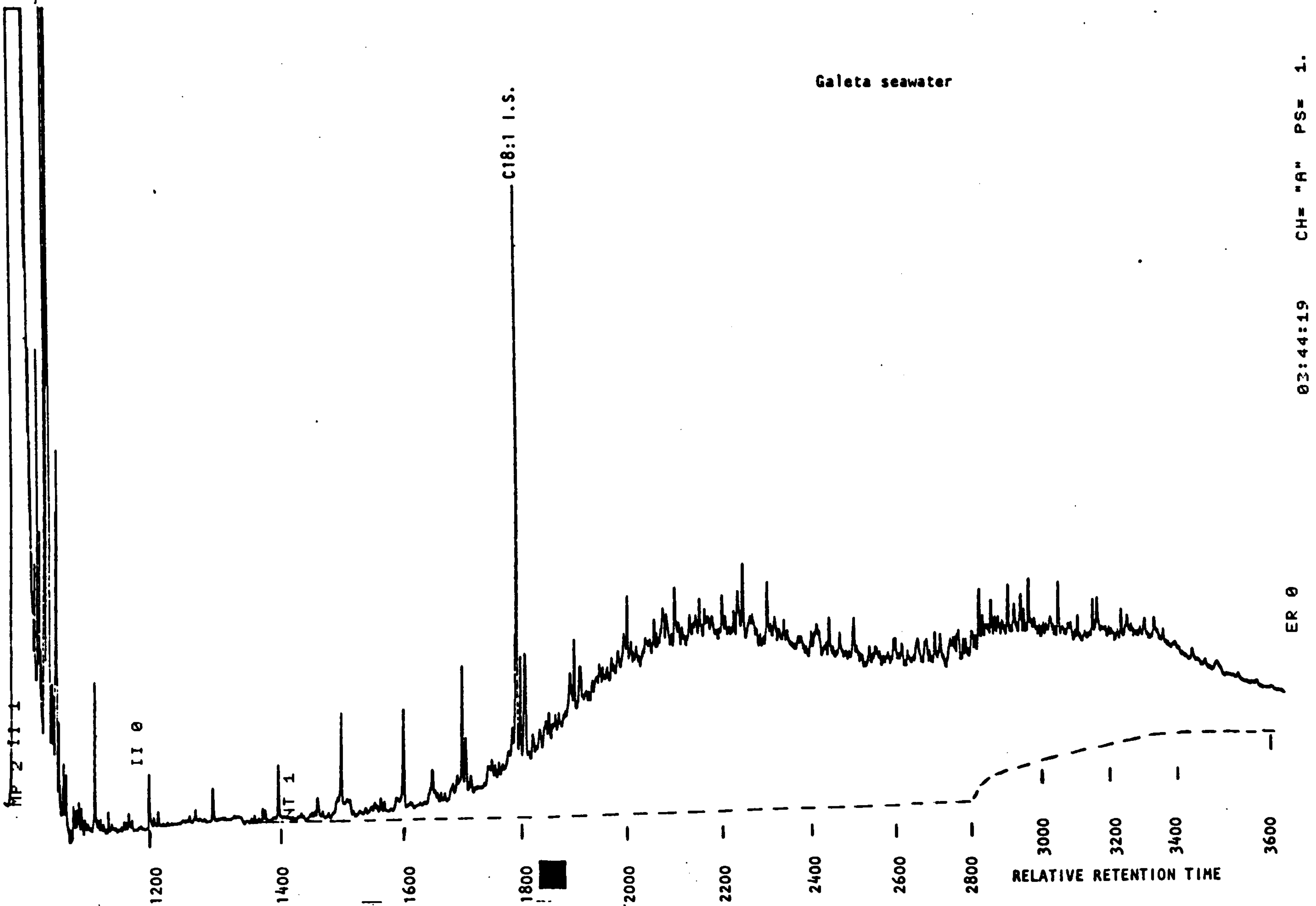
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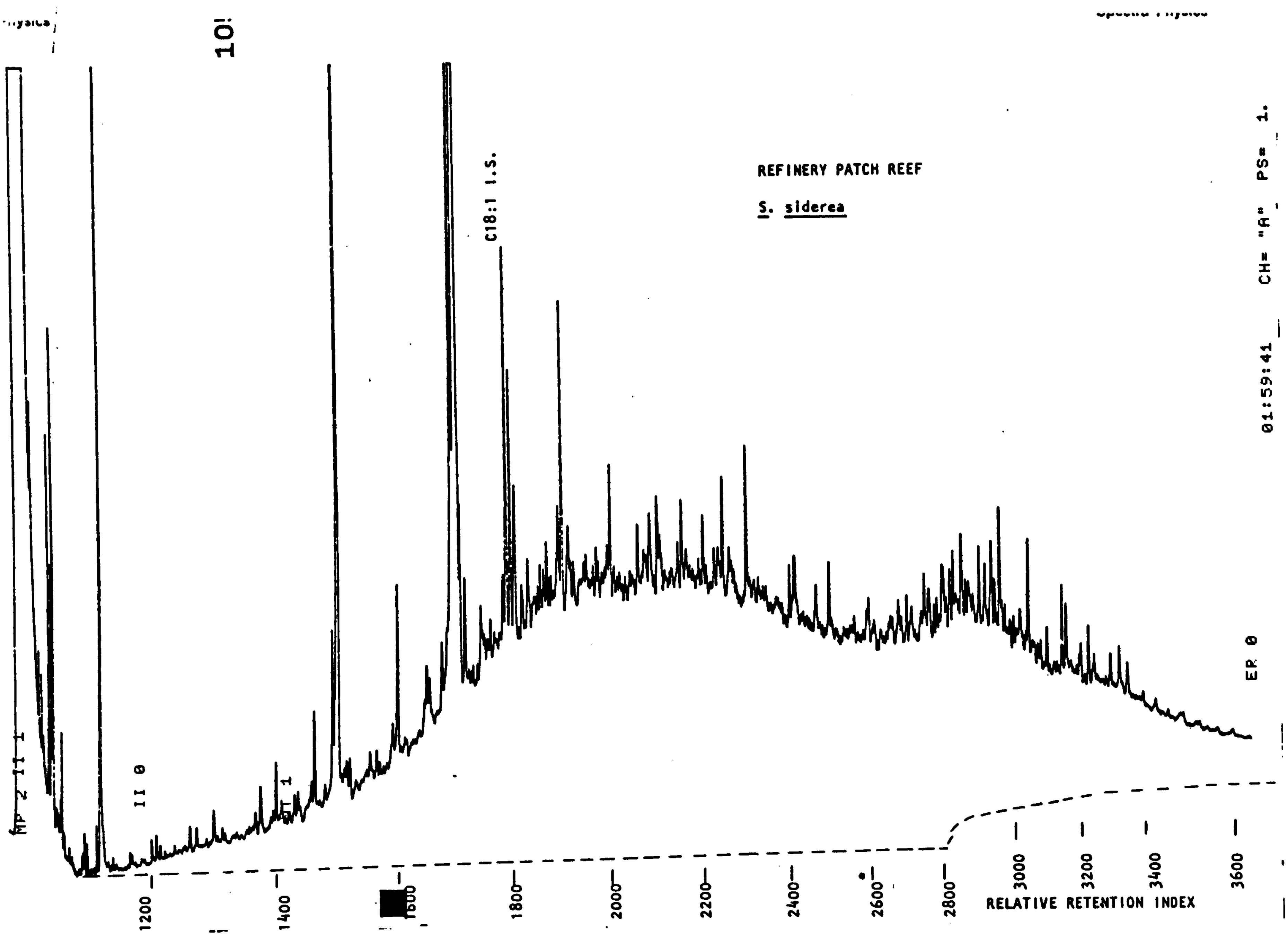
RELATIVE RETENTION TIME



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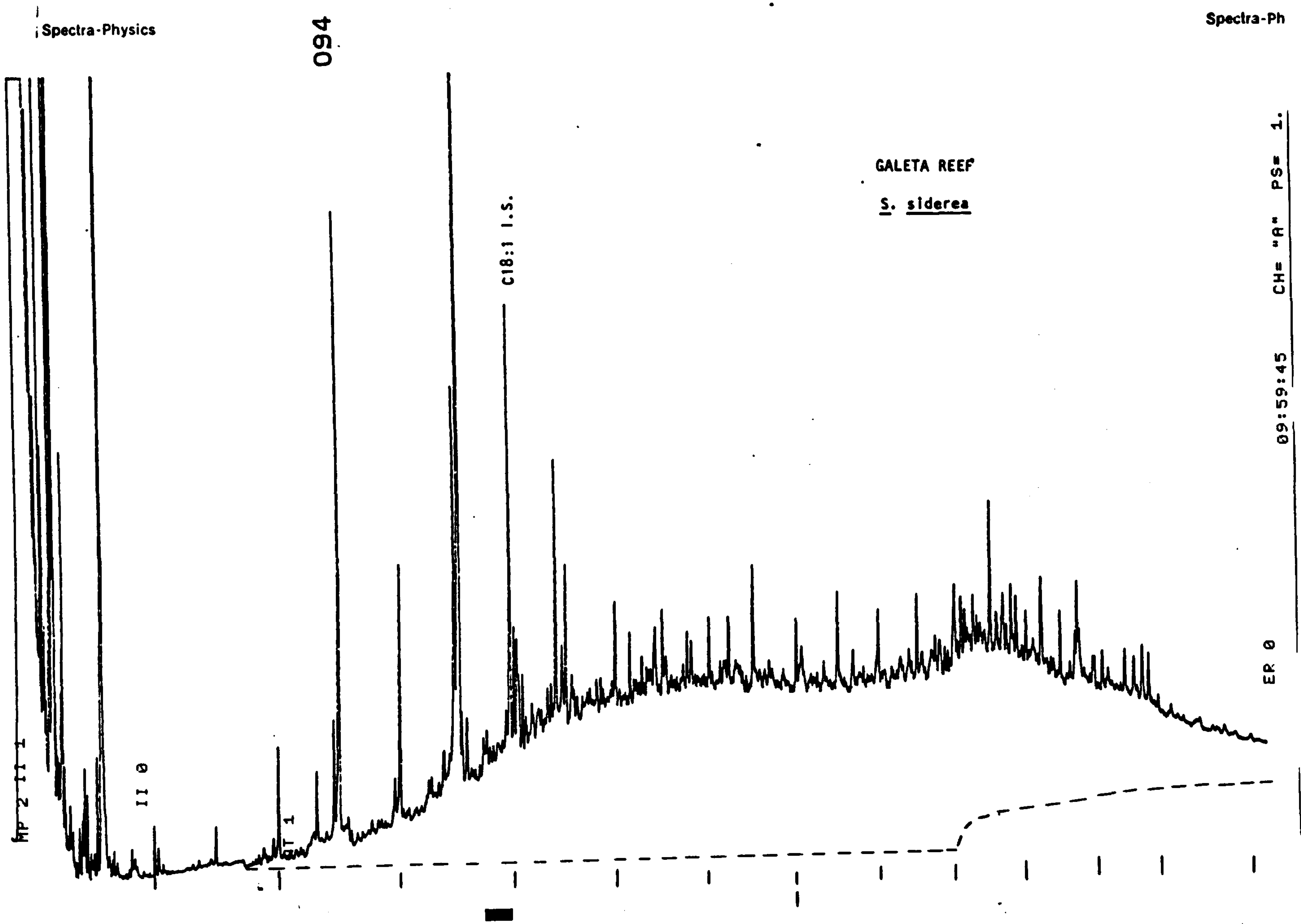
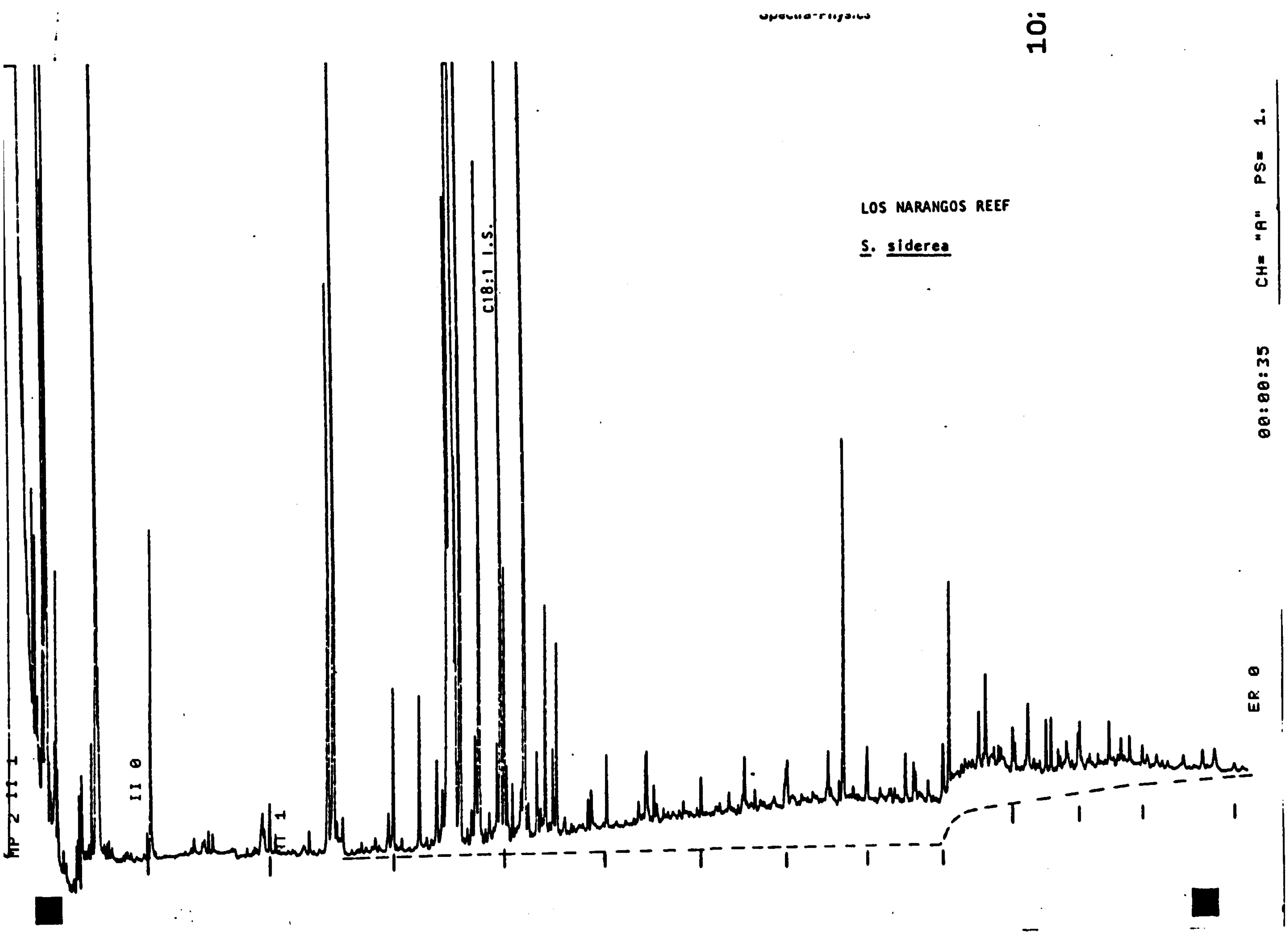
RELATIVE RETENTION INDEX

30

Spectra-Physics

094

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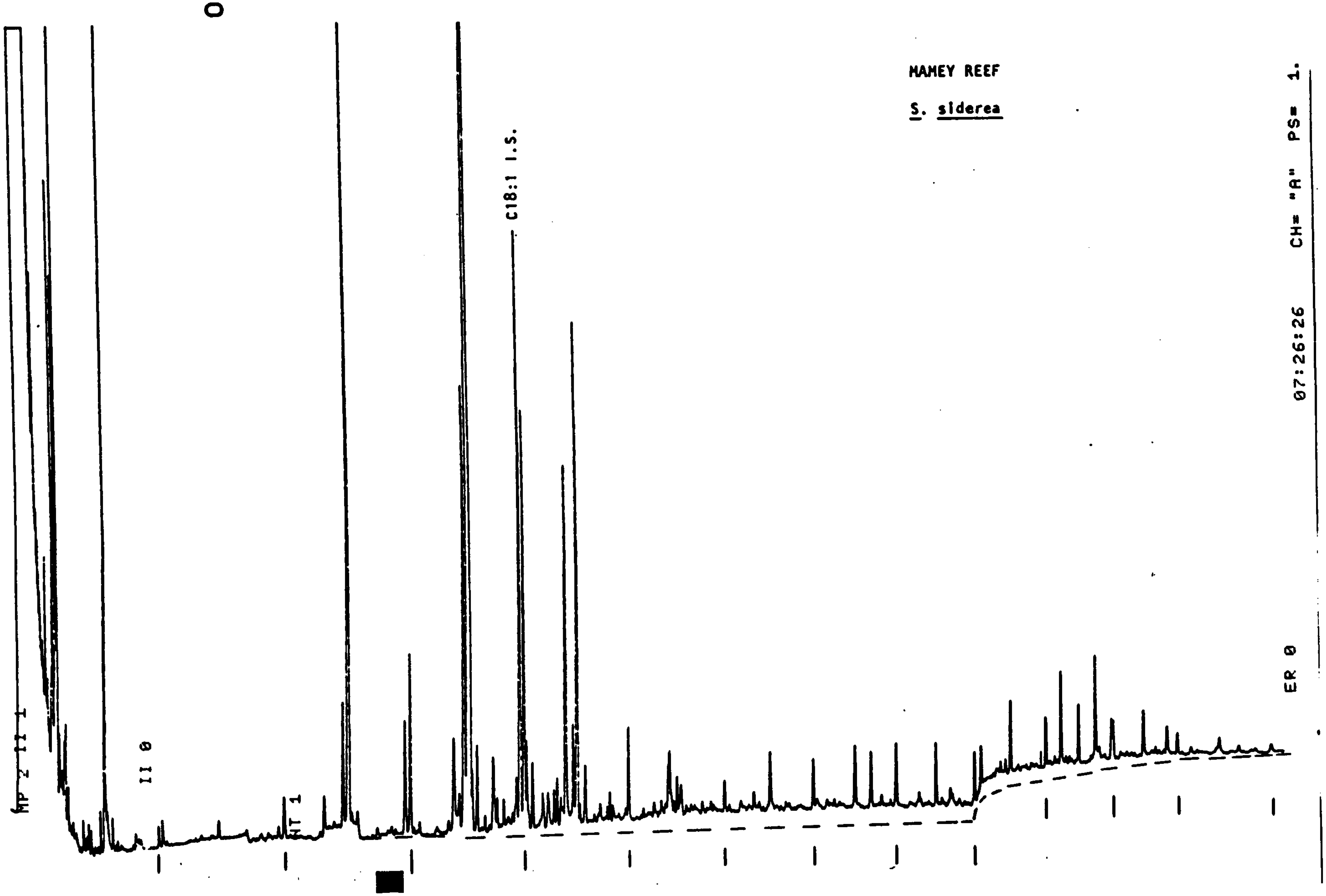
32

091

Spectra-Physics



33

Oil Spill from Refineria Panama S.A., Panama, starting 27th April 1986. Galeta(STRI)-BBS co-operative study.

INVENTORY OF SAMPLES FOR PETROLEUM HYDROCARBON ANALYSIS: collections by K.Burns,H.Caffey, M.Marshall and S.Wyers, 11-16th September, 1986 and by others on previous dates.

TABLE 1. Samples taken to BBS for Hydrocarbon Analysis 16.9.86.

(________ = *ditto* sample details;CG=Chuck Getter's study sites; MM=Mike Marshall & E. Weil's study sites;Hugh Caffey [HC] took KB & SW to additional sites indicated).

(a)Mangrove environments.

SAMPLE No.	Acc. no.	SPECIMEN TYPE	LOCATION	DATE(d.m.y)
P2 41	1	Sediment. 0-5cm core, fringe zone.	CG Reference site "RF F".	12.9.86
1	2	Sediment surface scrape.	—	—
2	3	—	—	—
3	4	—	—	—
P2 27	5	*Crassostrea rhizophorae.* dissected tissue. *n*=36.	—	—
P2 47	6	Sediment. 0-5cm core.	CG Reference site "RF B"	12.9.86
P2 43	7	Sediment. 15-20cm core.	—	—
4	8	Sediment. Surface scrape.	—	—
5	9	—	—	—
6	10	—	—	—
P2 44	11	Sediment.0-5cm. core.	CG Reference site "RF I"	12.9.86
7	12	Sediment. Surface scrape.	—	—
8	13	—	—	—
9	14	—	—	—

TABLE 1. (CONTD.)

SAMPLE No.	Acc. no.	SPECIMEN TYPE	LOCATION	DATE(d.m.y)
P2 46	15	Sediment.0-5cm core.	CG Oiled site "IF F" ('moderately' oiled.')	12.9.86
P2 45	16	Sediment.15-20cm core.	—	—
18	17	Sediment. Surface scrape.	—	—
11	18	—	—	—
15	19	—	—	—
P2 85	20	Sediment. 0-5cm core.	CG Oiled site "IF B"	12.9.86
P2 48	21	Sediment.10-15cm core.	—	—
16	22	Sediment. Surface scrape.	—	—
10	23	—	—	—
13	24	—	—	—
14	25	Sediment. Surface scrape.	CG oiled site "1F".Unmarked site close to high berm.	12.9.86
12	26	—	—	—
17	27	—	—	—
PX 8	28	Sub surface water sample, concentrated on Amberlite XAD resin column.	CG oiled site "IF". Fringe.	13.9.86
PX 10	29	—	—	—
P2 77	30	Sediment. 0-5cm. core.	CG oiled site "OF F" "heavily oiled" site.	12.9.86
P2 29	31	Sediment. 15-20cm. core.	—	—
25	32	Sediment. Surface scrape.	—	—
19	33	—	—	—
26	34	—	—	—

TABLE 1. (CONTD.)

SAMPLE No.	Acc. no.	SPECIMEN TYPE	LOCATION	DATE(d.m.y)
P2 25	35	Sediment. 0-5cm core.	CG oiled site "OF B"	12.9.86
P2 33	36	Sediment. 15-20cm core.	—	—
20	37	Sediment. Surface scrape.	—	—
23	38	—	—	—
24	39	—	—	—
P2 28	40	Sediment. 0-5cm core.	CG oiled site "OF 1"	12.9.86
21	41	Sediment. Surface scrape.	—	—
27	42	—	—	—
22	43	—	—	—
P2 95	44	Surface sediment scrape	Margarita Lagoon,S.edge. Collected by HC.	25.7.86
83	45	Sub-sample of 95.	—	—
P2 89	46	Sediment.0-5cm core.	Margarita Lagoon, "KB control". Inland of oil boom site[HC)	13.9.86
P2 74	47	Sediment. 15-20cm. core.	—	—
29	48	Sediment. Surface scrape.	Margarita Lagoon, "KB control"(HC)	13.9.86
30	49	—	—	—
31	51	—	—	—
P2 37	52	*Crassostrea rhizophorae.* dissected tissue. *n*=24.	—	—
P2 35	53	Sediment.0-5cm core.	Margarita Lagoon, "KB Oiled site". Approx. 100m seaward of oil boom site.(HC)	13.9.86
P2 81	54	Sediment. 15-20cm. core.	—	—
32	55	Sediment. Surface scrape.	—	—
33	56	—	—	—
34	57	—	—	—
P2 78	58	*Crassostrea rhizophorae.* dissected tissue. *n*=29.	—	—

TABLE 1. (CONTD.)

SAMPLE No.	Acc. no.	SPECIMEN TYPE	LOCATION	DATE(d.m.y)
P2 91	59	Sediment.0-5cm. core.	Mangrove Island nr.Los Naranjos ('dispersed site')	16.9.86
P2 88	60	Sediment.15-20cm core.	——	——
(b)Sandy Intertidal environments.				
35	61	Surface sediments, low tide level (exposed during spill)of reef flat.	Largo Remo, western edge of Lagoon shore (HC)	13.9.86
36	62	——	——	——
37	63	——	——	——
48	64	Surface sediments(low-extr. low tide level); upper 3 cm (mixed).	Largo Remo shore(W). Samples taken at approx. 10m intervals along transect parallel to shore (W-E). HC.	13.9.86.
42	65			
46	66			
39	67			
49	68			
50	69			
38	70 }			
40	71			
44	72			
47	73			
43	74			
45	75			
PX 9	76	Sub surface water sample, concentrated on Amberlite XAD resin column.	Galeta, sand zone on S. margin of STRI main lab, E. of mangroves.	14.9.86
PX 1	77	——	——	——
(c) *Thalassia* (shallow subtidal sand/mud) environments.				
P2 94	78	Sediments(about 60cm depth)	Isla Margarita. Oiled *Thalassia* bed. HC collection.	29.6.86
26	79	——	——	——
94	80	——	——	——
85	81	——	——	——
P2 82	82	Replicate of P2 94.	——	——
91	83	——	——	——
86	84	——	——	——
80	85	——	——	——

37

TABLE 1. (CONTD.)

SAMPLE No.	Acc. No.	SPECIMEN TYPE	LOCATION	DATE(d.m.y)
73	86	Surface sediments	Galeta STRI lab. reef flat *Thalassia patches* to N. of lab. NW-SE transect.	16.9.86
81	87			
82	88			
84	89 }			
93	90			
90	91			
P2 40.	92	Surface sediment(1-2cm).	Los Naranjos. Approx. 50m from shore opposite Witwater wreck. (Site#9[MM]).	11.9.86
P2 39	93	______	______	______
P2 36	94	______	______	______
P2 73	95	Surface sediment.	Opposite cement plant (off Isla Samba Bonita) [MM]	14.9.86
51	96	Sub-sample of P2 73		
56	97	______	______	______
58	98	______	______	______
P2 31	99	Surface sediment.	Largo Remo (Site#5.2 ? [MM])	14.9.86
63	100	______	______	______
53	101	______	______	______
65	102	______	______	______
P2 38	103	Surface sediment	Largo Remo lagoon (MM)	14.9.86
52	104	Sub-sample of 38.	______	______
66	105	______	______	______
67	106	______	______	______
P2 32	107	Surface sediment	Adjacent to Mamey Reef Reference site (#12[MM]).	15.9.86
68	108	______	______	______
76	109	______	______	______
88	110	______	______	______
P2 26	111	Surface sediment	Adjacent to Puerto Leone Reef .Reference site (MM)	15.9.86
69	112	______	______	______
70	113	______	______	______
78	114	______	______	______

(C) Coral Reef Environments(sub-tidal).

SAMPLE NO.	Acc. No.	SPECIMEN TYPE	FIELD LOCATION	DATE(d.m.y)
P2 86	115	Surface sediment at about 3m. depth.	Galeta Reef (extra site[MM]).	14.9.86
55	116	Sub-samples of 86.	———	———
60	117	———	———	———
61	118	———	———	———
PC01-5	119	*Siderastrea siderea* colonies. From about 0.5-1m depth.	———	———
PC06-10	120	*Agaricia tenuifolia* colonies. From about 0.5-1m depth.	———	———
P2 34	121	Surface sediment.	Largo Remo reef#2(MM)	14.9.86
64	122	———	———	———
54	123	———	———	———
59	124	———	———	———
P2 42	125	Surface sediment.	Patch reef off oil refinery. MM site#7.	14.9.86
41	126	Sub-sample of 42	———	———
62	127	———	———	———
57	128	———	———	———
PC21-25	129	*Siderastrea siderea* colonies. From about 0.5-1m depth.	———	———
PC26-30	130	*Agaricia tenuifolia* colonies. From about 0.5-1m depth.	———	———
P2 ~~86~~ 83	131	Surface sediments.	Los Naranjos reef. MM	16.9.86
72	132	———	———	———
96	133	———	———	———
98	134	———	———	———
PC41-45	135	*Siderastrea siderea* colonies. From about 0.5-2m depth	———	———
PC46-50	136	*Agaricia tenuifolia* colonies. From about 0.5-2m depth	———	———
P2 30	137	Surface sediments.	Mamey reef. Reference site (#12,MM).	15.9.86
74	138	———	———	———
75	139	———	———	———
79	140	———	———	———

TABLE 1. (CONTD.)

SAMPLE No.	Acc. No.	SPECIMEN TYPE	FIELD LOCATION	DATE(d.m.y)
PC61-65	141	*Siderastrea sidarea* colonies. From about 2m depth.	Mamey reef. Reference site (#12,MM).	15.9.86
PC66-70	142	*Agaricia tenuifolia* colonies. From about 2m depth.	———	———
P2 90	143	Surface sediments.	Puerto Leone reef. Reference site (MM).	15.9.86
71	144	———	———	———
77	145	———	———	———
87	146	———	———	———

(d) Standards.

P2 93	147	Refinery Crude oil sample. Venezuelen/Mexican Isthmus Blend.	STRI Galeta, 55 gal. stock	2.9.86 (15.9.86)
28	148	Avon™ "Skin So Soft" used as sand fly repellant.		14.9.86

TABLE 2. Samples stored frozen at STRI, Galeta Laboratory, for future petroleum hydrocarbon analysis at BBS.

(*KB/SW. In chest freezer; each replicate wrapped in foil; each set of replicates sealed in a clear bag with a BBS Reference Collection label inside, but not yet marked with codes. PLEASE DO NOT OPEN THESE BAGS. **EW/MM. Chest freezer. † HC. Upright specimen freezer, main lab).

SAMPLE No.	Acc. No.	SPECIMEN TYPE	FIELD LOCATION	DATE(d.m.y)
PC11-15*	(149)	*Porites astreoides* colonies about 0.5-1m depth.	Galeta Reef (additional site,MM)	14.9.86
PC16-20*	(150)	*Diploria clivosa* colonies about 0.5-1m depth.	______	______
PC31-35*	(151)	*Porites astreoides* colonies about 0.5-1m depth.	Patch reef off oil refinery. MM site#7	______
PC36-40*	(152)	*Diploria clivosa* colonies about 0.5-1m depth.	______	______
PC51-55*	(153)	*Porites astreoides* colonies about 0.5-2m depth.	Los Naranjos reef. MM	16.9.86
PC56-60*	(154)	*Diploria clivosa* colonies about 0.5-2m depth.	______	______
PC71-75*	(155)	*Porites astreoides* colonies From about 2m depth.	Mamey reef.Reference site#12. (MM).	15.9.86
PC76-80*	(156)	*Diploria clivosa* colonies From about 2m depth.	______	______
PC81-85*	(157)	*Siderastrea siderea* colonies From about 2m depth.	Puerto Leone Reef	15.9.86
PC86-90*	(158)	*Agaricia tenuifolia* colonies From about 2m depth.	______	______
PC91-95*	(159)	*Porites astreoides* colonies From about 2m depth.	______	______
PC96-100*	(160)	*Diploria clivosa* colonies From about 2m depth.	______	______
**		*S. siderea* colonies(*n*=6) 0-1m depth.	Margarita Reef.	14-15.8.86
**		*S. siderea* colonies(*n*=5) 3-5m depth.	______	______
**		*P. astreoides* colonies(*n*=5) 0-1m depth.	______	______

TABLE 2.(Contd.)

SAMPLE No.	Acc. No.	SPECIMEN TYPE	FIELD LOCATION	DATE(d.m.y)
**		*P. astreoides* colonies(*n*=4) 3-5m depth.	—	—
**		*D. clivosa* colonies(*n*=5) 0-1m depth.	—	—
**		*S. siderea* colonies(*n*=3) 0-1m depth.	Largo Remo Reef	—
**		*S. siderea* colonies(*n*=2) 2-5m depth.	—	—
**		*P. astreoides* colonies(*n*=6) 0-1m depth.	Largo Remo Reef	14-15.8.86
**		*D. clivosa* colonies(*n*=1) 0-1m depth.	—	—
**		*S. siderea* colonies(*n*=3) 0-1m depth.	Largo Remo Reef II	—
**		*S. siderea* colonies(*n*=1) 2-5m depth.	—	—
**		*P. astreoides* colonies(*n*=1) 0-1m depth.	—	—
**		*D. clivosa* colonies(*n*=4) 0-1m depth.	—	—
**		*S. siderea* colonies (*n*=6) 0-1m depth.	Punta Muerto Reef	—
**		*S. siderea* colonies (*n*=5) 3-6m depth.	—	—
**		*P. astreoides* colonies(*n*=5) 0-1m depth.	—	—
**		*P. astreoides* colonies(*n*=5) 3-6m depth.	—	—
**		*D. clivosa* colonies(*n*=7) 0-1m depth.	—	—
**		*D. clivosa* colonies(*n*=1) 3-6m depth.	—	—

TABLE 2.(Contd.

SAMPLE No.	Acc. No.	SPECIMEN TYPE	FIELD LOCATION	DATE(d.m.y)
**		*Diploria strigosa* colonies (*n*=4). 3-6m depth.	Punta Muerto Reef	14-15.8.86
†		Oil/tar scrapes. See Dr. Caffey's separate inventory.		
†		*Caulerpa racemosa*	Between Isla Margarita & Isla Naranjo	29.6.86
†		*Acanthophora spicifera*		
†		*Halimeda*		
†		*Thalassia testudinum*	———	———
†		*Palythoa caribaea*	———	———
†		*Echinometra Lucunter*	———	———
†		*Crassostrea rhizophorae* attached to mangrove root	———	23.6.86
†		Oiled mangrove roots, some with epifauna.	———	
†		Oil and seawater in jar	?	14.6.86

Samples labelled for "histopathological analysis", upright specimen freezer in main lab:

SPECIMEN TYPE	FIELD LOCATION	DATE(d.m.y)
D. clivosa (*n*=2);0.3-1m depth.	Largo Remo Reef.	23.7.86-7.8.86
S. siderea(*n*=5); 0.3-1m depth	———	———
Palythoa caribaea (*n*=1)	———	———

THE EFFECTS OF THE BAHIA LAS MINAS OIL SPILL ON *THALASSIA* MEADOW COMMUNITIES

Michael J. Marshall

Report Number One - May 28, 1987

THE EFFECTS OF THE BAHIA LAS MINAS OIL SPILL ON *THALASSIA* MEADOW COMMUNITIES

Introduction

The recent oil spill at Bahia Las Minas, Panama contaminated a large area of the nearshore environment, including many hectares of seagrass meadows, from the Atlantic entrance of the Panama Canal to Maria Chiquita. Effects of crude oil contamination on the structure of animal communities within seagrass beds have not previously been adequately described. Diaz-Piferrer (1962) provided an anecdotal description of the effects of a large oil spill on a seagrass bed in Puerto Rico. Zieman (1982) reviewed oil spill incidents which affected seagrass beds around the world. The 1978 *Amoco Cadiz* spill caused leaf damage to *Zostera marina* beds in France. Filter feeding amphipods and polychaetes were killed while other guilds were less affected. Eelgrass roots and rhizomes apparently prevented oil from mixing with the sediment and thus protected non-filter feeding infauna. A spill in Puerto Rico during March of 1973 killed many animal species including sea urchins, conchs, polychaetes, prawns, and holothurians. The oil, when mixed with seawater by stong winds, also killed *Thalassia*. Loss of dense beds of *Thalassia* resulted in sediment erosion. Some new growth of *Thalassia* was noted by January of 1974 and continued through 1976. Infaunal communities were insufficiently sampled but showed general declines soon after the spill. Seagrass bed destruction, for other reasons, resulted in drastic changes in the shape of a barrier island on Florida's west coast (Hine et al,1987).

In Fuerto Rico beds of Thalassia showed signs of continuing "degeneration" five months after an oil spill caused by the breakup of an Italian tanker (Diaz-Piferrer, 1962). The loss of Thalassia and other seagrasses in an area would have many negative effects on the animals living in the community. Dense beds of seagrasses serve as shelter for many organisms, they slow currents and decrease turbulence caused by waves, they act as sediment traps for silt and other fine suspended particles, through their photosynthetic activities they produce large amounts of oxygen, and they create a shaded micro-environment beneath their leaves (reviewed in Kikuchi and Peres,1977). They also act as a substrate for many species of epiphytic microalgae (Humm, 1964). Epiphytes on Thalassia and detritus derived from decaying seagrass blades have both been shown to be important foods in the diets of many marine species (Odum and Heald, 1975; Morgan, 1980; Leber, 1983; Howard, 1984; Marshall,1985). Thus, in addition to the direct effects of oil on marine organisms in seagrass beds, the loss of seagrasses should alter the environment (as reported in Zieman, 1982) and decrease the supply of food.

Results from this five-year project will be applicable to management issues which have arisen due to proposed oil exploration and drilling projects close to Thalassia meadows along the Florida reef tract. Seagrass meadows along Florida's central and northern Gulf coast are seasonally ephermeral with extensive blade-shedding occuring during the fall months in shallow water (Marshall, 1985). The effects of an oil spill in this region may be correlated with seasonal changes in seagrass biomass. Recolonization experiments usually show that recovery of artificially stressed environments occurs more rapidly in frequently disturbed environments (Boesch and Rosenberg, 1981). Colonization of oiled sediments in experimental trays, for example, was shown to follow different pathways at a marsh versus a deep bay site in Rhode Island (Hyland et al, 1985). The authors attributed these differences to the relative stability of these two environments and to differences in species composition. The vastly greater physical and biotic differences which exist between tropical and subtropical grassbed environments make it very important to directly observe the effects of oiling on both types of seagrass bed ecosytems.

This report describes the preliminary results of a five-year oil spill recovery study in tropical seagrass meadows. To date animals found in benthic core samples collected during September 1986 and November 1986 have been sorted to major taxonomic categories. Seagrasses from these samples were dried, weighed, and their root to leaf ratios were calculated. The animal taxa included in this report are those which are usually very abundant in temperate and tropical grassbeds. Very little prespill data exists for the grassbed infauna in the Galeta area. Thus the differences seen in this preliminary study between oiled and clean grassbed sites are probably due to the effects of oil but could be due to natural variation between geographically separated seagrass meadows.

METHODS

Seagrass meadows from Isla Margarita, near the Atlantic entrance of the Panama Canal, to Isla Juan Joaquin (near Isla Grande) were chosen as study sites. Criteria used in selecting sites were that each grassbed must lie adjacent to a mangrove shoreline and that the grassbeds must be subtidal but shallow enough to be sampled without SCUBA gear. Most of the sites also were located behind small patch or barrier reefs at the seaward edges of the grassbeds. Each seagrass meadow was classified as being either clean, lightly, or heavily oiled (Table 1) based on observations made in the field and knowledge of the path of oil immediately after the spill.

Samples of seagrasses, algae, and benthic fauna were collected, at wadeable depths, with a PVC coring tube (10.16 cm inside diameter). Each sample consisted of three pooled cores totaling 0.024m^2 in area. Eight samples were taken at each of 12 grassbed sites. Sample locations within each grassbed were randomly selected. Rock outcroppings or hard shell bottoms often prevented sampling precisely at the randomly selected positions. Sample locations were also adjusted to avoid sampling too near the edges of the seagrass beds. Patches of pure *Syringodium filiforme* were also avoided.

Upon collection samples were sieved through 500um mesh screen and preserved in buffered 10% formalin with rose bengal. In the lab samples were gently washed to remove formalin. Seagrass blades and roots were separated from the samples and dried at 90°C for five days. Prior to drying blade and root masses were carefully examined for hidden animals and attached epiphytic macroalgae were removed. After drying blades and roots were weighed. Macroalgae in the samples were identified to species, dried, and weighed. Animals were sorted to major taxa. For this report certain taxa, those which are usually abundant in tropical and temperate grassbeds, were counted and/or their wet weights were determined. Species identifications are underway for all animals collected in the core samples.

Mobile epifauna were collected by pushnet sampling along transects within each grassbed (started in November). The epifaunal community , which is not protected by sediment and seagrass roots, may be more adversely affected by oil than the infaunal community of seagrass beds.

Results

Polychaete biomass (Figure 1a) was much lower at the most heavily oiled stations than at the clean and lightly oiled sites during both September and November. There was a seasonal increase in polychaete biomass from September to November at all of the stations but polychaete biomass remained lowest at the most heavily oiled sample sites. This same pattern of biomass/sample held true for amphipods in September and November (Figure 1b). Ophiuroids (Figure 1c) were completely absent at the most heavily oiled sites in September. Ophiuroid biomass also decreased from September to November at the lightly oiled stations. During September no ophiuorids were found at the heavily oiled stations.

Counts of individuals in the various taxa generally were highest in the clean areas and lowest at the heavily oiled sites. The highest densities of bivalves were found in the clean, grassbed areas. Gastropods (Figurd 2d), although not abundant in any area, were most common in the clean and lightly oiled locations. Pagurids, the only exception to the general pattern, were more common in the oiled areas than in the clean areas (Figure 2e).

Seagrass root and leaf biomass distributions across the clean and oiled sites showed trends which could be attributed to the effects of oil (Figure 3). Root and leaf biomass were lowest at the heavily oiled sites during September. Leaf biomass at the heavily oiled sites increased between September and November until it equaled the seagrass leaf biomass of the clean and lightly oiled sites. A seasonal increase was obvious in leaf dry weights at the clean and lightly oiled sites between September and November. Root dry weights were highest at the lightly oiled sites in September and November. Root biomass was lowest at the most heavily oiled sites in September and increased slightly by November. Seagrass root to leaf ratios (Figure 3c) also showed trends which could be explained by the effects of oiling over the three-month duration of this preliminary study. A decrease in root to leaf ratios between clean, lightly, and heavily oiled grassbed sites was apparent in September but had disappeared by November.

Discussion

Polychaetes live at various levels within bottom sediments and are divisible into an array of feeding types (Fauchald and Jumars, 1979). Carnivores, herbivores, filter feeders, and/or deposit feeders are found in most soft-bottom communities. In this report polychaetes were apparently negatively affected by oil but not as greatly, on a wet weight basis, as were the amphipods and ophiuroids. After the Amoco Cadiz oil spill burrowing, non-filterfeeding benthic fauna were protected by the thick mass of roots and rhizomes of Zostrea marina (Zieman, 1982). The roots and rhizomes of Thalassia in the heavily oiled areas near Galeta Point may also have protected those polychaetes which burrow deeply and which do not filter feed. Comparison of the polychaete species, and the habits of each species, collected in the clean and oiled areas will show if the various polychaete feeding guilds are differentially affected by oil pollution.

Ophiuroids were not found at the most heavily oiled sites (4 geographically separated seagrass meadows) during September. Ophiuorids include many species which deposit- and suspension-feed (Sides and Woodley, 1985). Eleven species of ophiuroids have been reported from reef flat Thalassia beds at Galeta Point (Birkeland et al, 1976). The burrowing species among these may have been protected from oiling by the roots and rhizomes of Thalassia. Their sensitivity to oil however, as evidenced by their absence at the heavily oiled stations, might be related to their feeding habits. Suspension feeding would require contact with oiled surface sediments. Direct toxicity of the oil or fouling of respiratory surfaces may also have killed ophiuorids since other, non-filter feeding echinoderms were virtually absent from the oiled grassbeds (personal observation) in areas where they were abundant (John Cubit, personal communication) before the oil spill.

Amphipods were virtually absent from the most heavily oiled stations while they were abundant at the clean. Amphipoda include filter feeders but most species are detritus feeders or scavengers (Barnes, 1980). Most filter feeding amphipods are tube-dwellers but amphipod tubes were rare or completely absent in the core samples. Most of the amphipods I collected were probably surface dwellers or were associated with Thalassia blades. Most crustaceans seem to be very sensitive to oiling (Krebs and Burns, 1978). Ecdysis may be a period when crustaceans are especially sensitive to oiling (Laughlin and Neff, 1979) although Percy (1978) reported that an isopod, Mesidotea entomon, molted repeatedly in the water soluble fractions of fresh and weathered crude oils. Considering the amount of oil spilled at Galeta surface dwelling amphipods were probably coated in oil and/or were killed by its toxic effects.

Hermit crabs, unlike amphipods, were more abundant at all of the oiled sites than at the clean sites during September. Their densities may have increased due to an increased supply of empty gastropod shells. During September gastropod abundance was lowest in the same sites where hermit crab abundance was greatest. Aggregations of hundreds of pagurids were seen in September at the mouth of the heavily oiled Largo Remo channel grassbeds (personal observation) and in other oiled areas by

Caldwell and Steger (unpublished oil spill report). Hermit crab counts remained highest at the lightly oiled stations through November. Analyses of length-frequency distributions of hermit crabs and gastropod shells may provide an explanation for these patterns of abundance. Empty gastropod shells, saved from each sample, will eventually be examined to determine causes of death. Shells in the clean areas would be expected to have been killed by crabs. More intact shells might be found in the oiled areas if oiling killed both snails and crabs.

Bivalves were also adversely affected by oil. Bivalves were not very abundant in the Galeta area prior to the oil spill (Jackson, 1973). No living bivalves, however, were found in the heavily oiled areas at or near the grassbeds sampled by Jackson. Many dead bivalves were found with articulated (hinges intact) shells and/or with a rose bengal stained layer of periostracum which suggests that they had recently died. Oil at moderate to low concentrations has been reported to slow clam (*Mya arenaria*) growth rates (Gilfillan and Vandermeulen, 1978) and to alter their respiratory rates (Stainken, 1978). One would expect that tremendous amounts of oil emulsified in seawater would quickly clog bivalve gills irrespective of its chemical toxcity to bivalves.

Comparison between grassbeds of the biomasses of *Thalassia* rhizomes, roots, and leaves is difficult. Zieman (1982) reported a wide range of total *Thalassia* biomass, from 379g/m^2 to 2,613g/m^2, within a single Florida bay. Large differences in root and rhizome biomass between grassbeds have been attributed to sedimentary differences (Zieman, 1986). It is highly probable that the biomass differences seen between the oiled and clean seagrass meadows are due to factors other than oiling. Unlike the oil-induced death of dense beds of Thalassia in Puerto Rico (Zieman, 1982) no extreme changes in subtidal seagrass biomass were seen following the spill at Bahia Las Minas. An intertidal seagrass meadow was destroyed, however, at a very heavily oiled site adjacent to Largo Remo Island (Caldwell and Steger, unpublished oil spill report).

Species identifications of each of the above taxa, and the other taxa, collected in seagrass core samples will provide a tremendous amount of information on how each species responds to oiling. Since prespill data on infaunal community composition does not exist for most of the grassbed sites, with the exception of two sites near Galeta Point (Vasquez-Montoya, 1979), it is difficult to state that the differences seen between the clean and oiled areas are due to the effects of oil. Major prespill differences may have existed between the grassbeds. Definitive statements concerning prespill and postspill community differences can only be made by following the "recovery" of the oiled beds' animal fauna and by monitoring the natural seasonal fluctuations of the clean beds' fauna.

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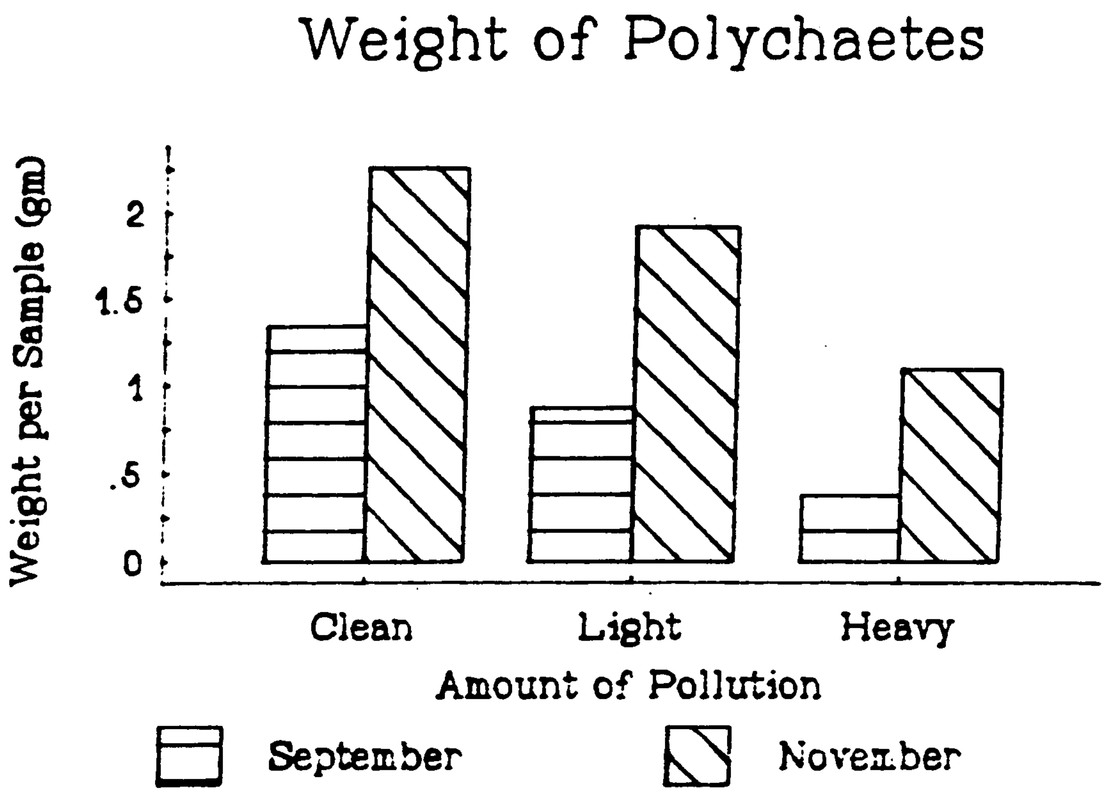
	September	November	January	April	Oiling
I. Margarita I	?	clean	ns	ns	light
I. Margarita II*	ns	clean	ns	ns	light
Galeta I	sed	sheen	cores	cores	heavy
Galeta II	sed	sed	ns	ns	heavy
Galeta III*	ns	cores	cores	cores	heavy
Galeta IV*	ns	sed	sed	sed	heavy
LR Entrance	sed/sheen	sed/sheen	sed/sheen	sed/sheen	heavy
LR Lagoon	sed	sheen	sheen	sheen	light
Concrete Fctry.	sed/sheen	sed/sheen	sed/sheen	sed/sheen	heavy
Los Naranjos I	sed	sed	ns	ns	light
Los Naranjos II*	ns	?	ns	ns	light
Buenaventura	clean	clean	clean	clean	clean
Porto Leone	clean	clean	clean	clean	clean
Mame I	clean	clean	clean	clean	clean
Mame II	clean	clean	clean	clean	clean
Isla Linton (K.C.)	clean	clean	clean	clean	clean

Table 1. Field observations on oiling conditions at each seagrass bed site. Locations marked by an asterisk were not included in this preliminary report. N.S. = not sampled; sed. = oil seen in core samples during field processing; cores = oil seen in cores during lab processing of samples; sheen = thin layer of oil on surface at sample sites prior to start of sampling; ? = not recorded.

Figure 1. Wet weights per sample of a) polychaetes, b) amphipods, and c) ophiuroids at clean (n = 40), lightly oiled (n = 32), and heavily oiled (n = 28 in September and n = 32 in November) Thalassia meadows during September 1986 (cross bars) and November 1986 (diagonal bars). No ophiuroids were found in samples taken at the most heavily oiled sites during September.

Figure 1


Weight of Polychaetes
Weight per Sample (gm)
0
.5
1
1.5
2
Clean
Light
Heavy
Amount of Pollution
September
November

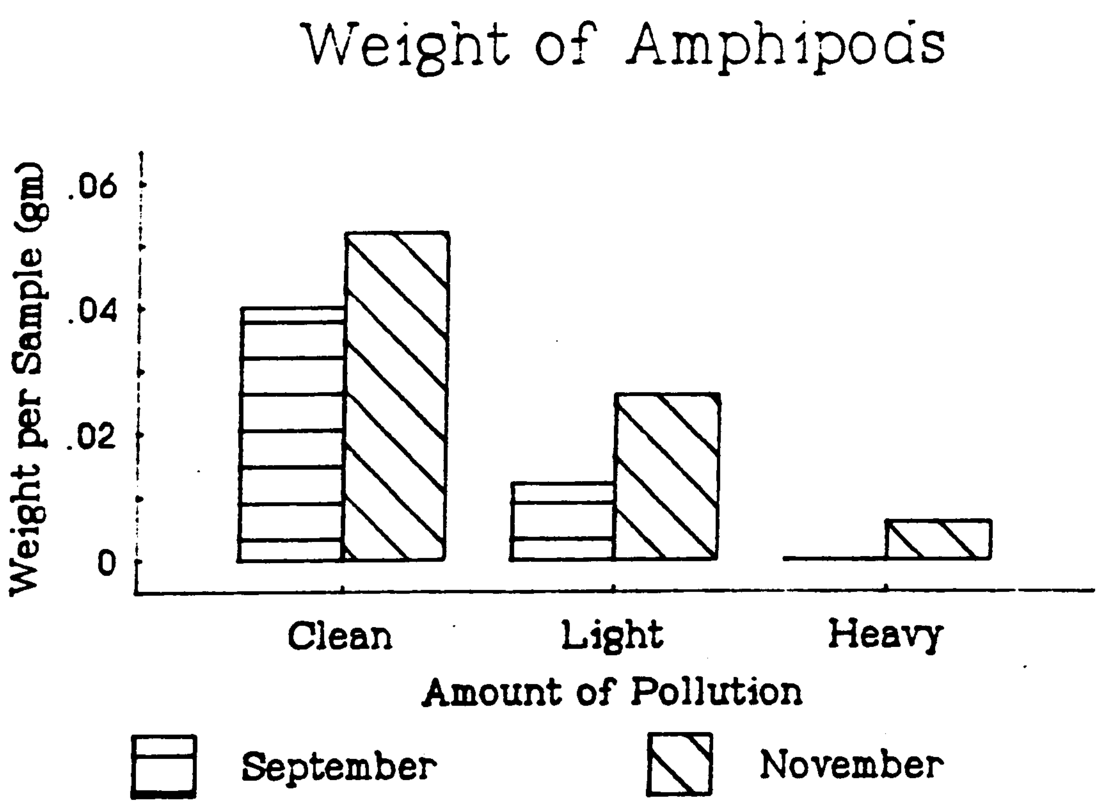

Weight of Amphipods
Weight per Sample (gm)
0
.02
.04
.06
Clean
Light
Heavy
Amount of Pollution
September
November

Figure 1 (cont.)

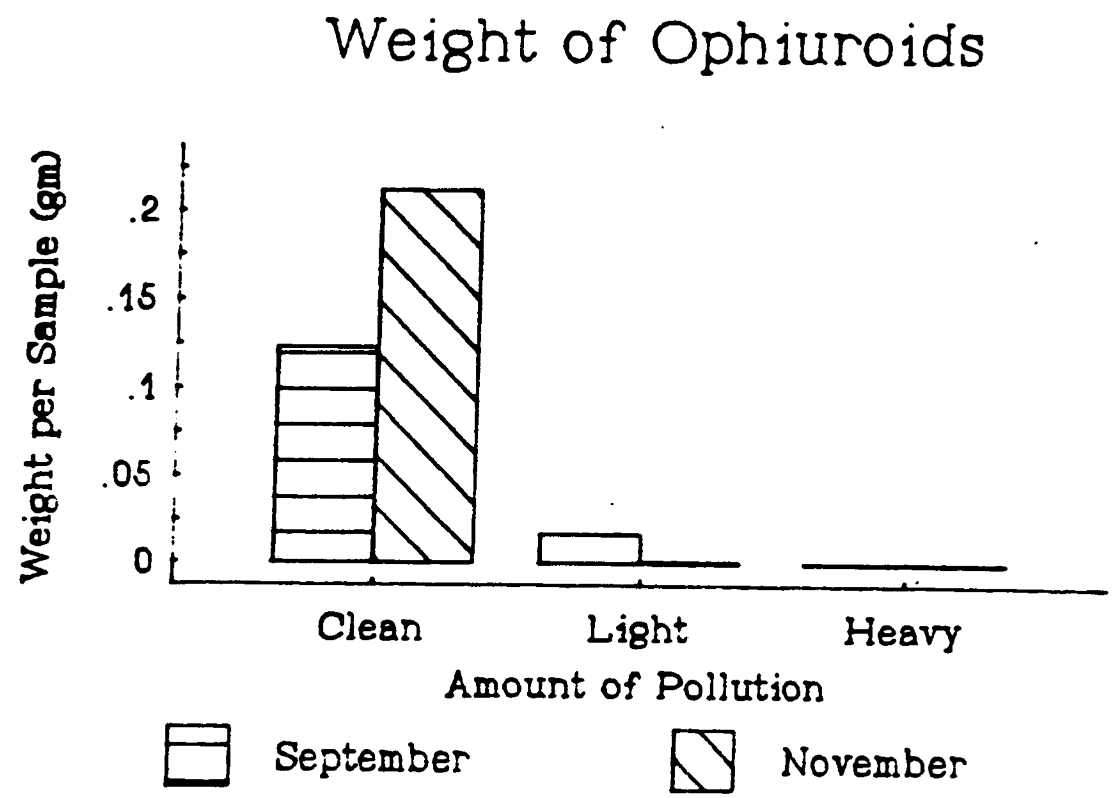


Figure 2. Counts of individuals per sample of a) amphipods, b) ophiuroids, c) bivalves, d) pagurids, and e) gastropods from clean (n = 40), lightly oiled (n = 16), and heavily oiled (n = 28 in September and n = 32 in November) *Thalassia* meadows during September 1986 (cross bars) and November 1986 (diagonal bars).

Figure 2

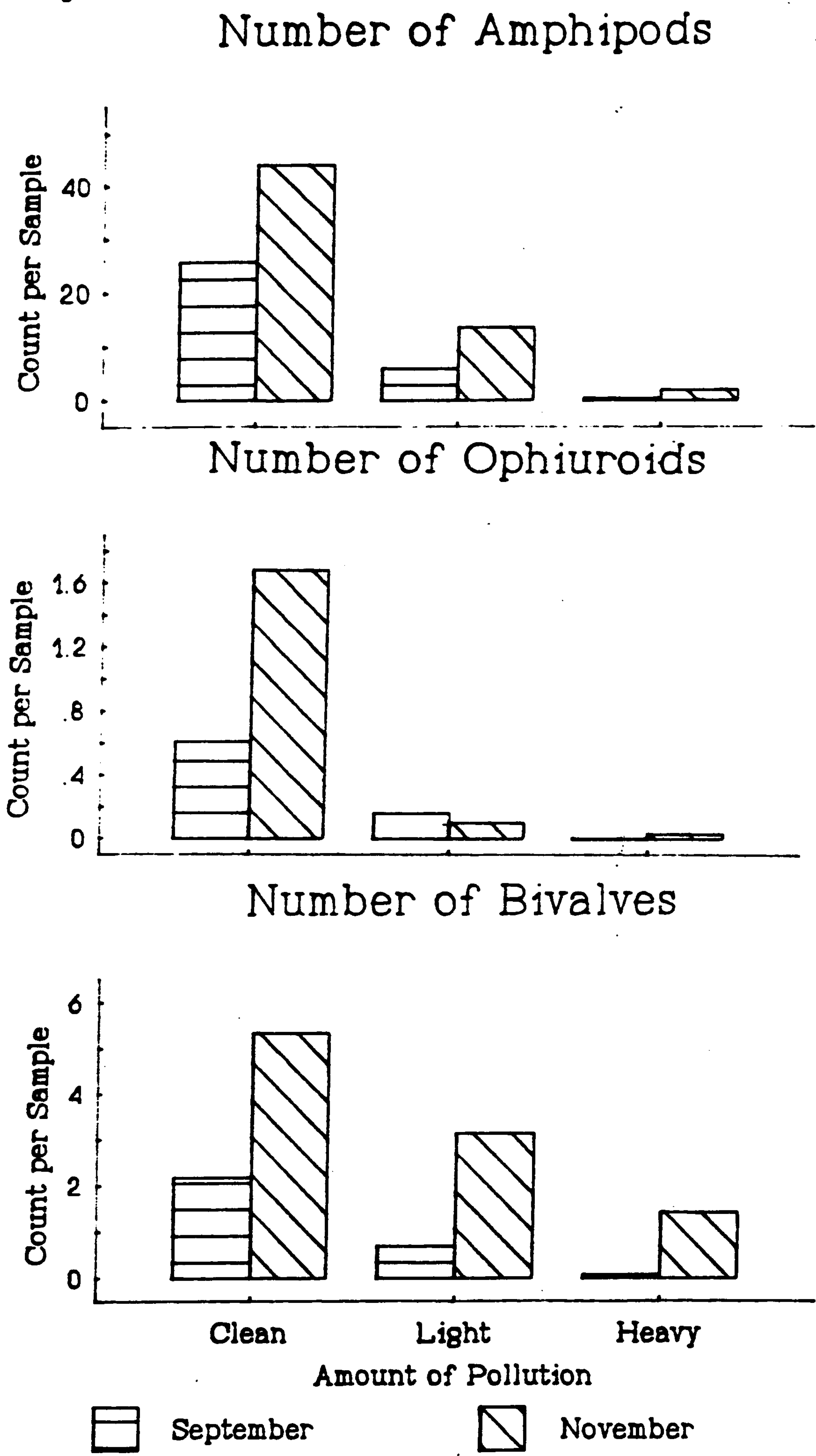

Number of Amphipods
Count per Sample
0
20
40
Number of Ophiuroids
Count per Sample
0
.4
.8
1.2
1.6
Number of Bivalves
Count per Sample
0
2
4
6
Clean
Light
Heavy
Amount of Pollution
September
November

Figure 2

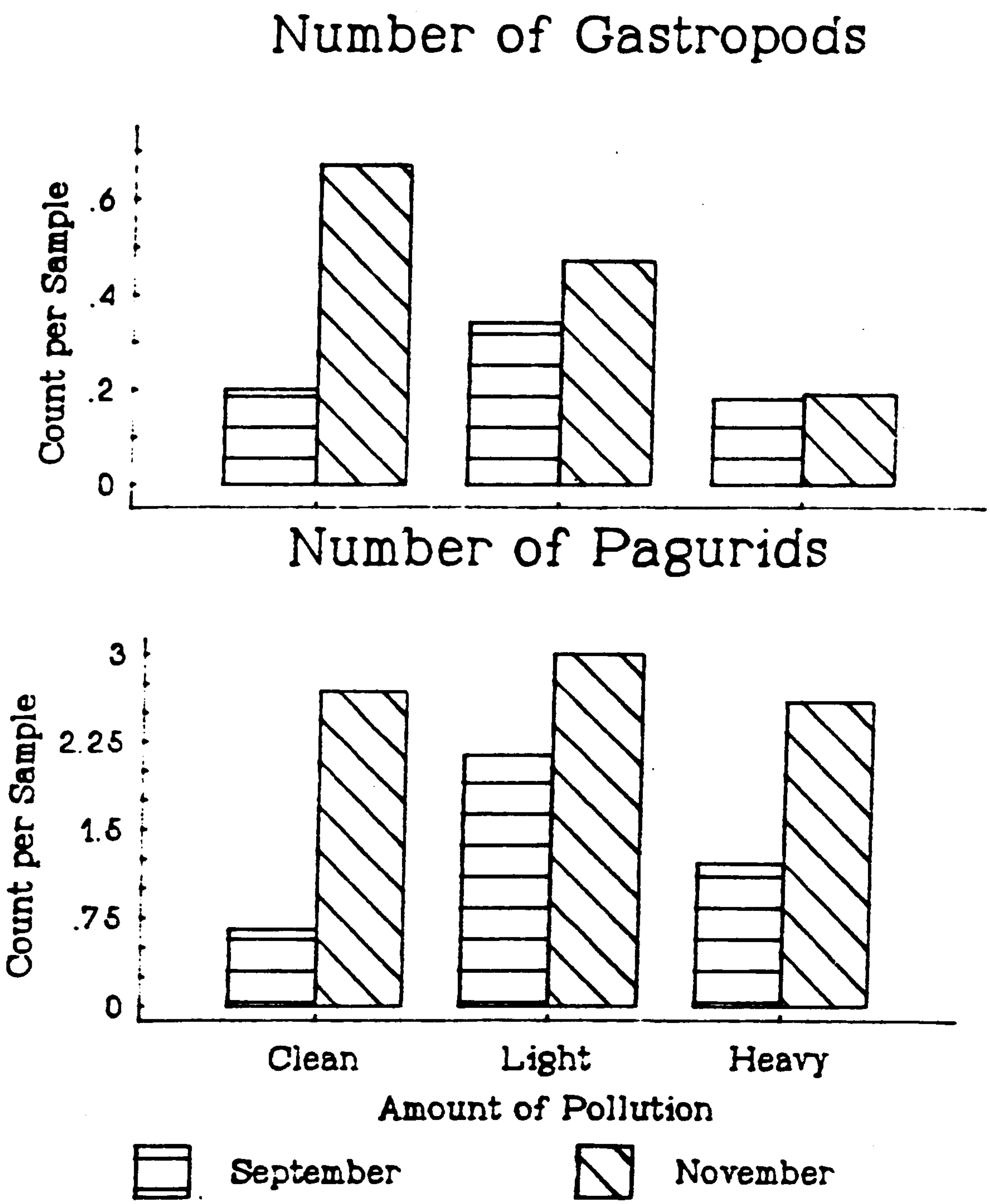
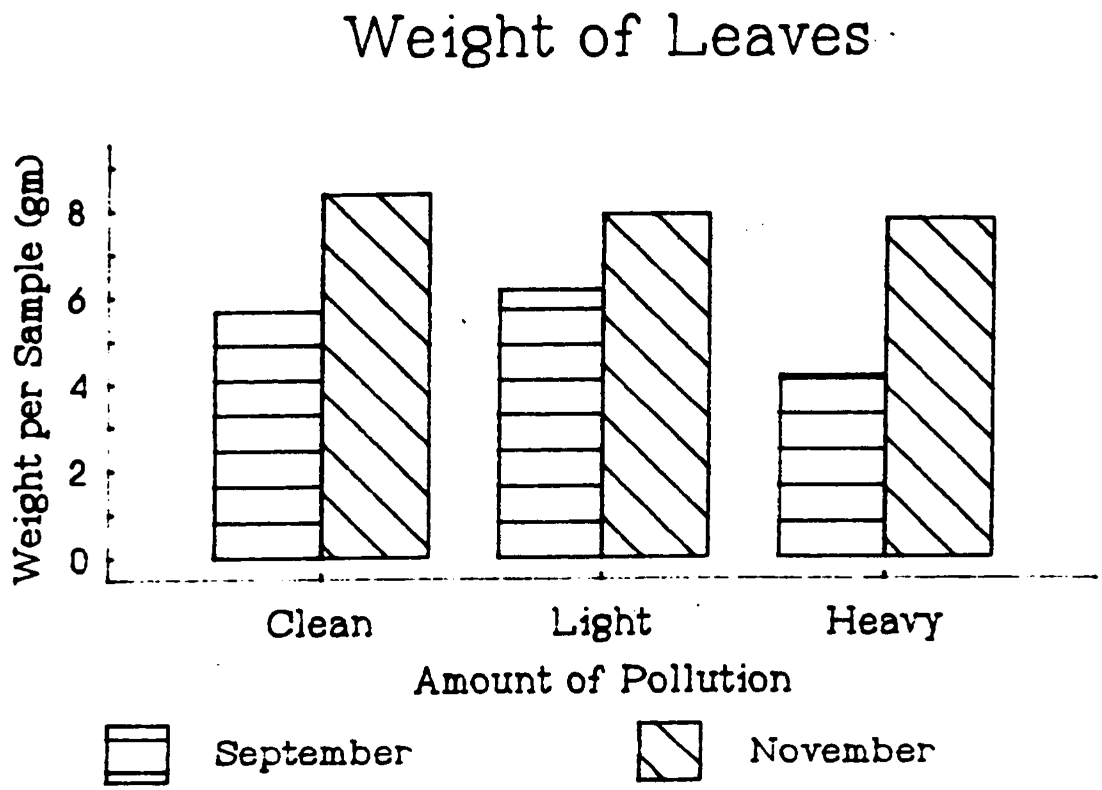
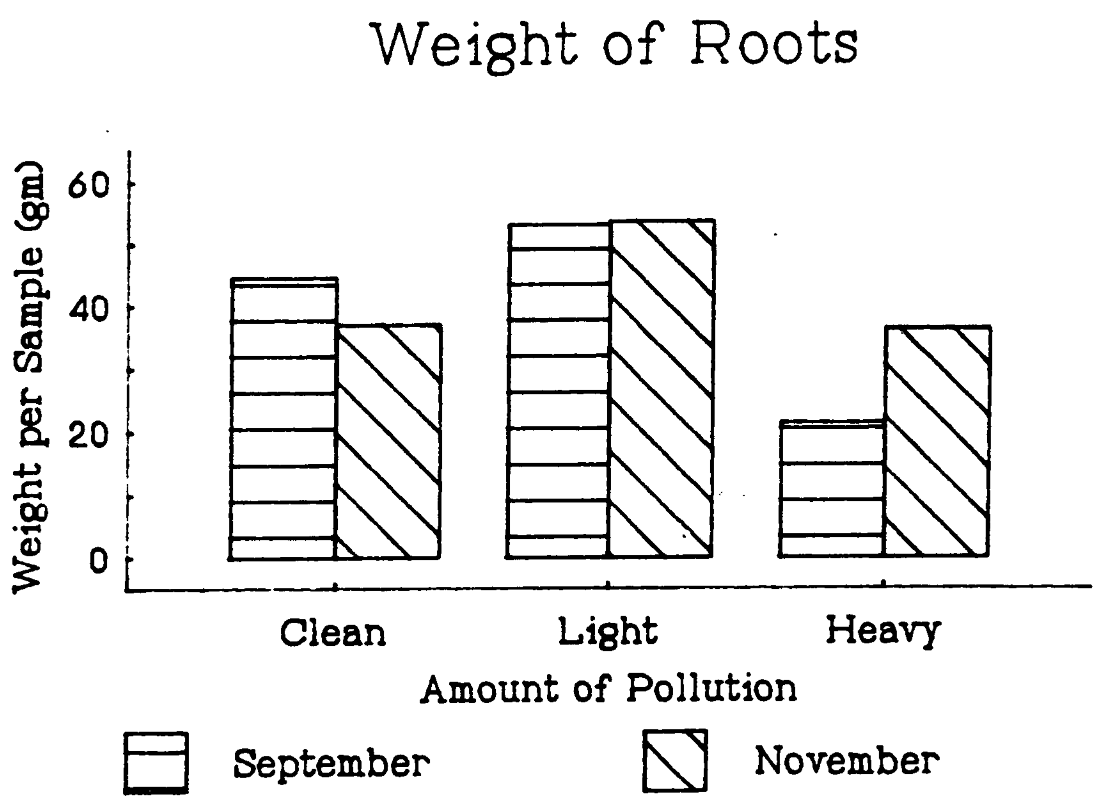
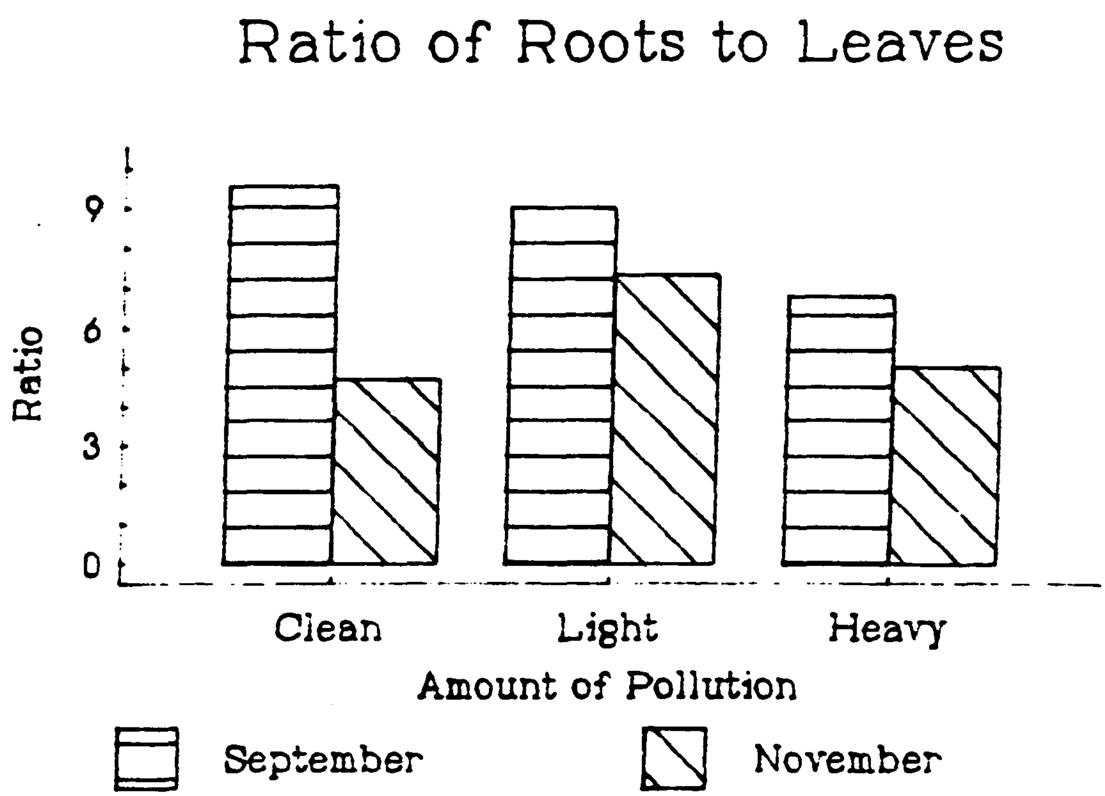

Number of Gastropods
Count per Sample
0
.2
.4
.6
Number of Pagurids
Count per Sample
0
.75
1.5
2.25
3
Clean
Light
Heavy
Amount of Pollution
September
November

Figure 3. Dry weights of *Thalassia* a) roots (=roots and rhizomes) and b) leaves at clean, light, and heavily oiled grassbed sites during September (cross bars) and November (diagonal bars) 1986. c) Root to leaf ratios were determined for these same sites.

Figure 3


Weight of Leaves
Weight per Sample (gm)
0
2
4
6
8
Clean
Light
Heavy
Amount of Pollution
September
November


Weight of Roots
Weight per Sample (gm)
0
20
40
60
Clean
Light
Heavy
Amount of Pollution
September
November



Ratio of Roots to Leaves
Ratio
9
6
3
0
Clean
Light
Heavy
Amount of Pollution
September
November

Submitted To:
Smithsonian Tropical Research Institute
A.P.O. Miami, FL 34002-0011

MANGROVE CANOPY AND SEEDLING SURVIVAL AT DIFFERENT FORESTS FOLLOWING A MAJOR OIL SPILL IN PANAMA

FINAL REPORT

Submitted By:

Charles D. Getter, Ph.D.
Scientist-in-Charge
Mangrove Subproject
915 Academy St. NE
Salem, OR 97303

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INTRODUCTION

Mangroves are long-lived saltwater trees that dominate low-lying coastlines of the tropics and subtropics, including much of the Caribbean and the Gulf of Mexico (West, 1976). In this region, they coincidentally dominate shores adjacent to areas of petroleum exploration, production, refining and transportation. From laboratory and field studies it is known that oil kills mangrove trees and their associated organisms; if only sublethal doses are received, oil will alter their growth (Getter et al., 1985). Moreover, fallen, dead trees may inhibit recovery of forests by disturbing newly established seedlings. This insidious, long-term problem may lead to a diminished value of mangroves as important nursery grounds for numerous fishes and shellfish for long periods of time. In addition, through the loss of mangroves, shorelines may be destabilized, resulting in beach erosion or in the extensive movement of sediment into adjacent environments.

Mangrove Forests in the Study Area

At least 4 mangrove species occurred along the Carribean Coast of Panama impacted by the oil spill. This included the red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), and the buttonwood (*Conocarpus erectus*). Of these, the red and white mangroves were the most seaward in occurrence; they were, therefore, the species most directly exposed to oil. Overflights in June, 1986 showed that over fifteen km of mangrove coastline between Isla Margarita and Maria Chiquita were oiled from the spill (Figure 1). Mangroves in this area ranged from highly sheltered forests at the heads of embayments, to fringing forests which were directly exposed to open sea surge during storms. In general, the more diverse, well-developed forests occurred at the sheltered bay heads where they were influenced by river drainages.

Several oiled mangrove forest types were identified during overflights in July, 1986; extensive mortality was documented throughout the heavily oiled area. These forest types included riverine, basin, overwash, and fringing forests according to the classification scheme of Lugo & Snedaker (1974). Riverine forests of this area were associated with small- to medium-sized river deltas at the bay heads. Fringing forests, however, tended to be associated with distinctive berms and beach faces in sheltered and exposed areas throughout the region. Basin forests were the most sheltered forests in the region; these were extensive and characterized by limited flushing, a lower canopy height, lower amounts of standing wood, and local recycling of nutrients.

Research Goals

The expanse and variety of forests, and the degree to which they were oiled, presented an opportunity to compare the effects of a single spill across a spectrum of mangrove forest types. This was significant since, in the past, many national governments have assigned a high, but uniform sensitivity ranking to mangroves regardless of their individual characteristics. These different types of forests may, however, respond differently and require different management. Therefore, in this paper, the following null hypothesis was tested:

H_o: All mangrove forests are uniformly sensitive to the effects of oil.

To narrow the research variables considerably, only fringe forest types of 2 different exposure regimes were examined. Therefore, sheltered, fringing forest type was compared with an exposed fringing forest type.

MATERIALS AND METHODS

Site Selection and Criteria

Overflights by helicopter were conducted in June and July 1986, in which color slides and videotapes were made of the entire, heavily oiled coast. These slides and videotapes were intensively reviewed. This allowed the selection of 3 sites, which objectively represented an oiled fringing forest (sheltered), an oiled fringing forest (exposed) and a fringing forest which was never oiled (Figure 1). Throughout this report, these forest sites will be referred to as the "sheltered", "exposed" and the "reference" forests respectively.

The sheltered forest was selected from the southeastern coast of Isla Samba Bonita; a 1.1 km strip of forest was available for study, all directly effected by the oil-spill. The exposed forest was selected from the northeastern coast of Largo Remo Island; a strip of forest 1.3 km was available for study, all directly effected by the oil-spill.

Reference sites were not available along the outer coast, due to the complete oiling of mangroves there during and after the spill. The search for, and selection of, a suitable site was done in the bay heads which (except for those directly adjacent to the refinery) were free from oil. Selected was a forest in a small bay west of Isla Samba Bonita. This forest was also the source for seedlings (propagules) for subsequent experiments since it was free of oil spill contamination.

Transect Placement and Zone Definition

The ultimate selection of the forest sites was based upon visual inspection, and was biased towards areas of equal forest development. For this selection, factors such as height and age of trees, and species composition were used. Forests were chosen which were free of cutting and other obvious perturbations. A bias was made toward forests which were accessible both for the initial survey and for monthly revisits. A bias was made as well as for a planned siliculture experiment, for which it would be necessary to maneuver medium draft vessels to and from the forests.

Each forest site was then staked out, with the (front forest) center stake being placed at the waterline. A Sumpto siting compass was then used to set a stake at the storm swash within the interior forest (mid-forest), and also to set a stake above the intertidal zone (back forest). All stakes were used to define the center of a zone; they were set perpendicular to the waterline at the front of each forest site. Throughout the remainder of this report, these are referred to as the front forest zone, the mid-forest zone, and the back forest zone.

Macrostructural Measurements

The variables used to quantify structural characteristics of the mangrove forests were: species composition, tree diameter at breast height (DBH), forest height and leaf area index (LAI).

All larger trees (greater than 5 cm DBH) along the transect were marked and numbered. Tree heights were determined with a telescoping fiberglass measuring pole. The diameters of each tree at DBH was measured at 1.3 m above the substrate surface. Because of the unusual growth form of some mangroves, the determination of trunk (bole) diameter and number of boles was sometimes difficult. To standardize these measurements, the following criteria were used: (Cintron and Schaffer-Novelli, 1984):

(1) If the tree had multiple boles and these forked or sprouted from a common base below breast height, each was measured as a separate bole;

(2) If the tree had multiple boles and they forked above or at breast height, the DBH was determined at breast height or just below the swelling caused by the fork (i.e., if the fork was at or above breast height, it was considered as only one bole);

(3) If the bole had prop-roots at breast height, the diameter was measured above them where the prop-roots did not bias the measurement; and

(4) If the bole had swellings, branches or abnormalities at breast height, the DBH was measured either above or below the irregularity where it stopped influencing normal form.

At each bole intersection, the LAI was determined; this was the area (one side) of the leaf material per ground surface area. The LAI was determined with a telescoping rod which was inserted through the forest canopy and the number of leaves touching the rod counted. The number of leaves touching the rod was the LAI.

Phytometry

At each forest, 9 groups (3 replicate plots x 3 zones) of twenty-five red mangrove propagules were planted in August; they were monitored monthly through November for sprouting success and total leaf area. Data given in this report are from the November survey.

RESULTS

Similarity in Tree Size and Species Composition

Larger organisms are generally more resistant to spilled oil; past observations made during spills indicate that smaller mangrove trees, with shallower root systems, are more prone to mortality or stress. By measuring forest height and tree diameter, forest similarity was established.

Table 1 and Figure 2A show that no significant differences existed between forest sites in terms of mean forest height. Within each forest, however, as is typical in fringe forests, the front forest zones are significantly taller than the back forest zones (means = 6.98 -vs- 4.29 m). In all cases, the mid-forest zone was similar in height to the back forest zone. In 2 out of 3 cases, the mid-forest zone was similar in height to the front forest zone. The mid-forest zone was, therefore, usually intermediate in size.

The mid-forest zone at the reference forest consisted of trees with a significantly larger mean diameter than those at the mid-forest zone of the sheltered forest (means = 12.05 -vs- 5.80 cm). Otherwise, there were no significant differences between forests measured in terms of mean tree diameter (Table 2; Figure 2B). The back forest zone was always somewhat smaller in forest height than the other zones, and in 2 of 3 cases, it was significantly smaller in tree diameter than trees in the front forest zone.

Species composition was also similar between forests. Red mangroves were found exclusively at the front forest zone in all three forests. In all three forests, the mid-forest zone was a mixed red-white mangrove forest, dominated by red mangroves. In only 1 case, at the back forest zone of the reference site, did white mangroves dominate in number and size over red mangroves.

Oil-Induced Changes to the Canopy and Sprouting Success

Significant differences in LAI were measured between forests and between zones (Table 3; Figure 3A). Interpreting these differences was complicated by the absence of prespill data for the canopy at oiled forests. The reference forest was used for some analysis of trends therefore. At the reference site, the LAI followed the same trends as did forest height and tree diameter (Figures 1A and 1B); that is, the smaller trees were in the back forest zone, intermediate size trees in the mid-forest zone, and the largest trees in the front forest zone. Some of the variability of forest height, diameter and LAI was created by the presence of an understory throughout the zones, since these measurements are sensitive to understory growth. Significance in the pattern of LAI between zones at the reference site was therefore masked by this phenomenon. It was concluded, however, that no significant difference between LAI at the zones at the reference forest existed.

A dramatically different situation was seen, however, at the oiled forests (exposed and sheltered; Table 3; Figure 3A). The mid-forest zone at the exposed forest, and the mid- and front forest zones at the sheltered forest were reduced to no leaves in the canopy (LAI=0). The front forest zone of the exposed forest was reduced in LAI, although not significantly.

The sprouting success and new leaf production of propagules at each zone in each forest was also measured. Dramatic differences were seen between the reference and the oiled (sheltered and exposed) forests. Table 4 and Figure 3B indicate a total failure to sprout of propagules in the mid- and front forest zones at the oiled forests. Table 5 and Figure 3C plot the new leaf area produced by these propagules indicating the same effect. From these results, it appears that propagules are more sensitive as an indicator of stress and mortality than is the LAI of adult trees. Furthermore, when combined with results of the LAI, there appears to be a clear difference between the pattern of canopy loss and failure of propagule sprouting between forest types.

DISCUSSION

Previous publications discussed qualitative models which described observations on patterns of oil spill effects between different mangrove forests (Getter et al., 1981). Figure 4 gives one such impact model; note the distinct area of defoliation at the mid-forest zone in the exposed forest, and that both the front and mid-forest zones of the sheltered forest are defoliated.

In proposing a mechanism for the distribution of impacts, the following is suggested:

(1) The pattern of defoliation may be controlled by degree of exposure to wave energy. In the exposed forest model, oil is pushed by wave action ever further back into the forest until it encounters a berm onto which it accumulates. Furthermore, these processes tend to cleanse the front forest zone resulting in survival of trees there. Figure 5A is an aerial photograph of a forest which illustrates this pattern of defoliation.

(2) In sheltered conditions, there is still sufficient kinetic energy to push oil into the forest. In the sheltered forest there is no cleansing of the front forest zone, however. This results in a uniform and lethal dose of oil throughout the front and mid-forest zones resulting in 1, single, wide band of defoliation. Figure 5B gives an illustration of a

forest which, in the Panama spill, resulted in this type of pattern.

(3) It follows that other forests within the study area in Panama might be accurately described using an analysis of forest type and exposure regime. For example, basin riverine, and overwash mangroves may follow similar trends.

Further comparative studies are planned to establish stations within other forest types throughout the study area in the near future.

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Table 1. Mean forest height (m) and 95% confidence limits at 9 sampling points (3 zones x 3 forests).

	Front Forest Zone	Mid-Forest Zone	Back Forest Zone
Reference Forest	7.57 (0.24)	6.20 (1.43)	4.01 (0.73)
Exposed Forest	7.04 (0.45)	4.79 (1.13)	5.27 (0.92)
Sheltered Forest	6.35 (0.54)	4.91 (0.97)	3.59 (0.33)

Table 2. Mean tree diameter (cm) and 95% confidence limits at 9 sampling points (3 zones x 3 forests).

	Front Forest Zone	Mid-Forest Zone	Back Forest Zone
Reference Forest	11.89 (1.83)	12.05 (2.90)	8.60 (3.31)
Exposed Forest	11.73 (2.17)	7.93 (2.07)	7.00 (1.11)
Sheltered Forest	9.46 (2.37)	5.80 (0.75)	5.87 (0.80)

Table 3. Mean leaf area index (LAI) and 95% confidence limits at 9 sampling points (3 zones x 3 forests). These data were collected in early September 1986, a little more than four months after the oil spill. For reference, an index of 1.00 = 100% canopy coverage.

	Front Forest Zone	Mid-Forest Zone	Back Forest Zone
Reference Forest	2.63 (1.21)	1.78 (0.61)	1.11 (0.71)
Exposed Forest	1.07 (0.73)	0.00 (0.00)	2.91 (1.16)
Sheltered Forest	0.00 (0.00)	0.00 (0.00)	0.81 (0.52)

Table 4. Mean sprouting success (%) and 95% confidence limits at 9 sampling points (3 zones x 3 forests). These data were collected in late October 1986, approximately six months after the oil spill.

	Front Forest Zone	Mid-Forest Zone	Back Forest Zone
Reference Forest	10.7 (7.1)	25.3 (19.8)	48.0 (19.8)
Exposed Forest	0.0 (0.0)	0.0 (0.0)	61.3 (30.7)
Sheltered Forest	0.0 (0.0)	0.0 (0.0)	66.2 (33.5)

Table 5. Mean new leaf area (cm2) and 95% confidence limits at 9 sampling points (3 zones x 3 forests). These data were collected in late October 1986, approximately six months after the oil spill.

	Front Forest Zone	Mid-Forest Zone	Back Forest Zone
Reference Forest	24.5 (15.0)	55.6 (44.8)	116.6 (11.6)
Exposed Forest	0.0 (0.0)	0.0 (0.0)	221.9 (134.8)
Sheltered Forest	0.0 (0.0)	0.0 (0.0)	285.2 (199.3)

Figure 1. Map of the Caribbean Coast of Panama; oiled mangroves were observed between the City of Colon and Isla Grande. The three mangrove forest sites are clustered between Punta Galeta and the oil refinery.

OVERLAY IS 30%

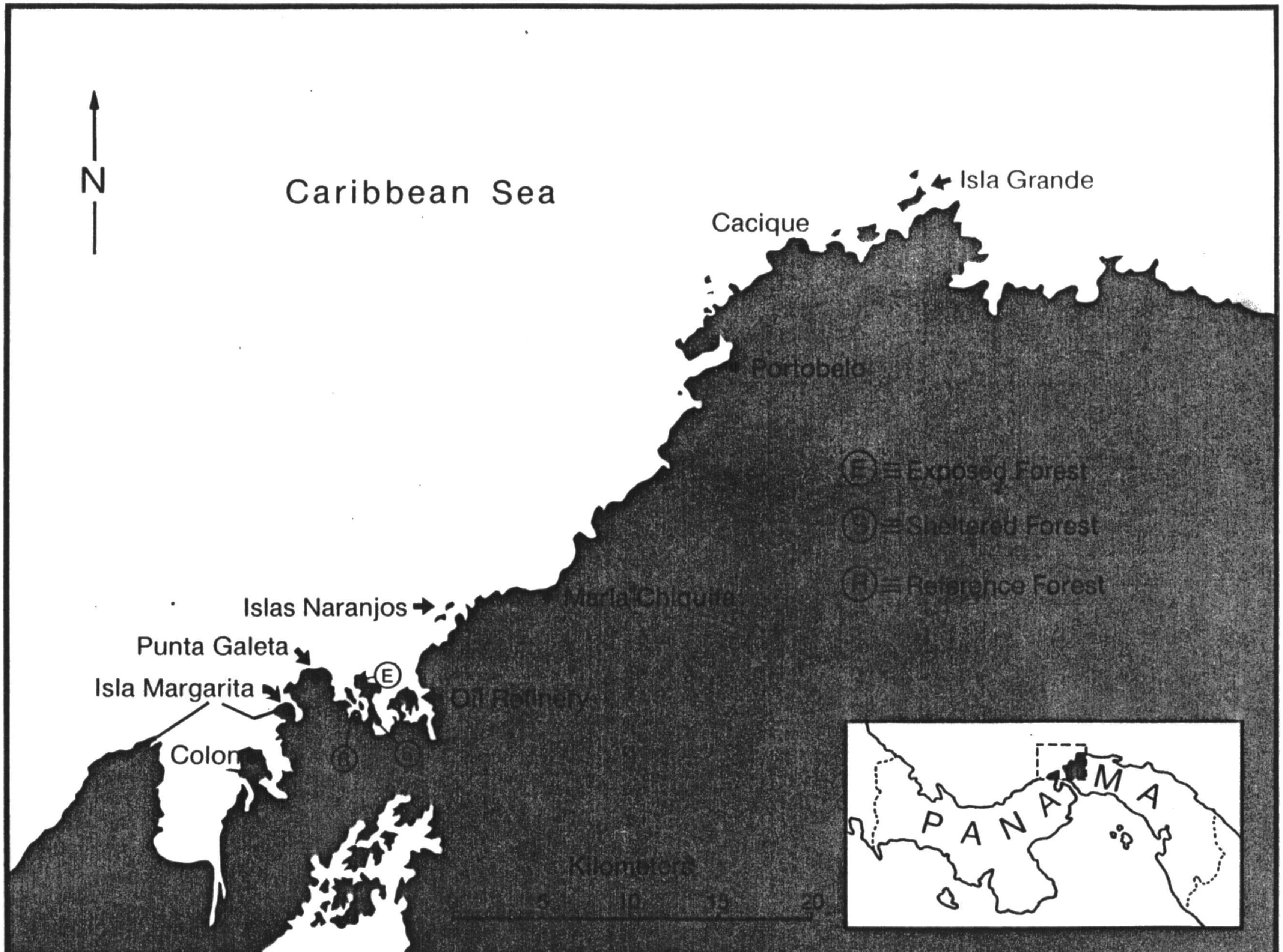


Figure 2. A) Mean forest height (m) and 95% confidence limits at 9 sampling points (3 zones x 3 forests). Data are from Table 1. B) Mean tree diameter (cm) and 95% confidence limits at 9 sampling points (3 zones x 3 forests). Data are from Table 2.

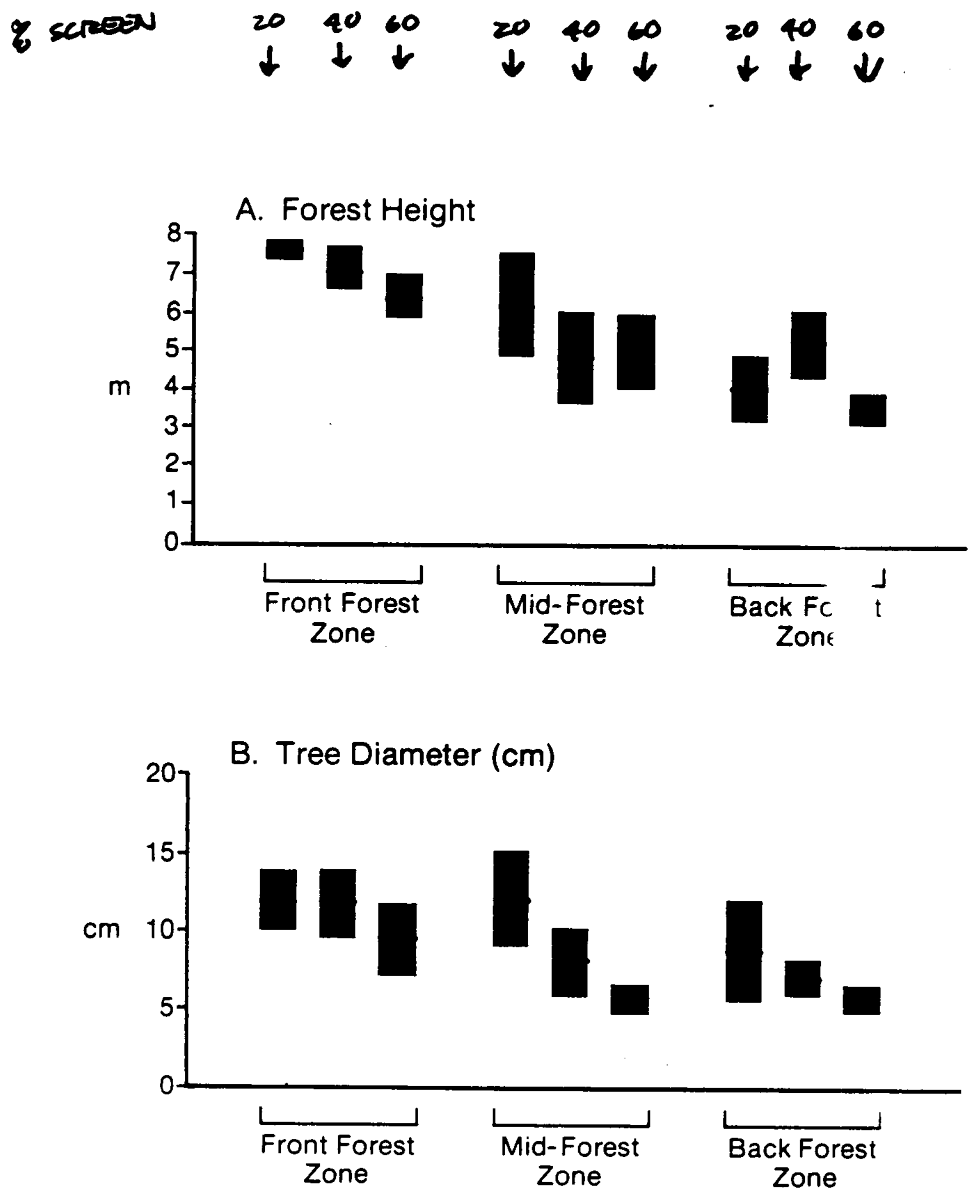


Figure 3. A) Mean leaf area index (LAI) and 95% confidence limits at 9 sampling points (3 zones x 3 forests). These data were collected in early September, 1986 a little more than four months after the oil spill. For reference, an index of 1.00 equals 100% canopy coverage, and the mean for reference site was 1.84. Data are from Table 3. B) Mean sprouting success (%) and 95% confidence limits at 9 sampling points (3 zones x 3 forests). These data were collected in late October, 1986, approximately six months after the oil spill. Data are from Table 4. C) Mean new leaf area (cm^2) and 95% confidence limits at 9 sampling points (3 zones x 3 forests). These data were collected in late October, 1986, approximately six months after the oil spill. Data are from Table 5.

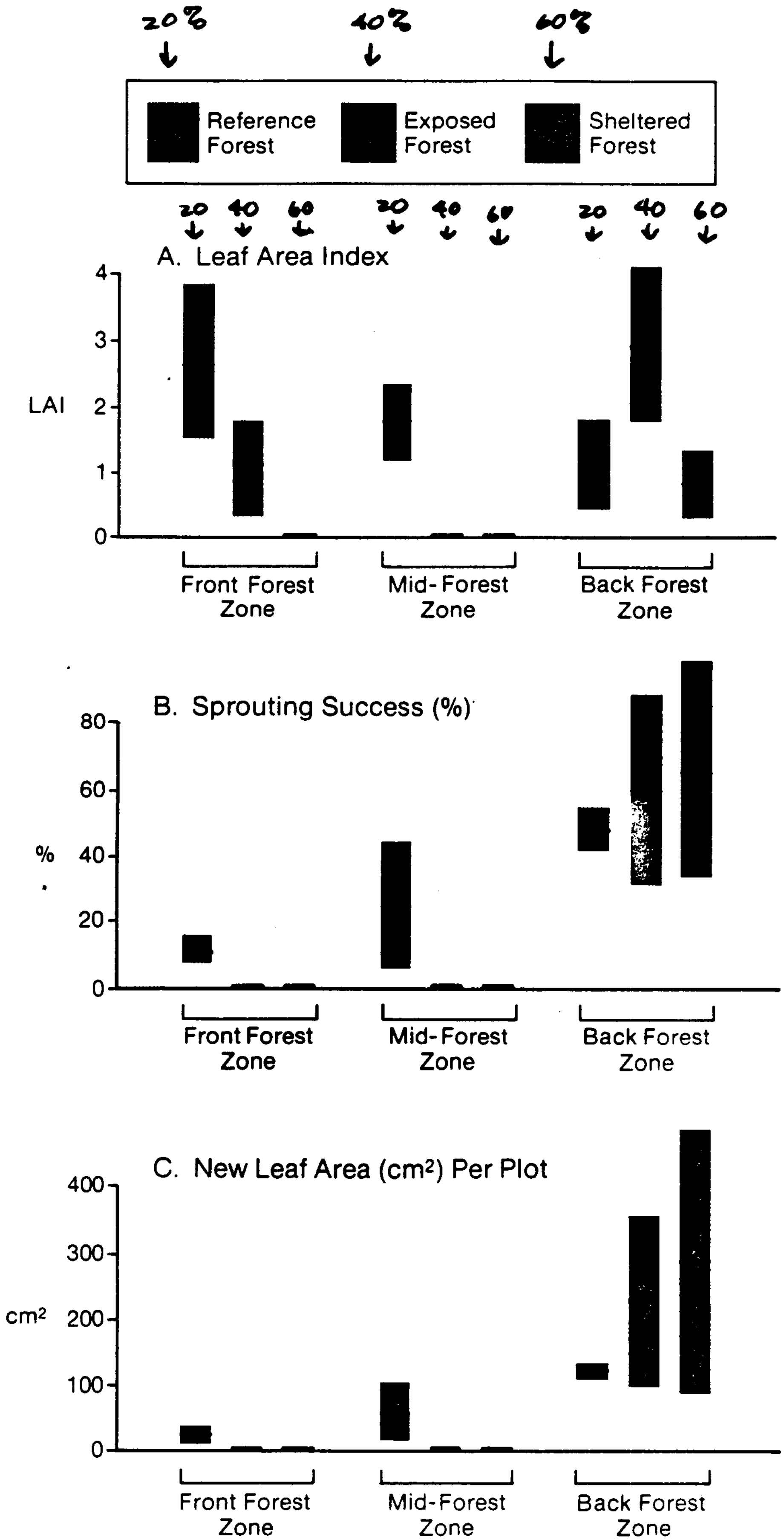

20%
40%
60%
Reference Forest
Exposed Forest
Sheltered Forest
20 40 60 20 40 60 20 40 60
A. Leaf Area Index
LAI
0
1
2
3
4
Front Forest Zone
Mid-Forest Zone
Back Forest Zone
B. Sprouting Success (%)
%
0
20
40
60
80
Front Forest Zone
Mid-Forest Zone
Back Forest Zone
C. New Leaf Area (cm2) Per Plot
cm2
0
100
200
300
400
Front Forest Zone
Mid-Forest Zone
Back Forest Zone

Figure 4. Two models of the distribution of oil spill effects in mangrove forests (from Getter et al., 1981).

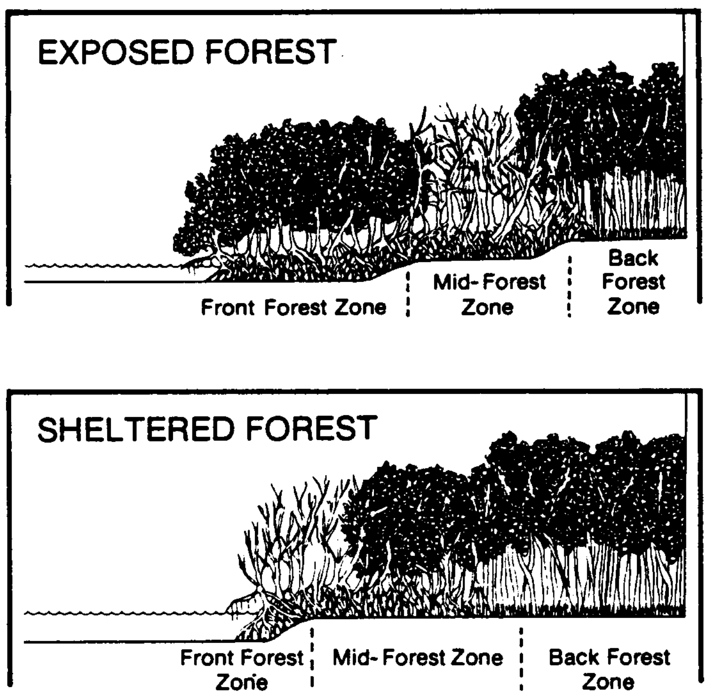
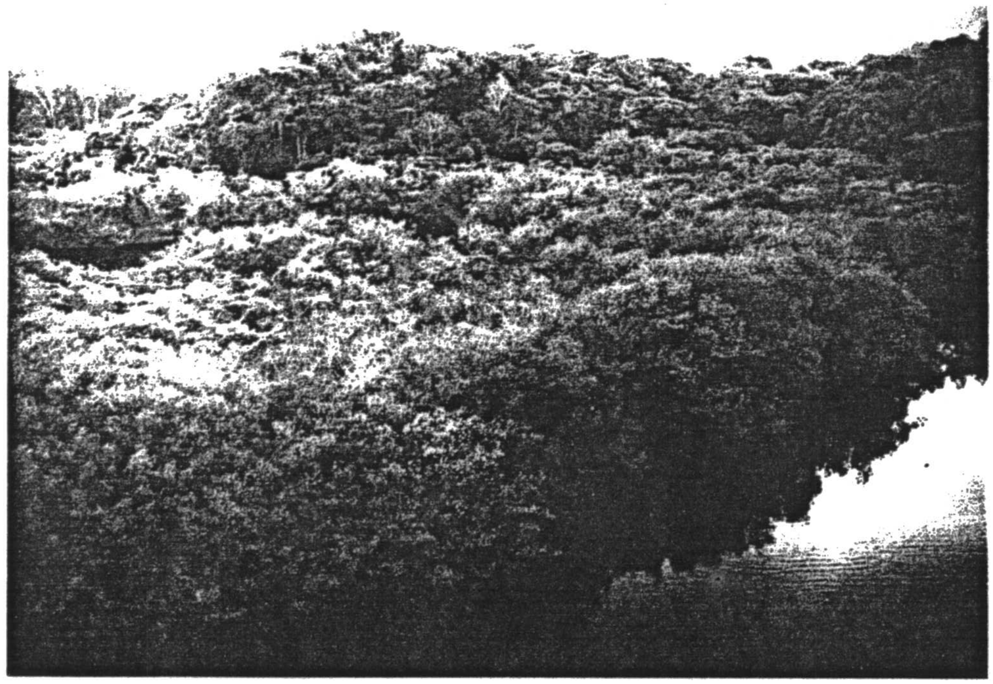
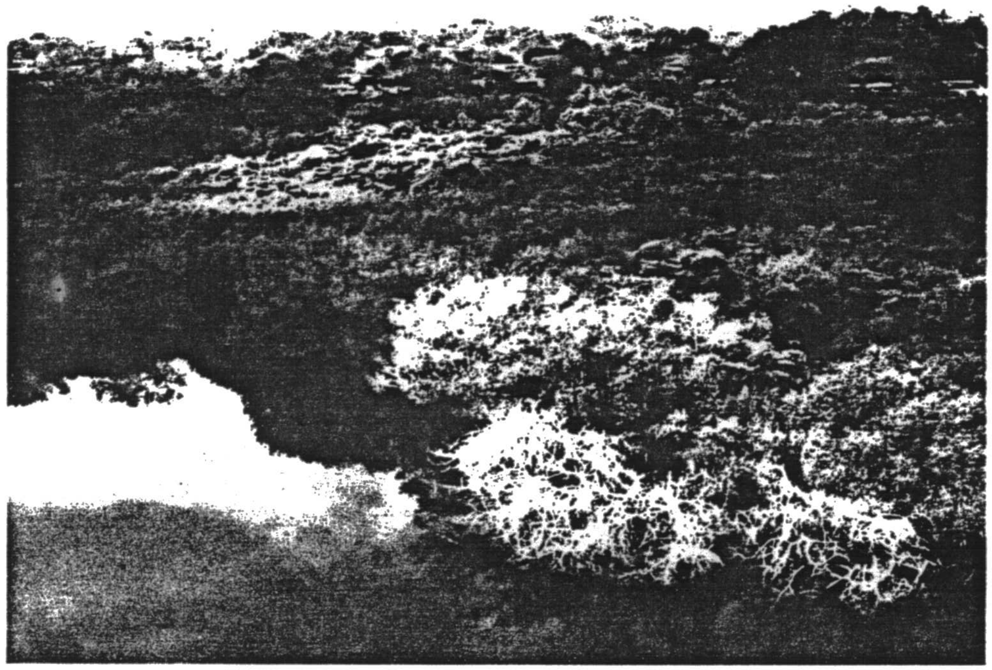


Figure 5. A) An exposed forest is shown which is expressing defoliation to the mid-forest zone. Photo is of an oiled fringe forest taken in June, 1986, approximately 1 mile southeast of Galeta Point. B) A sheltered forest is shown which is expressing defoliation of both the front and mid-forest zones. Photo is of an oiled fringe forest taken in June, 1986, approximately 1 mile southwest of the oil refinery.



EXPOSED FOREST



SHELTERED FOREST

EFFECTS OF THE APRIL 1986 OIL SPILL AT ISLA PAYARDI ON MANGROVE ROOT COMMUNITIES

December 22, 1986

INTRODUCTION

Mangrove coasts make up about 75% of ocean shorelines between 25° N and 25° S Latitude (National Research Council, 1985). This, and the high productivity of marine wetlands (Chapman, 1976; Cintron and Schaeffer-Novelli, 1983; Linden and Jernelov, 1980; Snedaker and Lugo, 1973) makes mangrove forests one of the planet's important ecosystems. The genus *Rhizophora* occurs world-wide at low latitudes. The red mangrove *Rhizophora mangle* is widely distributed in the Caribbean, and occurs extensively on both coasts of Panama. It also occurs along much of Florida (Odum *et al*., 1982), and is found patchily elsewhere along the southeastern coast of the United States. Its prop roots serve as breeding and nursery areas for many marine species, and as substrata and shelter for a diverse group of organisms (Sutherland, 1980; Odum *et al*., 1982).

Mangrove shores are extemely vulnerable to oil spills (Gundlach and Hayes, 1978; Bacon, 1970; Odum and Johannes, 1975). However, there has been little research involving the effects of oil on mangrove root communities. Cairns and Buikema (1984) suggest that studies of mangrove communities, combined with long-term monitoring at mangrove oil spill sites, are needed to help make appropriate decisions about management of future spills. The oil spill at Isla Payardi, Bahia las Minas, Panama, thus represents an opportunity to gain insight into the effects and potential management of oil spills in ecosystem that is extremely important on a worldwide scale, and is in addition a major component of the southeastern coast of the United States.

MATERIALS AND METHODS

Three intertidal zone habitats of the red mangrove, Rhizophora mangle L., in the area around Bahia las Minas include: (1) trees fronting the open ocean, generally along the inner margins of fringing reefs, (2) those along the banks of major channels leading from the open sea, and of large lagoons into which the channels lead, and (3) those in brackish water streams and man-made ditches which run from landward into lagoons and/or drain interior areas of mangrove forest.

The coverage of space on intertidal mangrove roots in the above three habitats (hereafter called open, channel and river) was first surveyed during September - October 1981. Several areas of shore within each habitat were haphazardly chosen, and a starting point (tree) within each area was picked at random. From this point, 25 roots to the left and 25 roots to the right were chosen for sampling using a random numbers table. Roots which hadn't grown down into the water and those which had grown firmly attached to the mud were rejected and the nearest root which met the sampling criteria was sampled instead. Each selected root was lifted from the water and length from waterline to root tip and diameter at the waterline was measured. Percent cover of fouling and encrusting organisms was visually estimated.

Sampling was repeated in January 1982, and again in June 1982, except that for the June 1982 survey, data exist for only

25 roots each in channel and river habitats, and for no roots in open habitat.

Mangrove roots were again sampled in July-August 1986, and in October-November 1986, roughly four and seven months after the oil spill. Percent cover of 100 roots was visually estimated in each of the three habitats described above in (a) an area where oil had drifted ashore and (b) where no oil had landed. Methods of selection and monitoring of roots were similar to those used in 1981-2, except (1) four separate subareas ("sites") within each habitat were sampled, (2) percent cover was estimated more quantitatively, by recording what lay under each of 50-100 (depending on root length) numbered plastic bands arrayed along a wooden dowel that was held against each root, and (3) some unoiled sites were located up to 25km away from the original area sampled.

RESULTS

Root dimensions - Table 1 shows mean lengths of roots sampled within each habitat for all dates sampled. Root lengths that increased significantly between monitoring periods (t-tests, $p \leq 0.05$) have a line between their dates. Roots sampled prior to the spill (October 1981, January 1982, June 1982) did not differ in mean lengths. Changes in root length between 1982 and 1986 were not considered, because of the extended time period between sampling and because exactly the same areas were not sampled. However, the same areas were sampled in August and November 1986, allowing comparison. In each habitat, root length increased significantly in both oiled and unoiled areas over this period, but the change was relatively greater in oiled areas. In November, roots averaged 81%, 98% and 65% longer than in August, at open, river and channel habitats respectively. At unoiled areas, respective increases were 12%, 32% and 30%. This non-intuitive result occurred because many smaller roots at oiled sites had died and fallen off by November, skewing the size distribution (personal observation).

Undisturbed epibiotic community on Rhizophora roots - To characterize similarities and differences among habitats in the epifaunal root community, I lumped all roots from prespill and postspill, unoiled area monitorings, for each of the three habitats. Table 2 shows the occurrence of various taxa in open, channel and river habitats. Overall, there is a decrease in the number of species from open (55) to channel (37) to river (19). For most groups that overlap between or among habitats, the same species occur (e.g. the species of bivalves that occur in river habitat also occur in channel habitat). Algae, however, overlap at species level only 25% between open and channel roots and 35% between open and river and between channel and river. Some entire groups are absent from a given habitat - sponges, hydroids and bluegreen algae from river roots; and bivalve molluscs from open roots.

Even though the same species may occur in two or more habitats (above), abundances can vary widely, and each habitat appears to support a distinct epifaunal community. Table 3 shows means and standard errors for the percent cover of major species or categories occupying space on open, channel and river roots. Open coast mangrove roots are characterized by a diverse group of erect algae (at least 24 species, combined mean cover of ~27%), diatoms and blue-greens, hydroids, and sponges. There is considerable (~22%) bare space on roots; the remaining ~15% is occupied by rare organisms, including amphipod tubes, coralline crusts, anemones, barnacles, tunicates, corals, ectoprocts, vermetids, stromatolites and vascular plants.

The channel root community is dominated by bivalve molluscs, which cover a combined average of 55% of the space on roots. The most abundant of these is the edible oyster *Crassostrea rhizophorae*; three other bivalves are also relatively common (Table 3). Barnacles, rare on open coast roots, average more than 10 percent cover on channel roots. Algae are also less abundant and less diverse than on the open coast (~11 species, mean cover of ~6%). There is relatively little unocuppied space (15%) on channel roots; the remainder (~13%) is covered by various rare species: sponges, anemones, diatoms and blue-green algae, dead bivalve shells, hydroids, ectoprocts, vermetids, tunicates and bryozoans.

A bivalve mollusc, the false mussel *Mytilopsis domingensis*, dominates river mangrove roots (mean of ~40% cover, Table 3). *Crassostraea*, the most common species on channel roots, is rare (<1% cover). Bare space averages 26%, similar to its abundance on open shore roots. Diatoms cover a mean of 12%, erect algae (~11 species) cover a mean of ~9%, and the barnacle *Balanus improvisus* averages 9% cover. Rare space occupants, including amphipod tubes, vermetids, another species of barnacle, dead mussel shells and empty barnacle tests account for the remainder (~2% cover).

<u>Rhizophora root community at unoiled and oiled areas</u> - I here compare space occupancy on <u>Rhizophora</u> roots in oiled and unoiled areas four and seven months after the oil spill. Taxa consisting of many species, rare species or those that have not yet been identified are grouped (e.g. erect algae, hydroids); others are given separately (e.g. <u>Mytilopsis</u>, <u>Crassostrea</u>). Within a given sampling period, comparisons between groups or species in oiled and unoiled areas are made using Mann-Whitney U tests.

Table 4 shows space post-spill space occupancy on open coast mangrove roots. The amount of bare space was significantly less at oiled than unoiled areas ($p<0.001$) on both dates. There was a concommittent increase in percent cover of diatoms at oiled areas ($p <0.01$, November 1986 - the cover of oil and diatoms could not be separated in August 1986 because diatoms had settled on oiled as well as bare space, obscuring oiled surfaces). Sponges, although never very abundant (overall mean cover of ~3% on undisturbed roots - Table 3), covered less space at oiled than unoiled areas in August ($p<0.05$), and had disappeared from oiled areas in November. Hydroids were relatively uncommon in August at both oiled and unoiled areas ($p>0.1$), but were significantly more abundant in November at unoiled sites than either at oiled sites ($p<0.05$) or on unoiled roots in August ($p<0.05$). Erect algae covered considerable space at all sites and dates. Percent cover did not differ between oiled and unoiled areas in August 1986 or between unoiled sites in August and November 1986 ($p>0.1$, both cases). However, erect algal cover decreased by about 40% from August to November at oiled areas, and was significantly less abundant than at unoiled areas in November ($p<0.05$). Since algae are a major component of the root community on open coast sites, I examined differences in species composition and abundance between oiled and unoiled areas. There were three major changes. First, at oiled areas, turf-forming species such as Ceramium spp., Derbesis spp., Ectocarpus spp., Cladophora spp., and Polysiphonia spp. totally disappeared. In August, these mixed turfs occurred on 59/100 unoiled roots at a mean cover of 21.8%, compared to 6/100 oiled roots at 9.7%. In November, mixed turfs were present on 58% of unoiled roots with a mean cover of 23.0%, but were absent on oiled roots. Second, there was an apparent "bloom" of the green alga Caulerpa verticillata at oiled sites, where it covered 62% cover on the 23 roots it occurred on in August 1986, and 28.4% cover on 32 roots in November 1986. At unoiled areas, C. verticillata was absent (in August 1986) or rare (found on 6/100 roots, mean cover on those six roots was 6.2%). Finally, at oiled areas, an unidentified crustose coralline alga covered 1.5% of the two (in August) and of the four (in November) roots where it occurred, compared to means of 7.2% cover of 18 roots (in August) and 8.6% on 51 roots (in November) where there was no oil.

Table 5 shows space occupancy of mangrove roots in channel habitat in oiled and unoiled areas since the oil spill. There was less bare space on roots at oiled areas than at unoiled areas both in August and November 1986 ($p<0.05$, both cases). Diatoms were significantly more abundant at oiled areas in August only ($p<0.05$). Bivalve molluscs are the most abundant group in this habitat; of these, the most common is the oyster Crassostrea rhizophorae (Table 3). Live Crassostrea were less abundant at oiled areas (~21% cover) than at unoiled areas (~36%) in August ($p<0.001$) and, by November, had dropped to about 5% at oiled areas compared to 32% at unoiled areas ($p<0.001$). The slight decrease in percent cover over time at unoiled sites was not significant ($p>0.1$). The shells of dead individuals remain attached to roots for some time - dead Crassostrea averaged between 1 - 2 percent cover on roots at unoiled areas and between 13 - 21 percent at oiled areas ($p< 0.05$). The barnacle Balanus improvisus covered significantly less space at oiled than unoiled areas at both post-spill sampling dates ($p<0.001$, both tests), as did two less common bivalves, Mytilopsis domingensis and Brachidontes exustus ($p<0.03$, all cases). Another relatively uncommon mollusc, the oyster Isognomon alatus, covered more space at oiled than at unoiled areas in August ($p<0.01$), but not in November ($P>0.3$). No oil was recorded in percent cover estimates for channel roots. However, oil was present. Crassostrea forms a nearly solid belt in the intertidal portions of the root; most Crassostrea were coated with oil.

Changes in space occupancy were most obvious on roots in the river habitat (Table 6). All ordinarily abundant groups (mussels, barnacles, erect algae, and diatoms - Tables 2, 3) were absent or rare at oiled sites in August, and all were absent in November. Instead, oil and a bacterial slime covered virtually all space (the space unaccounted for in both months was dead mussels and barnacles too covered by oil and bacteria to identify). At unoiled sites, *Mytilopsis* and diatoms became more abundant from August to November ($p<0.05$, $p<0.10$), and *Balanus* cover decreased ($p<0.05$).

DISCUSSION

Despite (1) the limited amount of data available on this region's mangrove root epibiota prior to the oil spill, (2) the absence of data from the period immediately prior to the spill, and (3) the short-term and limited nature of post-spill monitoring to date, several conclusions can be drawn.

First, there appears to be a distinct biological community on submerged *Rhizophora* roots in each of the three habitats examined (Tables 2, 3). Open shore mangrove roots have the highest species richness (Table 2). A moderate amount of bare space is available, and no single species dominates space. If species are lumped into higher taxonomic groups, erect algae and diatoms together average over 50% cover (Table 3). Roots in channels have intermediate species richness (Table 2). Algae are diverse, but rare. There is less bare space, and bivalve molluscs, especially *Crassostrea rhizophorea*, dominate space. Barnacles are also abundant (Table 3). The river habitat supports a less rich community (Table 2). Several taxa found in both open and channel habitats do not occur on river roots - notably sponges, hydroids, blue-green algae and ectoprocts. Roots in rivers have roughly the same bare space available as those in open habitat (Table 3). Space is dominated by the false mussel *Mytilopsis domingensis*. Barnacles, algae and diatoms are also relatively abundant.

The *Rhizophora* root community at Punta Galeta, described by Batista (1980), is dissimilar to the open coast areas examined in the present study (although many of the same species were found). Differences are probably attributable to different methods - I sampled roots only along the water/tree fringe, to reduce possible variation caused by shading, current, etc; Batista sampled trees well into the forest and those on the margin.

The second major conclusion of this investigation is that oil has had detrimental effects upon many organisms in all three root communities. The amount of bare root surface (i.e. space available for settlement) has been reduced significantly (Tables 4, 5, 6). Common or dominant organisms, including erect algae (in open habitat) and *Crassostrea* (in channel habitat) have become less abundant in oiled areas than in unoiled areas (Tables 3,4), and several less common species have disappeared (e.g. sponges). The species composition of erect algae on open roots has changed: mixed algal turfs have disappeared from oiled areas, and an ephemeral green alga (rare or absent in unoiled areas) has become the most common alga. *Rhizophora* roots in river habitat appear most seriously affected - the normal community has entirely disappeared and roots are now covered with oil and bacteria (Table 6).

Additional monitoring is needed to completely assess the effects of the April 1986 oil spill. Little evidence of recovery exists for any habitat to date; in fact observations of the poor state of trees and roots, particularly in channel and river habitats, suggest recovery may not occur for a considerable (many years) period. The community on open shores appears least affected (Table 4). Perhaps this, and the nearly constant washing by waves during dry season, make it the most likely habitat to show early signs of recovery.

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Table 1 Root Length Data

Habitat	Condition	Date	Mean ± S. E.	N
Open	Unoiled	X 1981	29.8 ± 2.3	48
		I 1982	34.7 ± 2.6	50
		VIII 1986	48.4 ± 1.7	102
		XI 1986	54.1 ± 2.5	99
	Oiled	VIII 1986	33.2 ± 1.6	100
		XI 1986	60.0 ± 2.4	100
Channel	Unoiled	X 1981	31.9 ± 2.6	49
		I 1982	29.8 ± 2.2	49
		VI 1982	29.5 ± 3.7	24
		VIII 1986	37.1 ± 2.5	100
		XI 1986	48.1 ± 2.3	100
	Oiled	VIII 1986	35.8 ± 1.8	100
		XI 1986	59.2 ± 2.8	100
River	Unoiled	X 1981	34.3 ± 2.7	50
		I 1982	32.6 ± 2.4	48
		VI 1982	32.5 ± 4.0	25
		VIII 1986	54.5 ± 2.6	100
		XI 1986	72.1 ± 3.0	100
	Oiled	VIII 1986	32.7 ± 1.9	100
		XI 1986	64.7 ± 3.2	100

Data are the mean ± one standard error for roots sampled in each monitoring period and habitat.

Table 2 Number of Species in the Epibiotic Community on the Submerged Roots of *Rhizophora mangle*

Habitat:	Open	Channel	River
Type of Organism:			
Algae[1]	24	11	11
Bivalve molluscs	0	4	3
Barnacles	3	3	2
Hydroids	3	3	0
Sponges	8	8	0
Diatoms	3	1	1
Blue-green algae	4	1	0
Other sessile invertebrates	10	6	2
Total:	55	37	19

1: Includes all erect and crustose algae, except blue-green algae.

Table 3 Percent Cover of Major Space Occupants on *Rhizophora* roots

Habitat	Group or Species	Mean ± S.E.
Open (n = 299)	Erect algae	27.3 ± 1.6
	Diatoms	26.9 ± 1.7
	Hydroids	6.6 ± 0.7
	Sponges	2.8 ± 0.5
	Bare	21.5 ± 1.5
Channel (n = 321)	Barnacles	11.1 ± 0.6
	Bivalves	55.0 ± 1.5
	Balanus improvisus	9.5 ± 0.5
	Crassostrea rhizophorae	40.7 ± 1.4
	Isognomon alatus	3.1 ± 0.3
	Diatoms	6.4 ± 1.0
	Bare	14.9 ± 1.2
River (n = 324)	Barnacles	9.4 ± 0.9
	Bivalves	41.4 ± 1.5
	Mytilopsis domingensis	40.1 ± 1.5
	Balanus improvisus	9.1 ± 0.9
	Erect algae	9.0 ± 0.7
	Diatoms	12.4 ± 0.9
	Bare	26.1 ± 1.3

Data are the mean ± one standard error from combined samples for pre-spill and unoiled areas (1981, 1982 and 1986).

Table 4 Patterns of Space Occupancy of Major Groups on *Rhizophora* Roots in Open Habitats in 1986 After the Oil Spill

	Unoiled		Oiled	
	August	November	August	November
Group:				
Erect algae	21.0 ± 2.2	22.3 ± 2.1	20.6 ± 3.2	13.3 ± 2.2
Hydroids	3.7 ± 0.8	10.8 ± 1.6	2.3 ± 1.8	1.0 ± 1.1
Sponges	3.2 ± 0.9	2.4 ± 0.7	1.0 ± 0.1	0
Diatoms	31.9 ± 2.7	25.4 ± 2.1	70.4 ± 3.5	41.9 ± 2.0
Oil	0	0	P (*)	29.3 ± 1.8
Bare	18.2 ± 1.7	16.5 ± 1.4	2.0 ± 0.4	9.7 ± 1.1

Data are the mean ± one standard error for percent cover estimates from 100 randomly-selected roots in each monitoring group

* "P" indicates present. Both bare and oil-covered root surfaces were covered with diatoms. These could not be separated during monitoring without damage to the diatom layer.

Table 5 Patterns of Space Occupancy of Major Groups on *Rhizophora* Roots in Channel Habitats in 1986 After the Oil Spill

	Unoiled		Oiled	
	August	November	August	November
Group:				
Crassostrea rhizophorae	36.1 ± 2.6	32.2 ± 2.0	20.6 ± 2.3	4.7 ± 0.7
Dead *Crassostrea*	2.2 ± 0.4	1.4 ± 0.2	21.4 ± 2.5	12.6 ± 1.3
Isognomon alatus	1.8 ± 0.3	2.8 ± 0.5	5.9 ± 1.0	3.0 ± 0.5
Mytilopsis domingensis	6.2 ± 1.1	5.3 ± 1.1	3.6 ± 0.7	1.2 ± 0.3
Brachiodontes exustus	6.3 ± 0.9	3.2 ± 0.6	0.6 ± 0.1	1.3 ± 0.3
Balanus improvisus	5.8 ± 0.7	11.3 ± 1.1	1.4 ± 0.3	3.9 ± 0.8
Diatoms	11.2 ± 2.1	9.2 ± 1.1	29.3 ± 2.7	8.7 ± 1.6
Bare	14.4 ± 1.8	13.8 ± 1.4	6.4 ± 0.9	8.2 ± 1.4

Data are the mean ± one standard error for percent cover estimates from 100 randomly-selected roots in each monitoring group.

Table 6 Patterns of Space Occupancy of Major Groups on *Rhizophora* Roots in River Habitats in 1986 After the Oil Spill

	Unoiled		Oiled	
	August	November	August	November
Group:				
Mytilopsis domingensis	34.4 ± 2.7	53.3 ± 3.6	0	0
Balanus improvisus	11.1 ± 1.7	6.1 ± 1.1	0	0
Erect algae	9.6 ± 1.5	10.4 ± 1.5	0	0
Diatoms	15.9 ± 1.7	21.4 ± 1.8	0.5 ± 0.2	0
Bacterial slime	0	0	33.0 ± 2.7	3.3 ± 0.7
Oil	0	0	49.9 ± 3.2	89.2 ± 1.4
Bare	25.8 ± 2.3	23.7 ± 1.7	2.9 ± 0.5	6.2 ± 1.0

Data are the mean ± one standard error for percent cover estimates from 100 randomly-selected roots in each monitoring group

EFFECTS OF MAY, 1986 OIL SPILL ON GONODACTYLID STOMATOPODS NEAR GALETA POINT

Stomatopods, or mantis shrimp as they are commonly known, are a small group of primative marine crustacea most commonly found in shallow tropical waters. The group is characterized by an enlarged pair of second thoracopods that serve as raptorial appendages and which are used in prey capture and processing. The raptorial appendages also function as effective offensive and defensive weapons in intra- and interspecific aggressive interactions. Caldwell and Dingle (1975) divided stomatopods into two functional groups, 'spearers' and 'smashers'. Spearing species generally have slender, multi-spined raptorial appendages used to impale or seize soft-bodied prey such as shrimp and fish. These species are most likely to be found in muddy or sandy habitats where they excavate burrows. Nine of the currently recognized 12 stomatopod families fall into this category.

In contrast, smashing species have heavily armored raptorial appendages which are used as hammers to crush hard-shelled prey such as snails and crabs. Typically, smashers occupy pre-existing cavities in coral or rock which they vigorously defend using their formidable weapons. There are three families of smashers, the most common being the Gonodactylidae. Because of their aggressiveness, highly developed communication systems, small size, abundance, and the ease with which they can be collected and maintained in the laboratory, gonodactylids have frequently been used in behavioral and ecological research (see Caldwell and Dingle, 1976; Reaka and Manning, 1980; Reaka, 1985; Caldwell, 1986b for reviews).

Much of the research on gonodactylid stomatopods has been conducted by Caldwell and his students on the Atlantic coast of Panama at the Galeta Marine Laboratory of the Smithsonian Tropical Research Institute. Here, gonodactylids are unusually abundant, occurring in densities of up to 20 m^2 on shallow reef flats and Thalassia beds. Almost every piece of coral rubble or coralline algae that contains cavities has at least one stomatopod living in it. There is also a high species diversity. Three Gonodactylus, G. bredini, G. oerstedii, and G. austrinus, commonly are found from the low intertidal to a depth of a few meters. Another species, G. spinulosis, is occasionally recorded from this habitat. Two other species, G. curacaoensis and G. torus, occur in deeper water.

Gonodactylids, given their size (up to 65 mm total length) and high local abundances, are often a major component of the low intertidal community. For example, during severe exposures of the reef flat at Galeta during the early summer, we have recorded herons and egrets taking up to 4 stomatopods per minute (Caldwell, 1986b). Gonodactylids are also frequently preyed upon by large fish and octopus (Reaka, 1985). As predators, gonodactylids have been shown to be capable of structuring local prey populations of hermit crabs and snails, each stomatopod consuming up to 10-12 gastropods per day (Caldwell et. al, 1986).

PREVIOUS STOMATOPOD RESEARCH AT GALETA

Because of the extremely large numbers of easily accessible gonodactylids around the Galeta Marine Laboratory, Caldwell initiated research on the behavioral ecology of stomatopods at the marine station in 1976 and 1977. Work at this time consisted primarily of collecting animals in the field for laboratory studies of aggressive behavior and communication. In 1979, we began a five year study, funded by the National Science Foundation, to explore assessment strategies in G. bredini. As part of this project, a systematic sampling program was established to monitor local gonodactylid populations with respect to over-all density, the size structure of the population, growth, reproduction, and recruitment. This was necessary since it was found early in our work that gonodactylid behavior varied considerably with several physiological variables. We discovered marked lunar and annual periodicities in such processes as molting, reproduction, and recruitment, but there also was considerable seasonal and annual variation. Much of this variation appeared to stem from differences in the severity of tidal exposures. But in other cases, such as the recruitment of postlarvae onto the reef flat, the reasons for large-scale fluctuations remain unclear. Nevertheless, this variation made it essential that we monitor any population from which were removing animals for behavioral experiments or on which we were taking field observations.

Over the five year period from 1979 to 1983, we worked primarily at four locations: Isla Margarita, Galeta Point (Antenna Site), Mina, and Largo Remo. These sites are all within 5 km of one another, yet there appears to be little or no movement of adults among them, possibly because they are separated by deep water channels and stretches of inappropriate habitat. The different sites were monitored at different times and using different techniques. However, for all but Galeta Point, we have data from all seasons spread at least over two years.

Three different sampling techniques were used. The first consisted of density studies where all suitable substrate that might contain gonodactylids was removed from a given area and broken apart to reveal the stomatopods. In some cases, we used 49 m^2 quadrates, but most consisted of 1 x 10 m transects or 1/2 m^2 quadrates. While this method yielded unbiased density estimates, it was extremely time-consuming and often did not produce a sufficient number of stomatopods required for behavioral experiments.

The second monitoring method consisted of collecting pieces of coral rubble or coralline algae that were judged likely to contain gonodactylids, breaking them, and retaining all stomatopods. Rocks were broken until we collected approximately 100 animals and the process was repeated every five days. While this method may slightly overestimate the proportion of large animals in a population because we did not select rocks smaller than 150 cc, it does give a good picture of the sex-ratio in a particular size class, the frequency of injury, reproduction, and molting activity.

The third monitoring technique made use of artificial concrete cavities which were placed in the field and from which stomatopods could be easily extracted. The cavities were checked every one or two days. By varying the size of cavity, we could selectively capture different sized animals. This technique allowed us to monitor which animals were moving in a population and had the advantage that we did not have to destroy natural cavities to collect gonodactylids. However, without one of the other two methods, its use as a population monitor was extremely limited.

All animals collected in the field were returned to the laboratory where they were identified, sexed, measured, staged for molt and reproductive activity, inspected for wounds, and then held for three days to record if they laid eggs or molted. If animals molted in the laboratory or were captured in the field with their molt skins, it was possible to calculate how much they grew by comparing the length of the old and new carapace. Animals were not returned to any of the collecting sites. During the five years that we continued this study, over 50,000 gonodactylids were processed. However, even after removing this many animals, we could detect no decline in local stomatopod populations. Recruitment was extremely heavy each year and there was continual colonization from adjacent areas with very large stomatopod populations.

(POST-SPILL SAMPLING)

To monitor gonodactylid populations after the May, 1986 oil spill which occurred near Galeta, we worked in the area from September 8 - 28, 1986. Originally, we had planned to repeat the same sampling procedures used previously at each of the four primary locations. However, after inspecting these areas and discussing with STRI personnel where the oil had come ashore, we decided to ignore Galeta Point since there appeared to be little damage to the stomatopod community in that area. Rather, we concentrated our efforts on Isla Margarita, Mina, and Largo Remo. Furthermore, the north reef flat of Largo Remo appeared to be much more effected by the spill than did the west reef flat. Since we collected data before the spill from both locations, we decided to sample the two as separate areas.

Because of seasonal changes in gonodactylid populations, we can only compare data that were taken at the same time of year. This further reduced the amount of information available about these four sites, particularly in the case of density estimates. Since there is the possibility that we will be able to follow these populations in the future, we decided that it still would be useful to conduct density estimates at each location. At each of the four sites, we selected a 400 m^2 area for future sampling. Each plot was as similar as possible with respect to substrate type, water depth, and *Thalassia*. Specifically, we selected low intertidal *Thalassia* beds with a firm, sandy substrate and only moderate amounts of coral rubble and coralline algae. We avoided areas with solid coral bench, soft mud, or rubble bars. The areas selected were in the same location or were similar to areas sampled in previous years. Sampling consisted of randomly choosing 30, 1/2 m^2 quadrates from within each plot. We then recorded the physical characteristics of each and removed all hard substrate with a volume greater than 2 cc. Each piece was then measured and broken apart and any stomatopod contained collected.

To increase our sample size, we also collected pieces of coral rubble (>150 cc) from areas near the density plots and extracted animals from them. This was done in each of the four areas until we had a minimum sample of at least 300 gonodactylids. These numbers were needed to estimate the frequencies of injury and molting in each area. A total of 1,489 gonodactylids were collected from the four areas. Over 90% were *G. bredini*, the remainder were *G. oerstedi*, *G. austrinus*, and one *G. spinulosis*. For the purposes of this report, all species of *Gonodactylus* are pooled.

POPULATION SIZE

Table 1 provides the size distribution and sex, as well as an estimate of density per m^2, of the Gonodactylus captured at Margarita, Mina, Largo Remo - North, and Largo Remo - West as part of the the density estimates (30, 1/2 m^2 quadrates). The only comperable data available for this time of year prior to the spill come from Margarita where were Steger (1985) estimated a mean density and standard error of 9.6 ±.59 Gonodactylus per m^2. This is remarkably close to the value of 9.9 ±1.51 that we obtained this year. The estimates from the other three areas taken September, 1986 were somewhat less, but without appropriate studies prior to the spill, it is difficult to determine if these populations are depressed.

One aspect of these data that appears unusual is the lack of large Gonodactylus over 40 mm in total length from Largo Remo - North and Mina. These animals would be at least two to three years old and their numbers normally do not fluctuate widely as does the abundance of smaller animals which reflect sporadic recruitment (Steger, in prep.). The pattern at Largo Remo - West and Margarita is more typical of gonodactylid populations that we have sampled in the past. Individuals in excess of 45 mm in total length are common and there are usually more large females than males. This skewed sex-ratio apparently is the result of greater risk to males who must abandond their cavities to breed (Caldwell, 1986c). Note that of the 101 Gonodactylus collected at Mina and Largo Remo - North, only 2 (both males) were 40 mm or larger. This contrasts with Margarita and Largo Remo - West where 31 (10 males, 21 females) of the 240 animals captured were at least 40 mm long (G-Test, $G = 12.2$, $P < .001$).

Further support for this is found by comparing the size frequency distribution of all Gonodactylus collected at both Largo Remo sites in 1986 with animals captured at the same locations and at the same time of year in 1981 (Figure 1). In 1986, Largo Remo - West had a considerably greater number of large animals (> 44 mm) than did Largo Remo - North (G-Test, $G = 25.4$, $P < .001$). In 1981, just the opposite was true (G-Test, $G = 14.3$, $P < .001$).

Also note that in 1981, there were many Gonodactylus under 15 mm long. These animals probably settled out of the plankton in the previous four months. In 1986, there appears to have been almost no recruitment during the summer, although a few animals did recruit in September. However, we cannot at this time attribute this difference in recruitment to the effects of the oil spill since recruitment is frequently erratic in the summer. To determine if there have been long-term effects on the recruitment of Gonodactylus, it will be necessary to follow these populations at least through the winter and spring when recruitment is typically much more constant.

CAVITY VOLUME

Gonodactylus typically live in some type of pre-existing cavity in a hard substrate. Cavities are essential to gonodactylids as a refuge from predators, as a site to ambush and process prey, for protection when molting, and for brooding eggs and larvae. At Galeta, cavities in coral rubble and coralline algae are most frequently used, although animals are occasionally found living in gastropod shells, cavities in live corals, seeds, wood, and even glass bottles. Frequently, these cavities are modified by using stones and shells to repair gaps in the walls or to alter the diameter of the entrance, but animals cannot usually construct and entirely new structures. Steger (1985) has provided evidence that in at least some populations, cavities are limiting and that Gonodactylus compete aggressively for them. He has also shown that there is a strong correlation between the size of a stomatopod and the volume of its preferred cavity. This probably occurs because the size and shape of the cavity is important with respect to how well it can be defended against other stomatopods as well as predators (Steger, 1985; Caldwell, 1986 b). Typically, large cavities are more limiting than are small ones (Steger, 1985). Also, in aggressive contests for cavities, larger animals are more likely to win (Caldwell, 1986 a). As a result, where competition for cavities exists, Gonodactylus are forced to occupy cavities of less than their preferred volume.

In September, 1986, we measured the volume of 46 cavities occupied by Gonodactylus at Largo Remo - North. This was done by haphazardly collecting pieces of rubble in the field and placed them in plastic bags. They were then returned to the laboratory where the resident stomatopods were carefully removed by alternately being proded and dipped in fresh water. Once the animal fled the cavity, all entrances but one were plugged with clay and the cavity filled with lead shot. The shot was then poured out and its volume measured. Steger (1985) had previously performed an identical procedure in 1980 measuring 119 cavities at Margarita.

Figure 2 compares the relationship between the length of a stomatopod and the volume of its cavity for these two area. Clearly, for any given body size, Gonodactylus at Largo Remo - North after the spill occupied larger cavities than they did at Margarita prior to the spill. Using analysis of covariance, the two slopes are not significantly different ($P = .3$), but the adjusted means are ($P < .001$).

Because of time constraints, we were only able to correlate animal size with cavity volume at one location. Largo Remo - North was selected because it appeared to have been most effected by the oil. Our previous experience at Largo Remo prior to the spill indicated that cavity limitation was just as severe as at Margarita. The situation at Margarita between 1980 and now does not appear to have changed.

WOUNDS AND INJURIES

One of the consequences of competition for cavities is that animals are frequently wounded during aggressive contests or, after being evicted, are injured by predators (Berzins and Caldwell, 1983). This effect is most pronounced in larger individuals since it is in these animals that competition for cavities is most intense (Steger, 1985). Since beginning our studies at Galeta, we have recorded the presence of such injuries in all animals collected.

Table 2 presents data on the number of large animals (> 35 mm) collected at the four sites studied after the spill that had at least one cuticular injury. These data are compared to records of injuries taken prior to the spill at the same locations and at the same time of the year. Injures are frequent at Margarita and did not differ significantly from year to year. The same was true at Largo Remo - West except that the frequency of injury was somewhat depressed in 1982. In contrast, at both Largo Remo - North and Mina, the incidence of injury in the population following the spill was significantly reduced from previous years. In fact, injury levels for these two areas in September, 1986 were the lowest that we have recorded for this time of year in the Galeta area.

GROWTH

Growth in gonodactylids can be measured by recording the length of the carapace before a molt and the length of the new carapace after the molt. Unfortunately, the old carapace is one of the first parts of the molt skin eaten (usually in less than a day) by stomatopods and it is rare that an animal is captured in the field with its recently molted carapace. We have found that by holding animals in the laboratory after capture and checking them daily for molt skins, we can greatly increase the number of animals for which we can measure growth. There is, however, one problem with this technique. The longer animals have been in the laboratory, the smaller the increment of growth measured. The smaller the animal, the stronger the effect. However, we have found that if adults molt within three days of capture, their is not a significant decrease in the amount that they grow (Steger and Caldwell, in prep.). For this reason, we only record growth for animals that molted in the laboratory within three days of capture or that were found in the field with a complete molt skin. Also, how much animals grow per molt varies with season. This is probably due to differences in prey availability. Therefore, cross-year comparisons must be made for the same time of year.

In Table 3, we present data for the percent growth recorded for individuals collected at the four study sites following the spill. These are compared to growth values obtained from animals collected between 1979 and 1983 at the same locations during the same season. To avoid the problems discussed above, only Gonodactylus greater than 35 mm in length that molted within three days of capture are included in the analysis. Because of small sample sizes, we pooled data from Largo Remo - North and Mina (apparent oil damage) and from Largo Remo - West and Margarita (little apparent oil damage). The relationship between body length and percent growth has a negative slope. We tested for differences among the four groups using analysis of covariance following the procedures outlined by Sokal and Rohlf (1981). The test for homogeneity of slopes was not significant ($F(3,45) = 1.82$, $p = .16$). However, there was a significant negative common slope of -0.18 %/mm ($F(1,48) = 7.78$, $p < .008$). And most interestingly, there was also a significant difference in the adjusted mean growth ($F(3,48) = 9.24$, $p < .001$); the animals collected from Largo Remo - North and Mina after the spill growing approximately 50% more per molt than those collected at the same locations prior to the spill. There was no difference between the adjusted mean growth values for Largo Remo - West and Margarita before and after the spill or between affected and unaffected areas prior to the spill.

The rate at which stomatopods grow depends both on how often they molt as well as how much they grow per molt. We can estimate the frequency of molting by calculating the percentage of animals that molt over a given period of time. Gonodactylus over 35 mm in length would normally molt every three or four months. Very large animals molt at an even slower rate. However, caution must be exercised when estimating inter-molt intervals because animals are most likely to molt at certain times in the lunar period. Therefore, we require data from at least one complete lunar cycle to adequately determine how frequently molting occurs. With this in mind, we examined the frequency of molting for animals captured last September. The four areas do not appear to differ with respect to inter-molt interval.

DISCUSSION

Our findings can be summarized into four major points. 1. At Largo Remo - North and Mina, there is a decrease in very large animals, particularly females. This is the case both when compared to previous samples taken at these two sites and when we compare them to other nearby locations at this time. 2. The volume of cavities occupied by animals at Largo Remo - North is larger than that previously measured for Gonodactylus in this area. 3. The percentage of injured large animals is much lower at Largo Remo - North and at Mina than was previously measured at these locations or than is currently found in other adjacent locations. 4. Large animals at Largo Remo - North and Mina are growing more per molt than did animals from these same areas prior to the spill and they are also growing more than individuals from other nearby areas.

How do we explain these phenomena? The loss of large animals from Mina and Largo Remo - North, but not Margarita and Largo Remo - West, appears to be correlated with the amount of oil that came ashore last May. STRI personnel report that both the north side of Largo Remo and Mina received a considerable amount oil. This is borne out by the large amount of oil that can still be found in these areas. The mangrove roots are covered by oil in both locations, many trees are dead, and any disturbance to the sandy substrate in the low intertidal produces oil. In contrast, little surface oil can currently be found at Margarita or on the outer reef flat were we sampled at Largo Remo - West. Also, the habitats in the areas where the oil came ashore appear to be much different while at Largo Remo - West and Margarita they look, at least superficially, as they did prior to the spill. At Largo Remo - North, the entire Thalassia bed that occurred in the low intertidal just in front of the mangroves is gone. No Thalassia blades are visable and the root systems appear dead. Also, there are far fewer invertebrates found living in the coral rubble and coralline algae nodules in there areas than occurred previously or than are currently found at Margarita and Largo Remo - West. We found few of the gastropods, crabs, snapping shrimp, annelids, or coelenterates that typically in this type of rubble. On the other hand, there has been an apparent explosion in the number of hermit crabs. Almost every piece of rubble is covered with hundreds of hermits. We suspect that this is due to the deaths of large numbers of snails in the upper intertidal. This provided a large supply of empty shells. Snails such as Battilaria minima and Cerithium sp., which used to be abundant in these areas, are now much less common and most of the hermit crabs are now living in shells from these species.

Mina appears less severely impacted than Largo Remo - North, but it is still much different than we remember it prior to the spill. There are stands of Thalassia, but there are fewere invertebrates in the rubble and there are many more hermit crabs. Also, in 1983, we observed the burrows of 34 Lysiosquilla scabricata in the low intertidal at Mina. This is a large (200 mm) stomatopod that excavates burrows up to 7 cm in diameter in sandy substrates. In the three weeks that we repeatedly searched this area, we did not see one.

Unfortunately, we do not have quantitative data on species other than stomatopods from these areas. Still, given the number of years that we worked in these habitats and the fact that other nearby areas that did not receive as much oil are still as we remember them, we must conclude that Mina and Largo Remo - North were effected by the oil. We did initiate sampling of hermit crabs and snails in these areas in September, 1986 and should be able to track changes in these populations in the future.

But why should just the large Gonodactylus be missing from the effected areas? For reasons that we do not understand, large Gonodactylus typically move into the intertidal to mate and brood their eggs. During severe early summer exposures of the reef flat, they are frequently driven to deep water, but then move back up into these areas to breed later in the summer. When the oil came ashore, it was a time of extreme tides. We suspect that the effects of the oil were most severe in the mid to upper intertidal. This is where the Thalassia bed and snails were killed at Largo Remo - North. Many of the Gonodactylus in this area would have been large, breeding individuals. There would have been a greater proportion of smaller animals in deeper water. If direct contact with oil killed stomatopods, it is most likely that the animals in the intertidal would have suffered most and this would have included a larger proportion of big animals. Also, brooding females are very reluctant to leave their cavities (Montgomery and Caldwell, 1984). They may have remained in the effected area longer than males and therefore been more at risk. Since we were not at Galeta during the spill, this is only speculation. But it is consistent with what we have been told about how the oil came ashore and with the biology of Gonodactylus.

Why are animals in the effected areas occupying larger cavities? As documented by Steger (1985, in prep.), there is competition for cavities by Gonodactylus with animals forced to live in cavities of less than the preferred volume (see above). If many of the large animals were killed at Largo Remo - North, their cavities would become available allowing smaller animals to move up into their preferred size of cavity. The release from competition in the largest sizes would cascade down so that most animals could eventually occupy cavities of the preferred volume. In fact, the size of cavities being occupied now at Largo Remo - North is almost identical to the preferred cavity volumes found by Steger (1985).

This release in competition for cavities can also help explain the reduced levels of injury recorded at Mina and Largo Remo - North. If most animals in these areas can acquire preferred cavities, there will be fewer animals looking for new cavities and less fighting. This means fewer injuries from predators and other stomatopods. Lower densities of stomatopods and predators would also contribute to this effect.

Finally, how do we explain the increased growth rates at Largo Remo - North and Mina? We see two contributing factors. First, with less competition, foraging may be easier and less time and energy spent on fighting for cavities. Second, the increased numbers of hermit crabs in these areas provide an almost unlimited and easily accessable food supply. Even though other prey are now harder to locate, almost every stomatopod has literally hundreds of hermit crabs within a few centimeters of its cavity. This means that foraging time is minimal and the animals can basically eat as many hermits as they can process. Interestingly, it does not appear that small stomatopods are growing any faster in these areas than they are elsewhere. This seems reasonable given that small Gonodactylus do not prey on hermit crabs of the sizes now so abundant (5 - 15 mm shell length)(Caldwell et. al, 1986).

PREDICTIONS

A natural experiment has been performed at Galeta which, because of the patchy effects of the oil, has selectively removed large stomatopods from certain areas. The results appear to have been a reduction in levels of competition in these areas along with a possible increase in prey availability. We predict that as stomatopods grow and again become more numerous in the larger size-classes, competition should increase. With this should come animals occupying cavities smaller than the preferred volume, more injuries, and reduced levels of growth, (depending, at least in part, on what happens to the hermit crab populations). If the small animals (15-30 mm) currently present on these sites survive and continue to grow and if recruitment is unaffected, these changes should begin to occur in one to two years. Colonization by large animals from adjacent, less-affected areas could accelerate this process.

However, we must point out that we do not yet know what effects, if any, the oil will have on recruitment or if there will be long-term effects due to continued exposure to oil. Given their position as major predators in this environment, there could easily be a build-up of hydrocarbons in these stomatopods that could ultimately impact on their growth and/or reproduction. We feel that it is important that these populations continue to be monitored for at least the next two to five years to determine if there are long term effects. Even if these populations quickly return to pre-spill equilibria, this is a rare opportunity to document how competitive interactions can structure a population.

RESPECTFULLY SUBMITTED:

Roy Caldwell

Rick Steger

Table 1. Numbers of gonodactylids found in 30, 1/2 m^2 quadrates taken at each of four similar sites near Galeta during September, 1986. Animals were removed from cavities in all pieces of hard substrate with a volume greater than 2 cc.

Size (mm)	Largo Remo North		Mina		Largo Remo West		Margarita	
	M	F	M	F	M	F	M	F
<12 *	0		2		1		5	
12-14	0	0	0	2	4	3	2	5
15-19	2	4	12	15	9	7	9	12
20-24	4	4	6	7	6	4	15	13
25-29	2	3	3	3	6	11	13	16
30-34	1	4	4	4	8	5	7	13
35-39	2	0	6	8	4	5	6	16
40-44	1	0	2	0	1	6	4	3
45+	0	0	0	0	4	7	1	5
Mean Gonodactylids per 1 m^2 ± 1 S.E.	1.8 ±.4		4.9 ±.85		6.1 ±1.53		9.9 ±1.51	

* Sex cannot be determined in gonodactylids less than 12 mm total body length.

Table 2. Number of wounds and injuries sustained by large (>35mm) gonodactylids collected at four locations near Galeta during September, 1986 (four months following the oil spill) and at various times prior to the spill.

Location	Year	# Injured	# Not Injured	% Injured
Largo Remo - North	1986	12	113	10%
	1981	24	94	20% *
Mina	1986	18	142	11%
	1981	22	41	35% **
	1983	47	155	23% **
Largo Remo - West	1986	49	79	38%
	1981	21	37	36%
	1982	27	101	21% **
Margarita	1986	42	70	38%
	1980	17	53	25%
	1981	16	35	31%

* Significantly different from 1986 at same location, G-Test, p <.05

** Significantly different from 1986 at same location, G-Test, p <.01

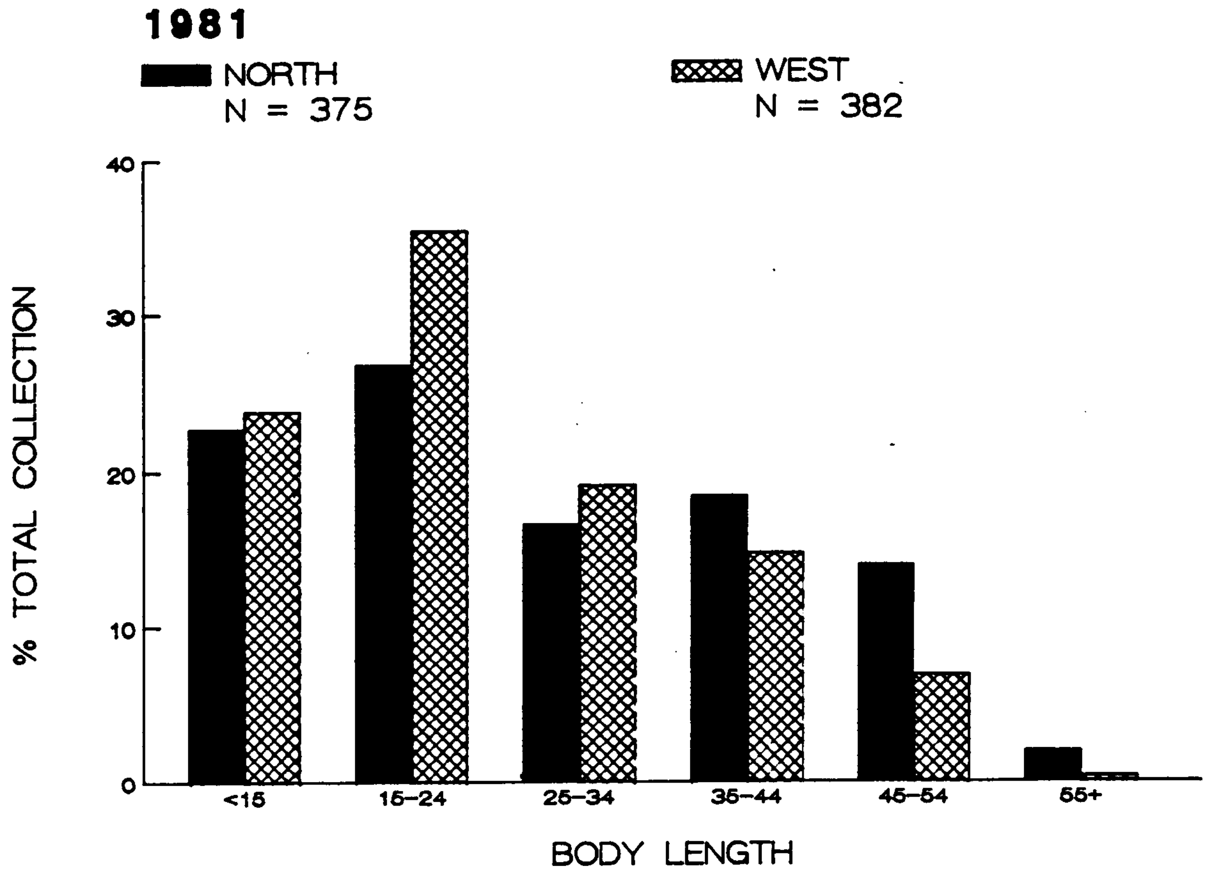
Table 3. Percent growth of <u>Gonodactylus</u> from sites with oil damage (Largo Remo - North and Mina) and with little apparent oid damage (Largo Remo - West and Margarita). Data collected September, 1986 are compared with values obtained from the same locations at the same time of year from 1979-83.

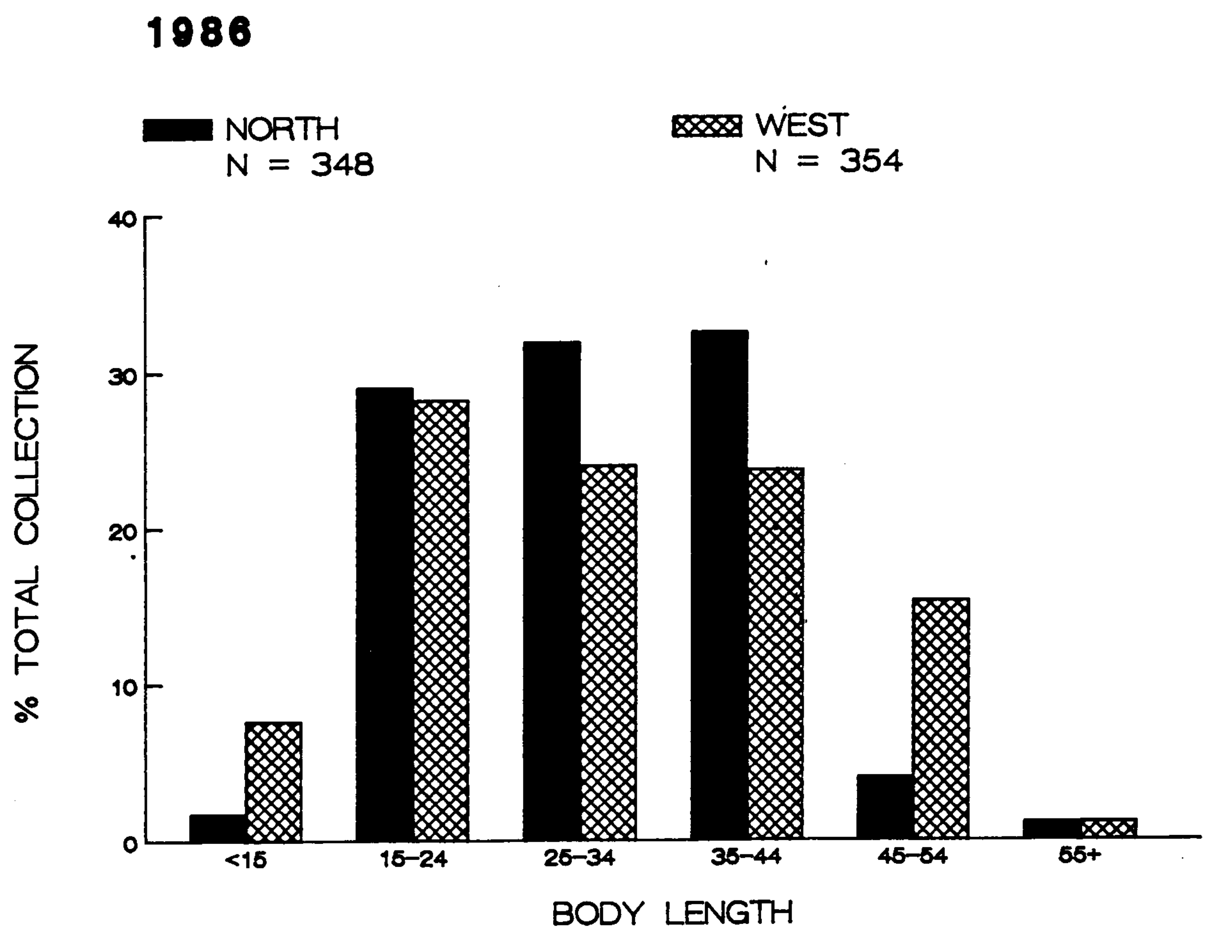
Location and Date of Collection	Adjusted Mean Growth (%)	± 95% Comparison Intervals	N
Largo Remo - North and Mina: 1986	9.44	1.15	14
Largo Remo - North and Mina: 1979-83	6.09	1.14	14
Largo Remo - West and Margarita: 1986	6.28	1.21	13
Largo Remo - West and Margarita: 1979-83	6.34	1.23	12

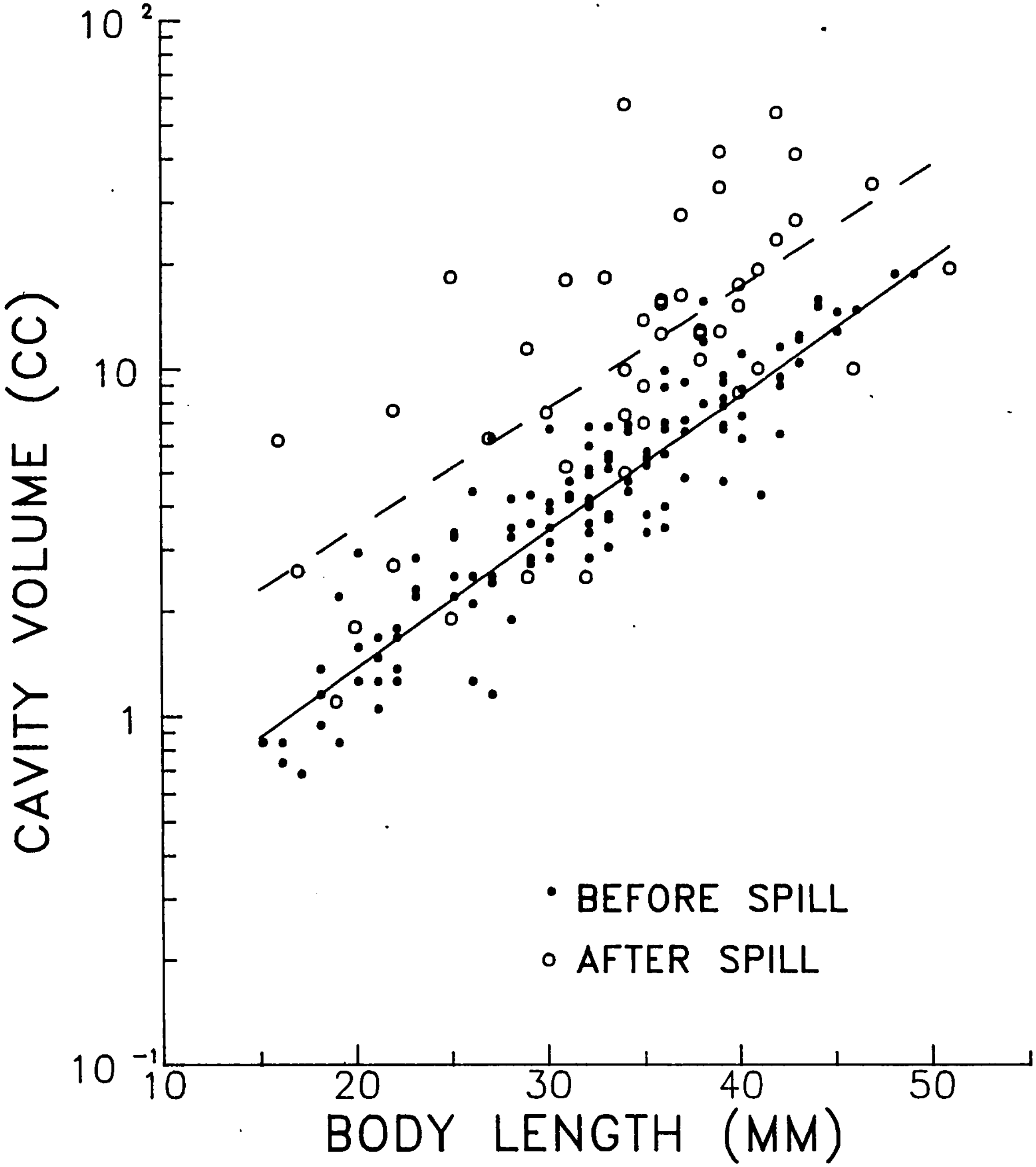
Figure 1. Gonodactylids collected from Largo Remo in 1981 and 1986. Animals were removed from coral rubble on the north and west sides of the island. All collections were made in late summer and early fall.

Figure 2. Relationship between body length and cavity volume for Gonodactylus collected before the spill (1980) at Margarita and after the spill (1986) at Largo Remo - North. Cavities containing animals were removed from the field in late summer and early fall. (Before the spill, N = 119; After the spill, N = 46).

GONODACTYLIDS FROM LARGO REMO







CAVITY VOLUME (CC)
10^2
10
1
10^{-1}
10
20
30
40
50
BODY LENGTH (MM)
• BEFORE SPILL
○ AFTER SPILL

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EFFECTS OF THE APRIL 1986 OIL SPILL ON INTERTIDAL REEF-FLAT GASTROPODS

INTRODUCTION

Gastropod molluscs are a diverse, abundant and important group of consumers on many tropical shores (e.g Vermeij 1978, Lubchenco et al. 1984). In Panama, the ecology and community roles of common gastropods have been examined on rocky shores of both the Pacific and Caribbean coasts (Garrity and Levings 1981, 1985, Levings and Garrity 1984, Lubchenco et al. 1984, Garrity, in prep.). However, relatively little work has been done on this group of potentially important consumers in the more heterogeneous coral reef flat habitat.

Brattstrom (1985) examined zonation of plants and animals at a number of sites, including reef flats, near the Caribbean entrance of the Panama Canal. Cubit and Williams (1983) cataloged the molluscs and other invertebrates found on the reef flat at Galeta Point (see also Radwin 1969). Garrity and Guttierez (unpublished) quantitatively sampled the density and size structure of gastropods in different habitats on the Galeta reef flat between November 1982 and January 1983.

This latter study provides the best available pre-spill data on gastropod distribution, abundance and size structure from Galeta. I here use these data, resurveys of the Galeta reef flat after the 1986 oil spill, and additional surveys of unoiled reef flats to examine effects of the oil spill to date on the gastropods that inhabit various reef flat habitats.

METHODS

Seven discrete habitats within the reef flat were sampled. Running roughly from the shore out toward the reef's seaward edge, they include: high rubble, low rubble, sand and reef rock, as well as beds of *Thalassia testudinum*, *Laurencia papillosa* and *Zoanthus sociatus*. The high rubble habitat is on the reef's shorward margin, and is never submerged; low rubble, sand, and reef-rock areas are intermittently submerged and emersed depending upon the tidal cycle and wave action. Seagrass, algae and zoanthid beds are emersed only during extremely low tides when seas are calm (see Cubit et al. 1986 for detailed information on tidal regime and emersion phenomena at Galeta).

Within each habitat, twenty randomly selected $0.25m^2$ quadrats were laid along a 50-100m transect line. To obtain estimates of relative abundance, all gastropods within each quadrat were identified and counted. To sample molluscan size structure, common gastropods were collected and shell lengths measured (to the nearest millimeter). Snails were then returned to the appropriate habitat.

The initial monitoring was done between November 1982 and January 1983. The Galeta reef flat was resurveyed in August 1986 (3-4 months after the spill) and November 1986 (6-7 months after the spill). Less than one week after the August 1986 sampling, a contract clean-up crew worked through this area, removing oil and oiled debris from the high and low rubble habitats and using water hoses to blow oil from these and from the sand habitat. These "cleaned" habitats were remonitored about a week after cleaning operations.

The following additional data from the oiled site were collected: (1) during August 1986 sampling, snails within quadrats were recorded as having oiled or unoiled shells, (2) dead snails that were either cemented to the rock by oil (low rubble zone) or in a habitat where movement of shells by wave action did not occur (high rubble zone) were separately counted along with live individuals in abundance transects, and (3) collections were made within each of the two habitats for later measurement of the sizes of dead snails.

Unoiled reef flats were sampled similarly for gastropod distribution, abundance and size structure in August and November 1986. These were located (1) west of Toro Point, (2) seaward of Maria Sota and (3) at the mouth of Portobello Bay. Three unoiled sites were sampled because no one area had all habitats founnd at Galeta; in fact, no sufficiently large area of Zoanthus could be located to sample on any unoiled flat.

RESULTS

High Rubble: This zone was characterized by the herbivorous snails Tectarius muricatus and Nodilittorina tuberculata; other herbivorous species, notably Littorina angustior, L. ziczac, and L. lineolata, also were present (Table 1). The abundance of most species increased considerably between 1982 (before oiling) and 1986 (after the spill) at Galeta. There were slight decreases in mean density of the three most common species following clean-up activities, and possibly a continued decline in numbers for two the three between August and November 1986. However, none of these changes in abundance were statistically significant. Roughly the same occurred at the control site -- there were changes in mean abundance of the snails present, but none were significant. Although this habitat is above the high tide mark, at least some individuals of every species but L. lineolata were oiled. Forty-nine percent of the Tectarius counted in quadrats, 30% of Nodilittorina, 28% of all Littorina angustior, and 17% of the L. ziczac had shells coated with oil in August 1986.

Dead snails of the three littorinid species and of Nodilittorina were found within quadrats in November. Dead L. angustior density was $0.3 \pm 0.6/0.25m^2$; dead L. ziczac was $0.2 \pm 0.7/0.25m^2$, dead L. lineolata was $0.1 \pm 0.2/0.25m^2$, and dead N. tuberculata was $0.1 \pm 0.3/0.25m^2$.

Several species that were absent from the high rubble habitat at Galeta prior to the spill (and from the control area after the spill) were found in low abundance after the spill (L. angulifera) or after the clean-up (Nerita versicolor, N. tessellata). These species are usually found lower on the shore (the latter two) or in mangroves (the former). All were again absent from the high rubble zone in November 1986. Additionally, dead individuals of these three species were found in high rubble quadrats in November 1986 ($0.1 \pm 0.2/0.25m^2$ for L. angulifera; $1.0 \pm 1.5/0.25m^2$ for N. tessellata; and $0.3 \pm 0.7/0.25m^2$ for N. versicolor. Two other species, never found alive in this habitat, were found dead in November (Melampus coffeus - $0.8 \pm 1.2/0.25m^2$;

Planaxis nucleus - 0.3 ± $0.6/0.25m^2$).

Size frequency distributions changed little over time in both oiled and unoiled sites (Table 1). Tectarius did not vary in median size in any Galeta sample. Median size shifted upwards between August and November at the unoiled area. The other three species that were abundant enough to sample each dropped in median shell length between 1982-1983 and August 1986, but changes between August and November 1986 were negligible. Only dead shells of L. lineolata were sufficiently abundant to measure. Their median shell lenth was 11 mm (range 4-13, n = 162) while that of living snails was 9mm (range 7-12). Thus although all size classes suffered mortality, there is some indication that larger sizes were more likely to die.

Low Rubble: The low rubble habitat at Galeta in 1982 was dominated by the large-bodied, herbivorous snails Nerita tessellata and N. versicolor; two other neritids were present in low abundance (Table 2). The three littorinids found in high rubble occurred in greater density in this zone, while N. tuberculata occurred in lower density compared to higher on the shore.

Abundances all dropped roughly by a factor of ten between 1982 and August 1986; two species of Nerita and Nodilittorina disappeared completely. N. tessellata and N. versicolor decreased further in abundance immediately following clean-up and L. lineolata and L. ziczac disappeared. However, Planaxis nucleus and Littorina angustior were more abundant following cleanup.

Most species of snails in low rubble were heavily oiled. One hundred percent of Planaxis, Littorina angustior, and L. lineolata had oiled shells, as did 68% of the Nerita versicolor and 14% of the N. tessellata. No oiled L. ziczac were found.

In November 1986, four species that had been present in 1982 were no longer found, and two "new" species had appeared. One of the latter, Melampus coffeus, is usually found only in mangrove detritus; the other, Planaxis nucleus, had previously been restricted to the undersides of rocks in the low rubble habitat. For the two previously most abundant species, Nerita tessellata dropped further in density between August and November 1986, while N. versicolor increased considerably (Table 2). There were no significant changes in density for any species of gastropod at the unoiled site.

Much of the substratum in the low rubble habitat was coated with a thick, viscous layer of oil in August 1986. I counted the number of dead snails stuck to or covered with oil along with the counts of live individuals, then removed them. Many could be identified only to genus. Their abundances (means and standard deviations, n = 20 0.25m^2 quadrats) were: Nerita versicolor - 0.8 $\pm$ 1.2; N. tessellata - 0.3 $\pm$ 0.9; N. fulgurans - 0.6 $\pm$ 1.2; Nerita spp. - 1.7 $\pm$ 1.9; Littorina spp. - 0.9 $\pm$ 1.4; and Planaxis nucleus - 0.4 $\pm$ 0.7.

At Galeta, many species of molluscs in the low rubble habitat became too rare to estimate size frequencies (Table 2). None of the Littorina species changed significantly in size among samples; similarly, dead individuals did not differ in median size from living snails at the same monitoring. N. tessellata increased in size between 1982-1983 and August 1986, then apparently decreasedin size between August and November at Galeta. This latter resulted from low sample size due to its decreased abundance -- only 13 living snails were found in November. Median size of dead N. tessellata was 13mm in both August and November. Thus, mortality appeared spread across all size classes. Although N. versicolor remained more abundant, the pattern of mortality and size structure was similar to that of N. tessellata, except median size decreased rather than increased between 1982-3 and August 1986.

Reef Rock: The only abundant snail in this habitat at Galeta in 1982 was Nerita tessellata; Nerita fulgurans occurred in low density, as did Littorina ziczac, L. lineata, and Nodilittorina tuberculata (Table 3). In August 1986, all except the neritids had disappeared, and both these were less abundant than in 1982. N. versicolor, not found in 1982, was rare in August 1986, but N. fulgurans had disappeared. None of the littorinids reappeared by November 1986, and N. tessellata continued to decline in numbers. A single chiton, Acanthopleura granulata, was found, and N. versicolor increased slightly in abundance. On the unoiled reef, gastropod densities within the reef-rock habitat did not change between August and November 1986 (Table 3).

Only Nerita tessellata was abundant enough to measure after the oil spill; its size was the same as it had been four years previously. No empty shells were found, probably because of nearly constant current and wave action. Hermit carbs were observed, sheltering in shells of _Nerita_ species (these could not be assumed to come from the reef-rock habitat, since hermit crabs are mobile). Finally, there were no significant changes in size for any species sampled at the unoiled site.

Sand: Only _Battillaria minima_ occurred on the intertidal sand habitat of the Galeta reef in 1982; it was patchily abundant in aggregations. Its abundance had decreased significantly by August 1986 and it virtually disappeared after cleaning of this habitat by salt-water hoses (Table 4). My observations of the cleaning process indicated that snails, oil and small detritus were washed seaward several meters into deeper water. No live individuals of this species were found in November 1986. _Cerithium eburneum_ occurred in high density in August 1986, was also washed seaward by cleaning and did not reappear in November 1986. However, the small-bodied herbivore _Neritina virginea_, previously absent, recruited into the sand habitat in very high density in November 1986 (Table 4). At the unoiled site, _C. eburneum_ was absent in August and rare in November 1986; _B. minima_ was patchily abundant in both monitorings, and _N. virginea_ showed considerable recruitment in November 1986, like it did at the oiled area.

Thalassia: This habitat was characterized by two species of cerithids, _C. eburneum_ and _C. literatum_ in 1982 (Table 5). In August 1986, _C. eburneum_ was not found, and _C. literatum_ was extremely rare; in November 1986, neither species was found. On the control reef, both species occurred in low abundance during the August and November 1986 monitorings.

Laurencia: Galeta's Laurencia zone in 1982 was characterized by relatively high diversity and low abundances. Both predaceous and herbivorous gastropods occurred within this habitat; the most common were Cypraea zebra and Thais deltoidea (Table 6). No gastropods were found in the two monitorings since the oil spill (August and November 1986). In the control area, three species occurred in August and four were found in November, all in low abundance.

Zoanthus: The Zoanthus zone was also characterized by low abundance of the species found there (Table 7). Of the five species present in 1982, none were found in 1986 monitorings. The only snail found in August 1986 was a single Thais deltoidea. Three Thais were found in November, along with a total of three individuals belonging to two other species (Table 7).

DISCUSSION

The effects of the oil spill at Bahia las Minas on gastropod molluscs inhabiting the nearby Galeta reef flat are as yet an open question. Any conclusions must be speculative, given (1) the four year time period between the pre- and post-oil spill monitoring, (2) the natural scarcity of gastropods in some habitats, (3) the patchy distribution of most abundant species and (4) the limited number (two) of quarterly remonitorings of the reef flat since the spill.

Based on the limited data on hand, several points can be made. Of the habitats sampled, oil was most heavily concentrated in the low rubble and the emergent portions of the reef-rock habitats, where wave action added layer after layer of oil to the rock surface following the spill. Some oil splashed up onto the high rubble, which was above the level of the tides. Other habitats were primarily affected by oil flowing over them as the tide rose or fell, but did not collect the amount of oil seen in habitats exposed to nearly constant wave splash.

Both the reef-rock and the low rubble habitats showed apparently major changes in gastropod abundance. Prior to the oil spill, five species inhabited the reef-rock; in August 1982, only two of these original five remained, and in November, only one, Nerita tessellata was found. Its abundance decreased markedly from 1982 when it was the most abundant species in this habitat and it continued to decrease between August and November 1986. During the same period, at an unoiled site, it showed a small increase. In the low rubble zone, nine species were found during the 1982-3 monitoring. Six of these were still present in August 1986, but the number dropped to four after cleanup activities, and remained at four in November 1986. Additionally, after the cleanup, both dead and live snails of species not ordinarily found in this habitat were observed. Abundances of all species dropped between 1982-3 and August 1986 and abundances of every species but Planaxis nucleus (which spends most of its time under rocks) changed after cleanup. In November, Nerita versicolor and P. nucleus appeared more common than in August, despite additional mortality. Size frequency data indicated probable recruitment in the control reef snails Littorina lineolata and L.

ziczac between August and November 1986; there appeared to be no corresponding recruitment on the oiled reef.

Gastropods are normally rare in areas dominanted by either *Laurencia* or *Zoanthus*, but many species are usually recorded (Tables 6, 7). Since the oil spill, almost no molluscs have been found in either habitat. Oil flowed over both areas at Galeta with each tidal cycle; in some areas the algal mats and zoanthid beds were completed fouled. At the unoiled *Laurencia* site, four species of molluscs were recorded, all in low density.

At Galeta, in areas dominated by sand and *Thalassia* beds, there were strong differences between 1982 and post-spill monitorings. In sand, *Battillaria minima* dropped in density by an order of magnitude, but *Cerithium eburneum* appeared in moderate abundance immediately after the spill. Both species disappeared after cleanup operations. Six months after the spill, *Neritina virginea* had recruited in high density. At the unoiled control site, *Battillaria* was abundant in both 1986 monitorings, as was *Neritina*. It appears that the oil spill and subsequent cleanup operations eliminated *Battillaria* from sand at Galeta and that an opportunistic settlement of *Neritina* has occurred since the spill. In support of this suggestion, the size structure of *Neritina* populations in November was identical at both sites. In the *Thalassia bed*, there were also strong differences between pre- and post-spill monnitorings. Two species of *Cerithium* were present at Galeta before the spill and were absent or rare after the spill. However, at the unoiled site both species were also rare in 1986. Although it seems likely that oil affected the gastropods of the _Thalassia_ bed at Galeta, I cannot yet separate these results from those expected if populations along this section of the coast were fluctuating in synchrony.

The size data for those species where sufficient data are available suggest that mortality has been uniform across the size range present at the time of the oil spill. As quarterly monitorings continue, data on snail size should provide useful information on sublethal effects and population recovery.

Reef flats are complex communities and the data contained in this report point out the problems of interpretation when results could be due to natural variation or to a man-made perturbation. Until sufficient data are available on the patterns of variation in reef flat populations (e.g. Cubit et al. 1986), we will be unable to assess the true magnitude of an event such as an oil spill. For both those species known to be seriously affected (e. g. those in low rubble and _Zoanthus_ beds), and for species which do not at present appear to have been damaged (e.g. those in the high rubble zone), long-term uptake of hydrocarbons may have as yet undetected biological effects. Recovery rates will certainly vary among species, depending upon the details of their life histories, the extent to which larval stages are affected, interactions among species and stochastic events.

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Density and Size Structure of Gastropods in the High Rubble Zone

Species:	Galeta Reef Flat Pre-Spill XI 1982 - I 1983	 Post Spill VIII 1986	 Post Cleanup IX 1986	 X - XI 1986	Unoiled Control VIII 1986	 X - XI 1986
Tectarius muricatus	6.0 ± 8.7 19 (9-24)	14.8 ± 10.2 19 (9-25)	7.2 ± 13.3 19 (8-22)	12.1 ± 11.3 19 (8-24)	12.0 ± 6.6 15 (11-19)	10.1 ± 4.8 20 (5-28)
Nodilittorina tuberculata	1.1 ± 2.1 14 (5-17)	2.2 ± 3.6 10 (5-16)	1.4 ± 2.7 9.5 (5-13)	1.1 ± 1.2 11 (4-15)	2.0 ± 2.1 9 (7-11)	1.5 ± 1.5 10 (3-13)
Littorina angustior	4.0 ± 8.1 14 (6-17)	14.8 ± 12.8 10 (3-14)	13.0 ± 18.9 8 (3-14)	10.4 ± 13.5 9 (2-12)	0 N. D.	0 N. D.
Littorina lineolata	1.7 ± 4.4 11 (5-16)	0.9 ± 1.3 9 (7-12)	0 N. D.	0.4 ± 0.8 9 (1-14)	6.6 ± 7.7 9 (6-13)	8.4 ± 6.8 9 (3-15)
Littorina ziczac	0.2 ± 0.7 N. D.	0.6 ± 1.6 N. D.	0 N. D.	0.8 ± 1.0 10 (7-14)	10.4 ± 8.9 11 (6-16)	4.0 ± 3.5 11 (3-17)
Littorina nebulosa	0 N. D.	0 N. D.	0.1 ± 0.2 N. D.	0 N. D.	0 N. D.	0.2 + 0.5 N. D.
Littorina angulifera	0 N. D.	0.1 ± 0.2 N. D.	0 N. D.	0 N. D.	0 N. D.	0 N. D.
Nerita versicolor	0 N. D.	0 N. D.	0.8 ± 2.7 N. D.	0 N. D.	0 N. D.	0 N. D.
Nerita peloronta	0 N. D.	0 N. D.	0.1 ± 0.3 N. D.	0 N. D.	0 N. D.	0 N. D.

For each species and monitoring date, the top number is the mean density/0.25m^2 + one standard deviation (n = 20 quadrats) and the bottom number is median size with the range of sizes observed in parentheses (sample size variable, usually > 150). N. D. = no data.

Density and Size Structure of Gastropods in the Low Rubble Zone

	Galeta Reef Flat				Unoiled Control	
	Pre-Spill	Post Spill	Post Cleanup			
	XI 1982 - I 1983	VIII 1986	IX 1986	X - XI 1986	VIII 1986	X - XI 1986
Species:						
Tectarius muricatus	0 N. D.	0 N. D.	0.1 ± 0.5 N. D.	0 N. D.	2.6 ± 3.1 N. D.	3.6 ± 4.1 N. D.
Nodilittorina tuberculata	0.9 ± 1.7 10 (5-15)	0 N. D.	0 N. D.	0 N. D.	2.2 ± 2.1 8 (5-10)	1.5 ± 1.2 9 (5-11)
Littorina angustior	8.8 ± 9.0 11 (5-14)	0.2 ± 0.7 8 (4-12)	1.4 ± 5.8 N. D.	1.0 ± 1.3 8 (4-12)	0 N. D.	0 N. D.
Littorina lineolata	3.3 ± 4.4 8 (4-15)	0.1 ± 0.2 8 (4-11)	0 N. D.	0 N. D.	5.8 ± 6.7 9 (7-13)	3.5 ± 2.8 9 (3-14)
Littorina ziczac	1.3 ± 2.7 9 (5-14)	0.1 ± 0.2 10 (7-15)	0 N. D.	0.5 ± 1.1 11 (8-15)	0.9 ± 1.2 9 (6-10)	1.0 ± 1.5 8 (2-11)
Nerita fulgurans	0.8 ± 1.5 17 (10-24)	0 N. D.	0 N. D.	0 N. D.	0 N. D.	0 N. D.
Nerita tessellata	12.1 ± 22.7 10 (5-16)	1.0 ± 2.5 13 (9-18)	0.1 ± 0.2 N. D.	0.1 ± 0.3 6 (4-16)	2.1 ± 2.3 N. D.	3.3 ± 4.8 13 (5-17)
Nerita versicolor	11.4 ± 16.6 18 (12-26)	1.3 ± 2.2 15 (7-19)	0.3 ± 0.9 15 (9-18)	4.3 ± 4.0 14 (8-20)	1.8 ± 2.2 16 (10-18)	2.6 ± 4.5 16 (7-19)
Nerita peloronta	0.3 ± 0.7 24 (13-33)	0 N. D.	0 N. D.	0 N. D.	0 N. D.	0.1 ± 0.2 N. D.
Planaxis nucleus	0.6 ± 2.2 13 (9-15)	0.1 ± 0.2 13 (11-14)	0.1 ± 0.4 N. D.	1.2 ± 2.2 N. D.	0 N. D.	0.5 ± 1.2 N. D.
Melampus coffeus	0 N. D.	0 N. D.	0 N. D.	0.1 + 0.5 N. D.	0 N. D.	0 N. D.

For each species and monitoring date, the top number is the mean density/0.25m^2 + one standard deviation (n = 20 quadrats) and the lower number is the median size with the range of sizes observed in parentheses (sample size variable, usually >150). N. D. = no data.

Table 3

Density and Size Structure of Gastropods in the Reef Rock Zone

Species:	Galeta Reef Flat: Pre-Spill XI 1982 - I 1983	Galeta Reef Flat: Post Spill VIII 1986	Galeta Reef Flat: Post Spill X - XI 1986	Unoiled Control VIII 1986	Unoiled Control X - XI 1986
Nodilittorina tuberculata	0.1 ± 0.2 N. D.	0 N. D.	0 N. D.	1.1 ± 4.5 7 (3-10)	1.8 ± 2.6 6 (2-11)
Littorina angustior	1.0 ± 4.0 11 (9-14)	0 N. D.	0 N. D.	5.7 ± 8.7 4 (1-9)	8.6 ± 8.1 5 (2-11)
Littorina lineolata	0 N. D.	0 N. D.	0 N. D.	9.3 ± 8.9 5 (1-10)	9.0 ± 8.0 5 (2-11)
Littorina ziczac	0.2 ± 0.9 N. D.	0 N. D.	0 N. D.	0.4 ± 0.7 N. D.	0.3 ± 0.6 N. D.
Nerita fulgurans	0.3 ± 0.6 N. D.	0.1 ± 0.2 N. D.	0 N. D.	0.4 ± 0.7 N. D.	0.3 ± 0.6 N. D.
Nerita tessellata	10.9 ± 9.4 15.5 (3-22)	0.7 ± 1.2 15 (10-20)	0.4 ± 0.9 N. D.	1.1 ± 1.0 11 (6-21)	1.7 ± 1.4 12 (3-23)
Nerita versicolor	0 N. D.	0.1 ± 0.3 N. D.	0.2 ± 0.5 N. D.	3.5 ± 4.3 15 (6-19)	4.5 ± 4.0 15 (5-20)
Nerita peloronta	0 N. D.	0 N. D.	0 N. D.	0.2 ± 0.4 N. D.	0.4 ± 0.8 N. D.
Acanthopleura granulata	0 N. D.	0 N. D.	0.1 ± 0.2 N. D.	0.1 ± 0.2 N. D.	0 N. D.

For each species and monitoring date, the top number is mean density/0.25m^2 + one standard deviation (n= 20 quadrats) and the bottom number is median size with the range of sizes observed in parentheses (sample size variable, usually >150). N. D. = no data.

Table 4

Density and Size Structure of Gastropods in Sand

Species:	Galeta Reef Flat Pre-Spill XI 1982 - I 1983	Galeta Reef Flat Post Spill VIII 1986	Galeta Reef Flat Post Cleanup IX 1986	Galeta Reef Flat Post Cleanup X - XI 1986	Unoiled Control VIII 1986	Unoiled Control X - XI 1986
Cerithium eburneum	0 N. D.	24.3 ± 69.3 16 (8-24)	0 N. D.	0 N. D.	0 N. D.	0.1 ± 0.2 N. D.
Battillaria minima	96.4 ± 97.3 9 (4-13)	11.1 ± 41.2 N. D.	0.1 ± 0.2 N. D.	0 N. D.	901.3 ± 1136.5 7 (3-13)	172.8 ± 176.0 7 (3-14)
Neritina virginea	0 N. D.	0 N. D.	0 N. D.	415.0 ± 497.4 3 (1-7)	1.5 ± 6.5 N. D.	91.5 ± 146.3 3 (1-7)

For each species and monitoring date, the top number is the mean density/$0.25m^2$ + one standard deviation (n = 20 quadrats) and the bottom number is the median size with the range of sizes observed in parentheses (sample size variable, usually > 150). N. D. = no data.

Table 5

Density and Size Structure of Gastropods in the *Thalassia* Zone

	Galeta Reef Flat			Unoiled Control	
	Pre-Spill	Post Spill			
	XI 1982 - I 1983	VIII 1986	X - XI 1986	VIII 1986	X - XI 1986
Species:					
Cerithium eburneum	4.5 ± 6.6 15 (10-21)	0 N. D.	0 N. D.	0.2 ± 0.5 N. D.	0.9 ± 1.1 N. D.
Cerithium literatum	12.3 ± 13.1 23 (17-30)	0.1 ± 0.2 N. D.	0 N. D.	0.3 ± 0.6 N. D.	0.7 ± 1.5 N. D.
Strombus gigas	0 N. D.	0 N. D.	0 N. D.	0.1 ± 0.2 N. D.	0 N. D.

For each species and monitoring date, the top number is the mean density/0.25m^2 + one standard deviation (n = 20 quadrats) and the bottom number is median size with the range of sizes observed given in parentheses (sample size variable, usually >150). N. D. = no data.

Table 6

Density of Gastropods in the *Laurencia* Zone

	Galeta Reef Flat			Unoiled Control	
	Pre-Spill	Post Spill			
	XI 1982 - I 1983	VIII 1986	X - XI 1986	VIII 1986	X - XI 1986
Species:					
Thais deltoidea	0.5 ± 1.1	0	0	0.2 ± 0.4	0.3 ± 0.6
Conus sp.	0	0	0	0.1 ± 0.3	0.1 ± 0.3
Leucozonia nassa	0.1 ± 0.2	0	0	0	0
Astraea phoebia	0.3 ± 0.6	0	0	0	0
Opisthobranch sp. 1	0.2 ± 0.5	0	0	0	0
Diodora dysoni	0.1 ± 0.3	0	0	0	0
Chiton sp. 1	0.3 ± 0.4	0	0	0	0
Gastropod sp. 6	0.1 ± 0.3	0	0	0	0
Olivella sp.	0	0	0	0.4 ± 0.7	0.2 ± 0.4
Mitra sp.	0	0	0	0	0.1 ± 0.2
Cypraea zebra	2.6 ± 2.6	0	0	0	0

Data are mean density/0.25m^2 + one standard deviation.
N = 20 quadrats in each monitoring.

Table 7

Density of Gastropods in the *Zoanthus* Zone
on the Galeta Reef Flat

	Pre-Spill	Post Spill	
	XI 1982 - I 1983	VIII 1986	X - XI 1986
Species:			
Thais deltoidea	0	0.1 ± 0.2	0.2 ± 0.5
Cantharus sp.	0	0	0.1 ± 0.3
Gastropod sp. 7	0	0	0.1 ± 0.3
Heliacus cylindricus	0.1 ± 0.3	0	0
Risomurex sp.	0.1 ± 0.4	0	0
Opalia crenata	0.6 ± 1.1	0	0
Coralliophila aberrans	0.4 ± 0.9	0	0
Olivella pusilla	1.0 ± 3.1	0	0

Data are mean density/0.25m^2 + one standard deviation.
N = 30 quadrats in 1982-1983 and 20 quadrats in both other monitorings.

Oil Spill Project:

Reef Flat Studies through December 1986

(Updates information in 1987 Oil Spill Conference paper and the supplements of October and December 1986.)

Emergent reef flats form large areas of coastal habitat in the region of the oil spill. Between 10 and 19 May 1986, extreme low tides exposed the reef flats above water level as the thickest oil slicks came ashore; consequently, winds and waves deposited the oil in concentrations along the seaward margins of the reef flats. At high tides, the oil tended to float over, and pass, the reef flat, except where caught by pieces of coral rock projecting above the reef platform. A program of biological monitoring conducted at Galeta Reef before the oil spill included all habitats of the reef flat; sampling intensity was higher at the seaward edge of the reef flat (Figure 1). The monitoring quantified variations in the distribution and abundance of the reef flat biota and all measurements had been made in relation to a permanent sampling grid on the reef flat. This allowed us to do three things: (1) compare the distributions and abundances of reef flat organisms before and after the oil spill, (2) account for normal seasonal variations, and (3) relate spatial variation in changes of the biota to the gross pattern of oil deposition on the reef flat.

Here we use three sources of pre-spill data for post-spill comparison: (1) surveys of percent cover of sessile species on the entire reef flat (1981-1982), (2) surveys of percent cover of sessile species and thickness of the algal bed on the seaward section of the reef flat (1983-1984), and (3) censuses of sea urchins on the reef flat (continuous from 1978). Locations of the sampling areas are shown in Figure 1. These and other studies have demonstrated that the distribution and abundance of reef flat species change seasonally (Hendler 1976, Cubit 1985, Cubit et al. 1986; Kilar, Norris, Cubit, and Hay in prep.; Connor, Cubit, and Norris in prep., Burgett and Cubit, in press; Burgett and Cubit, unpubl.).

METHODS

Abundance of sessile species on the reef flat

The abundance of sessile species was measured as percent coverage. In the reef-edge surveys we also recorded vertical thickness of the algal turf. We estimated percent cover with point sampling methods; i.e., by determining what organisms were under each sampling point of a transect line or quadrat. Points were treated as exact points, not areas. We distinguished organisms actually attached to the substratum from those overlying or attached to the organisms on primary substratum. In all the surveys, each species was categorized as follows: primary cover (species of plants and animals growing directly on the substratum at the sampling point) or as any of the following types of secondary cover (drift plants, epiphytes on the primary cover, and species that overgrow or overlay the primary cover species). In this system, primary cover cannot exceed 100 percent. Diatoms, bluegreen algae, and sporelings of macroalgae were classified as "microalgae." Crustose coralline algae were not identified beyond this general level of classification, except the distinctive crustose coralline, Neogoniolithon sp. Other organisms were identified to species. Bare substrata were categorized as rock, rubble or sand.

Whole reef-flat surveys-- We made 22 monthly surveys of coverage of sessile organisms across the range of reef flat habitats between January 1981 and October 1982. The post-spill surveys employed the same methods on 25 June and 17 September 1986. Each month, the percent coverage was measured at 100 randomly chosen locations on the reef flat. Computer-generated random coordinates determined the positions for sampling, which were measured with a surveyor's tape from permanent markers on the reef flat. A separate set of coordinates was used for each survey. The sampling area (Figure 1), excluding foot paths and surf zone, was about 14,000 m^2 and was divided into four subsections. Sampling was random within each subsection, and the number of samples per subsection was proportional to the area of that subsection. Coverage was estimated at each sampling position using a 0.25 m^2 sheet of clear polycarbonate plastic (3 mm thick) divided into 100 squares (5 x 5 cm). Within each square, the exact center point of a randomly placed hole marked the position for critical examination of the reef surface. All organisms were recorded as dead, healthy, or covered with epiphytes.

Reef-edge surveys-- These surveys provided higher-resolution data in the zone of heaviest oiling. We measured biotic cover and thickness of cover along transects across the Laurencia and Coralline zones on the seaward side of the reef flat (Figure 1). Before the oil spill, surveys were conducted 16 times in the period between March 1983 and December 1984. After the oil spill the surveys were repeated in 25 June, 2 Sept, and 4 Dec 1986. All surveys were performed along 10 permanent transects, 9 to 22 m long (average length = 15.6 m), which were perpendicular to the reef edge and spaced randomly within 20 m intervals. Using point sample methods, we determined the spatial coverage of organisms on the substrate at random points in sets of 5 per 0.5 m interval. Using a probe, we measured the thickness of turf-forming algae at each point, thus getting a better measure of abundance by reducing the tendency to equate percent covers of organisms with different thicknesses. The number of points sampled per survey ranged between 1510 and 1560. The positions of the transects are shown in red on the map of the reef flat.

Censuses of Sea Urchins

Systematic counts of sea urchins at Galeta were made in permanent transects or plots in all major communities of the reef-flat. The principal species of sea urchins were Echinometra lucunter, E. viridis, Lytechinus variegatus, Diadema antillarum, Eucidaris tribuloides, and Tripneustes ventricosus. Some transects have been censused since 1971, but here we use data since 1978, when all plots were being censused simultaneously. The urchins were counted in fixed transects and plots. The transects were 1 x 20 m; the plots ranged in area from 15 to 29 m^2. There were 3 transects and 12 plots at Galeta (Map of reef flat). The urchins were counted species by species within a square meter quadrat moved over the census area. Counts were made once per month, depending on water conditions. To standardize results, we report all densities as the number of urchins per 10 m^2.

RESULTS

Changes Immediately following the Oil Spill (May-June 1986)

Sessile Species

The remains of dead organisms and the smell of decomposing invertebrates in the weeks following the oil spill indicated heavy mortality of biota on the reef flat. By the first week of June 1986, a distinct, light-colored band 1-3 m wide of vacated carbonate substratum, dead corals, and bleached coralline algae appeared at the extreme seaward margin of the reef flat--the area which had been awash in oil during low tides. The reef flat populations of hydrocorals *Millepora* spp., scleractinian corals *Porites* spp., and zoanthid *Palythoa caribaeorum* only occurred on this part of the reef flat; their combined abundance within a 2 m wide band at the extreme seaward edge of the reef flat was reduced from an average of >10% coverage in pre-spill surveys to <3% in June 1986 (Table M p.14). Another zoanthid *Zoanthus sociatus* has a wider range of distribution than the other cnidarians; its abundance was also reduced within 2 meters of the seaward margin of the reef edge, but not further away (Table M p.13). Overall, the post-spill abundance of sessile cnidarians (anemones, zoanthids, scleractinians, and hydrozoans) in the full width of the reef edge surveys was reduced to about 60% of pre-spill measures (Table T). Not counting *Zoanthus*, the overall post-spill reduction of cnidarians in the reef-edge was to <10% of pre-spill averages; in a 2-cluster K-means analysis of these data for all surveys, the June and September 1986 data separated from all the rest at $p<.001$. The same result in K-means analyses were obtained using just the data for *Palythoa* alone, and for all species of cnidarians together. Sample sizes for cnidarians were relatively low in the whole reef-flat surveys. The mean June coverages for the more abundant *Zoanthus sociatus* showed a post-spill increase for reef flat as a whole (Table Consurv).

In pre-spill surveys, crustose coralline algae formed a distinct zone along the seaward margin of the reef flat. Within the first five meters from the reef edge, the June 1986 coverage of crustose coralline algae was less than a tenth of the coverage recorded in the pre-spill months of June. Crustose corallines, including *Neogoniolithon* sp. nov. (cf. *westindianum*), that were further from the seaward edge of the reef flat showed no such reduction in the reef edge surveys (Table M p.9). The overall reduction of coralline algae, exclusive of *Neogoniolithon*, in the reef-edge zone was reduced from a pre-spill average of 5.8% to 2.3% in June 1986. In a 2-cluster K-means analysis, the June 1986 separated from all other surveys at $p<.005$. In the whole reef-flat surveys, the post-spill abundances of the crustose corallines, including *Neogoniolithon* showed no unusual changes for the month of June (Table Consurv).

The alga *Laurencia papillosa* formed a dense, turf-like zone that paralleled the shoreline in a band averaging about 20 m wide and 20 mm thick in 16 reef-edge surveys conducted before the oil spill. The coverage and thickness of the bed varied seasonally, and was normally at its lowest coverage (about 30%) and its thinnest (about 10 mm) in the months of June. During the spill, oil coated the upper branches of the *L. papillosa*. After the algae died back, both the coverage (20%) and thickness (0.7 mm) of the turf in the reef edge surveys were lower than in any surveys before the spill (Tables M pp. 3 & 3a, T, Fig M). *L. papillosa* generally forms >90% of all the cover of fleshy macroalgae at the reef edge, and the figures for this broader category follow those of *L. papillosa* (Table M p.4). In the whole reef-flat surveys for the months of June, the post-spill abundances of *L. papillosa* were comparable to coverages recorded before the oil spill (Table Consurv).

In the June 1986 surveys, the abundance of *Halimeda opuntia* was more severely reduced in the seaward portions of the reef-edge habitat (Table M p.10). *H. opuntia* was common on the entire reef flat and in the whole reef-flat surveys, post-spill abundances of this alga were slightly lower than pre-spill abundances in the month of June (Table Consurv).

Despite the large mortality of sessile organisms, little of the reef-edge substratum was barren after the oil spill. In June 1986, the total proportion of the reef edge habitat that was bare rock was 1%, which was lower than any previous record (Table T). The reduction in free space was most pronounced at the seaward half of the reef edge habitat, where the amount of bare rock in the months of June normally exceeded 10% of the space; in June 1986, bare rock accounted for less than 1% of the space in the seaward half of the transects (Table M p.16), even though this was the zone of highest mortality. In surveys of the reef-flat overall, the amount of bare rock was slightly higher after the oil spill (Table Consurv).

The absence of free space at the reef edge in the month after the oil spill was largely a result of a bloom of microalgae, which covered 54% of the reef edge zone (Tables T and M p.1), and was most abundant in the seaward half of the reef edge zone--the area of heaviest oiling (Table M p.1). In pre-spill surveys in the month of June, microalgae had not covered more than 29% of the reef edge zone, and most of these microalgae normally occurred in the landward half of the reef edge zone (Figure M, Table M p.1). In a 2-cluster K-means analysis, the coverage for microalgae in June 1986 separated from the coverages in all other surveys at $p<.001$. The post-spill bloom of microalgae was present as the oil sloughed off the substrata and in some cases covered oil on substratum. On 7 June 1986, visual inspection of the reef edge habitat showed that it was being colonized by a thin, transparent mat of algae. Six samples of this mat were examined microscopically in the laboratory. Cladophora sp., Enteromorpha sp., and epiphytic diatoms consistently made up >90% of each sample. On 29 June, the mat had become thicker and had overgrown both the vacated substrata and the sessile organisms that had survived the oil spill. In a second systematic collection of 18 samples, *Cladophora* sp., *Centroceras* sp., and diatoms uniformly composed >90% of the algal volume. *Enteromorpha* was no longer present. In contrast, the surveys of the whole reef flat showed that the microalgae occupied little primary space either before or after the oil spill (Table Consurv).

The seagrass *Thalassia testudinum* formed only 1-2% of the coverage in the reef edge habitat (Table T), all of which was in the landward part of the sampling area (Table M p.12). On the reef flat overall, however, *Thalassia* constituted 13 to 15 percent of the biotic coverage in the months of June. The post-spill coverage of this seagrass was not significantly lower in either sampling area (Tables T and Consurv).

Sea urchins

By mid-May of 1986, numerous empty tests in the reef-edge zone indicated a high mortality of sea urchins (principally *Echinometra lucunter* and *E. viridis*). In the transect near the reef edge, the numbers of *E. lucunter* per 10 m^2 dropped from 154 on 8 May (when the oil began to arrive) to 27 on 31 May 1986 (after the largest masses of oil had come ashore). The count for *E. viridis* declined from 28 to 4 in the same period. No urchins were found where deposits of oil still covered the transect. By 19 June 1986, densities of *E. lucunter* and *E. viridis* in the reef edge transect had increased, respectively, to 66 and 10 urchins per 10 m^2.

The urchins further from the reef edge were less affected. In the two May censuses of the *Thalassia* zone transect, the number of *E. lucunter* per 10 m^2 declined from 55 to 51, and *E. viridis* dropped from 28 to 15. In the east reef transect, the populations of both *Echinometra* species increased between the May counts: *E. lucunter* densities rose from 17 to 20 per 10 m^2, and *E. viridis* rose from 8 to 12 per 10 m^2. The 19 June 1986 census of the *Thalassia* transect showed a further decline of *E. lucunter* and *E. viridis*, respectively, to 9 and 3 urchins per 10 m². The June census of the east reef transect showed almost no change in the abundance of urchins.

In the other census plots within the *Thalassia* bed, the counts of *E. lucunter* and *E. viridis*, respectively, declined from 29 to 21 and 25 to 14 urchins per 10 m². Censuses in the *Thalassia* bed required examining the undersides of pieces of coral rubble. In the 19 June 1986 census, oil was still trapped beneath the rubble and floated to the water surface as the rocks were lifted. In the other three sets of census plots (Figure 1), populations of urchins were near zero before and after the oil spill. In all plots the densities of the other species of urchins were also too low to compare pre- and post-spill changes in abundances.

Compared with May-June changes before the oil spill, the relative reduction in abundances of *E. lucunter* and *E. viridis* in the reef edge transect between 8 and 31 May were much larger than recorded previously (Figs. U). Despite the recruitment of urchins in early June 1986, the relative reductions in abundance were also aberrant for the period between 8 May and 19 June 1986 in this transect (Figs. U). In other habitats, further from the reef edge, the relative changes in the abundances of *E. lucunter* were not unusual. In the *Thalassia* habitats, however, *E. viridis* did show larger than usual relative decreases in abundances between 8 and 31 May 1986 and between 8 May and 19 June 1986.

The oil spill apparently occurred during a period of settlement of *E. lucunter* and *E. viridis*. In the pre-spill survey of 8 May 1986, about 80% of the *E. lucunter* and 90% of the *E. viridis* in the reef edge transect were less than 1 cm in test diameter. On this date, all the *Echinometra* spp. in the *Thalassia* bed surveys were also in this size class. In the post-spill surveys of 19 and 20 June 1986, more than 95% of the *E. lucunter* and all of the *E. viridis* in the reef-edge and *Thalassia* bed censuses were in this small size category.

Longer-term changes (June-December 1986)

Sessile Species

Surveys of the reef-edge habitat conducted in September and December 1986 showed little regrowth of the corals, zoanthids, and other cnidarians that had occupied the seaward margin of this zone before the oil spill. The crustose coralline algae, however, did increase to pre-spill abundances. The mean percent cover and vertical thickness of *L. papillosa* also increased to values within the range of those recorded before the spill. Moreover, the *L. papillosa* spread seaward, occupying more of the outer two meters of the reef edge survey area than seen in any previous surveys.

Both the reef-edge surveys and the whole reef-flat surveys in September 1986 showed a drop in the abundance of *Halimeda opuntia* to the lowest coverages on record. Only the reef-edge surveys were repeated in December and indicated a small, possible increase of this alga, but coverages in December 1986 were still below those recorded in June 1986 or at any time before the oil spill.

The amount of bare rock at the reef edge increased slightly in September 1986, but in December 1986 the bare space in all meter intervals was 2% or less, and the mean bare space per meter interval was near zero. The coverage of microalgae decreased after the June 1986 surveys, dropping from 54% in June to 18% in September and 12% in December 1986. Contrary to pre-spill patterns, however, most of the microalgae remained in the seaward half of the reef-edge transects.

Sea Urchins [note--the following data are in the Urchin Tables]

The post-spill decrease and rise of *Echinometra* populations in the reef edge transect in May-June 1986 were followed by gradual changes in abundance that were standard for the same times of year in the pre-spill years. In November and December 1986 the number of *E. lucunter* was 75 and 53 per 10 m^2, respectively, as compared with 1977-1985 means of 47 (s.d.=42) and 135 (s.d.=150) urchins per 10 m^2 for the same months before the spill. The counts of *E. viridis* for November and December were 10 and 8.5 urchins, respectively, per 10 m^2, as compared with the long term means of 5 (s.d.=7) and 6 (s.d.=5) urchins per 10 m^2 for the same months before the spill.

Lytechinus variegatus is normally absent from the reef flat in the midyear months when the oil spill occurred, but recolonizes at the end of the year (Hendler 1976, Cubit et al. 1986). The post-spill recolonization took place as usual beginning in September 1986. By December 1986, the counts of *L. variegatus* in the *Thalassia* bed plots were over 100 urchins per 10 m^2. The seasonal mean for this time of year during 1977-1985 was 49 (s.d.=88) urchins per 10 m^2.

DISCUSSION

The spatial patterns of mortality indicated that prolonged, direct oiling was the principal factor causing immediate reductions in the abundance of the benthic biota on the reef flat. Where oil accumulated and surged over the seaward flanks of the reef flat during the low tides of nine consecutive days in mid-May, all major biota were reduced in abundance. Most of the same taxa that occurred away from the reef edge appeared to be less affected. This suggests the high mortality at the margin of the reef flat was not entirely due to this zone being inhabited by species that were hypersensitive to the oil, or that the mortality resulted from conditions that occurred at the same time as the oil spill, but were otherwise unrelated to the oil.

Adaptations to the harsh physical conditions on the reef flat may have contributed to the recovery of some species after the oil spill. Although the abundances of the reef flat biota decline each year during the seasonal, physiologically stressful emergences of the reef flat (Birkeland et al 1976, Hendler 1976, Cubit 1984, 1985, Cubit et al. 1986), the reef flat species persist by regrowth from clone-mates, regeneration from resistant basal tissue, or by rapid recruitment of juvenile stages. For example, during seasonal drying of the reef flat, the branches of the *L. papillosa* turf are killed, but this alga regenerates during more favorable conditions by regrowth from basal portions of the thalli (J. Burgett, unpubl. data). The same mechanism may have operated after the upper thalli of the *Laurencia* were lost when coated with oil.

The populations of sea urchins on the reef flat also suffer heavy mortality during emergences of the reef flat (Hendler 1976, Schneider 1985, Cubit et al. 1986). Populations of *L. variegatus* on the reef flat generally decline to zero during the seasons of emergences, and thus were already absent at the time of the oil spill. In this season, the populations of *E. lucunter* and *E. viridis* usually increase, presumably because concurrent recruitment more than compensates for mortality. These urchins are generally most abundant between March and June, when E. lucunter may reach population densities of more than 500 individuals per 10 m^2 (Cubit et al. 1986) The small sizes of the *Echinometra* species just before and after the oil spill, suggests that recruitment was in progress at the time and continued long enough after the worst part of the spill to partially restore the numbers of urchins in the census plots. In three of the eight years between 1978 and 1985, multi-month recruitment episodes raised the densities of *E. lucunter* in the reef edge transect to more than 300 urchins per 10 m^2. This population might have peaked again in 1986, if not for both the 83% reduction between 8 and 31 May 1986 and the probable loss of urchins recruiting in the meantime.

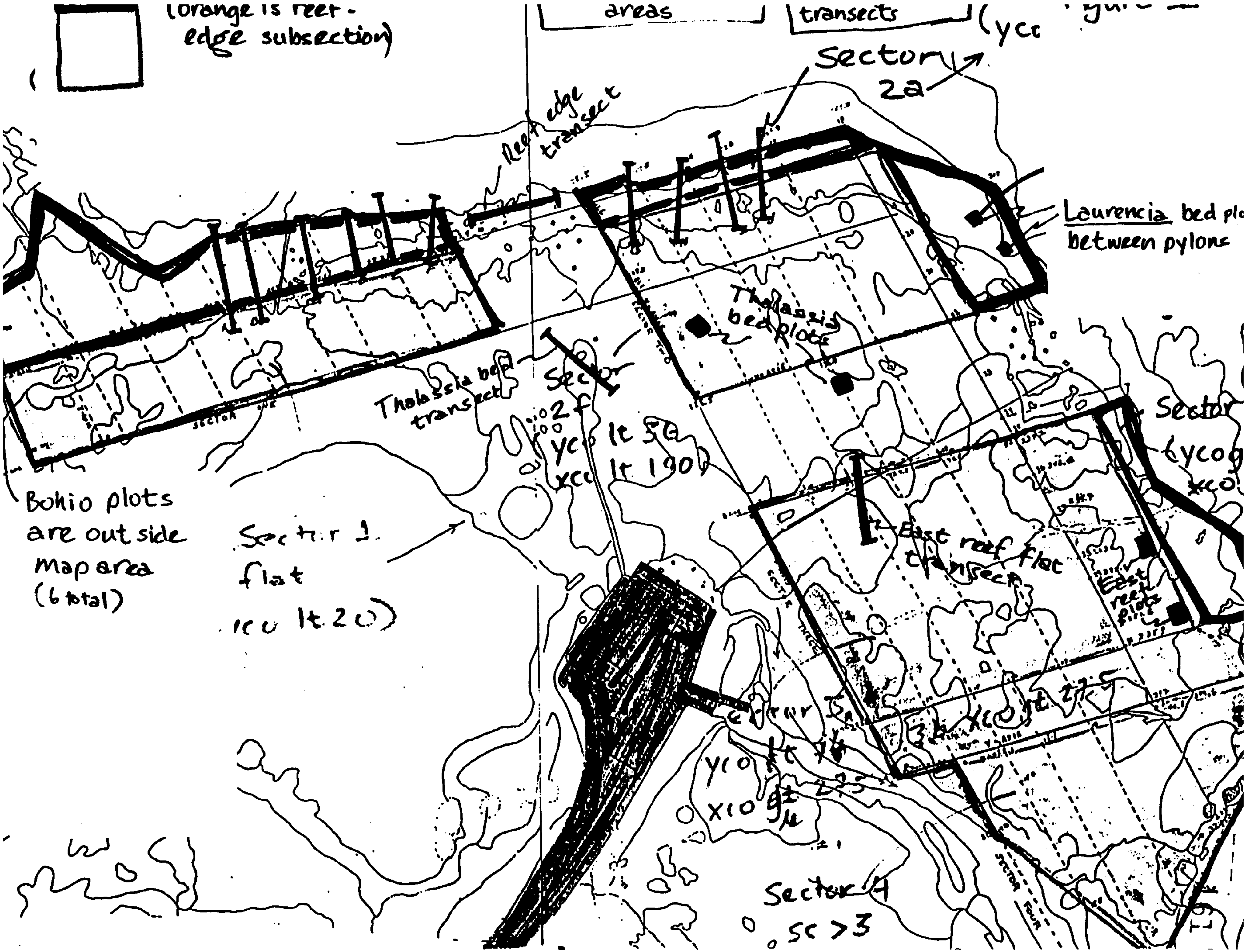
The post-spill decrease in abundance of *E. viridis* in the *Thalassia* bed transect and plots may be related to the fact that this urchin stays well beneath pieces of coral rock on the reef flat, a microhabitat where visible amounts of oil persisted after the spill. *E. lucunter*, which remains more on the open surface of coral rubble, exhibited no such decline.

Post-spill changes in the abundance of *Halimeda opuntia* did not fit the general pattern. In June 1986, the percent coverage of this calcareous green alga was lower than average, but within the range of values recorded in the pre-spill surveys; however, in September 1986 the coverage was about half that measured in June, and was the lowest abundance ever recorded (Tables T and Consurv). Any combination of the following explanations are possible: (a) this alga dies slowly; (b) because this alga is tougher than most, the thalli take more time to slough off the subtratum; (c) the dense masses formed by this alga may have gradually accumulated more oil over time until the clumps were killed; (d) the abundant growth of *L. papillosa* and other fleshy algae may have overgrown or displaced the *H. opuntia*. Unlike the other common algae of the reef flat, *Halimeda opuntia* had not recovered to its pre-spill abundance by the December 1986 census of the reef edge.

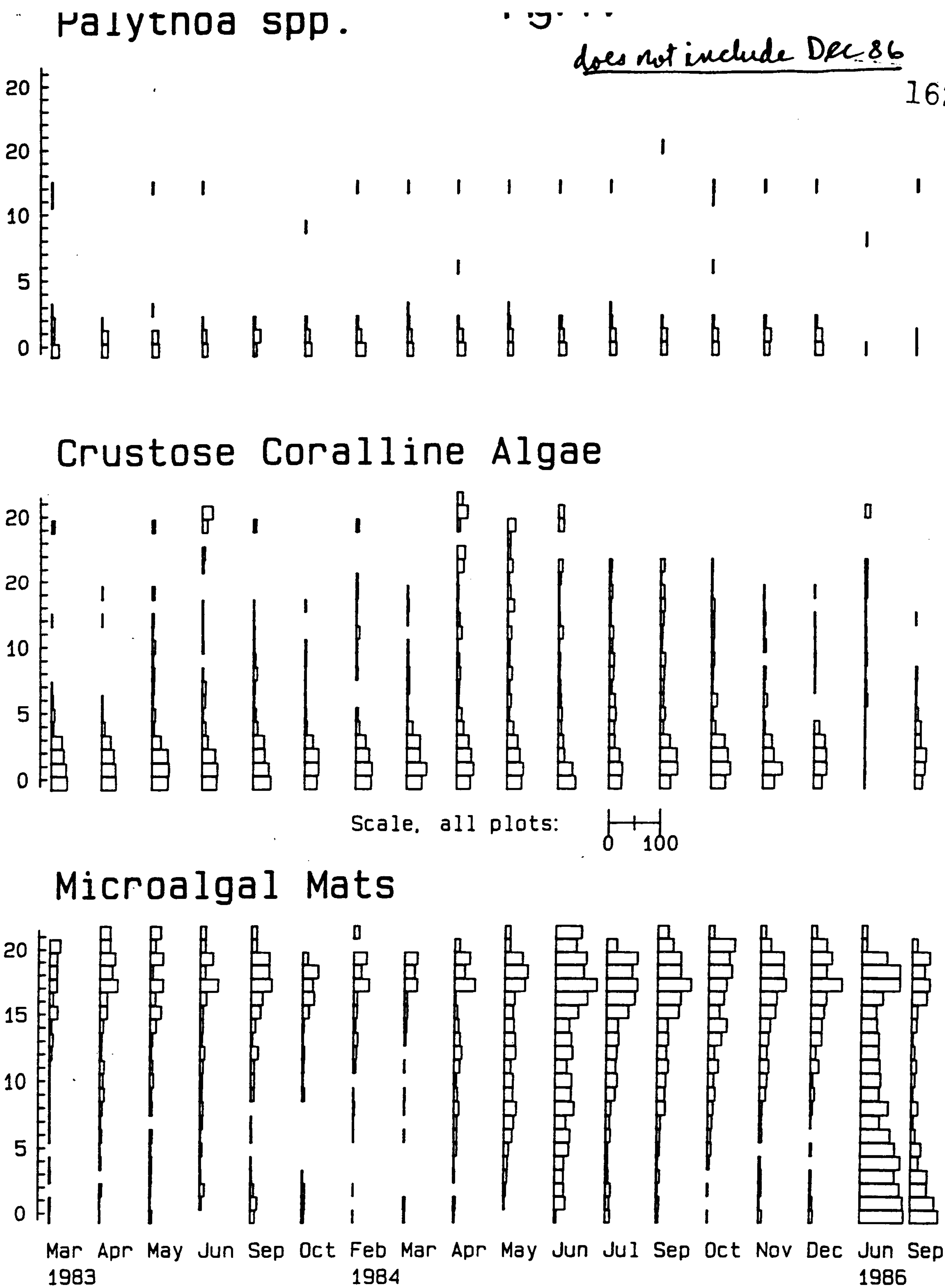
The bloom of microalgae in the heavily oiled areas was comparable to the "green-shore phenomenon" that has been reported in association with other oil-spills, both temperate and tropical (e.g., Bellamy et al. 1968; Southwood and Southwood 1978; Russell and Carlson 1978). There is no consensus as to their cause, and three categories of explanations have been proposed: (1) The oil acts as a fertilizer or other stimulant for algal growth (Nelson-Smith 1971; Kauss and Hutchinson 1975); (2) Organisms that compete with the algae are killed or weakened (Bellamy et al. 1968; Russell and Carlson 1978); and (3) Numbers of herbivores are reduced (Bellamy et al. 1968). The bloom was most extensive in the area of heaviest oiling and greatest mortality of herbivores and competitors at the seaward margin of the reef flat, so any combination of these explanations could be correct. The same explanations may also account for the unusual seaward expansion of the *Laurencia papillosa* bed. Whatever the explanation(s), the fact that extensive mortality of the benthic fauna and flora resulted in less, rather than more, bare space indicates that after the oil spill, an extraordinary change took place in productivity of the algae, consumption by herbivores, or interactions, such as swamping of herbivores and competitors.

The changes observed may have long-term impact on the physical structure and biological environment of the reef flat. The mortality of hydrocorals and scleractinian corals at the reef edge may diminish the accretion rate of the reef flat as a whole. The growth of various types of corals and crustose coralline algae at the seaward margin of the reef flat formed a bulwark behind which sediment and coral rubble accumulated to form the much larger platform of the reef flat. These organisms also contributed part of the rubble (Macintyre and Glynn 1976, Graus et al. 1985). *Halimeda opuntia* produced much of the sediment. The height of the reef flat edge is critical to the amount of wave energy reaching the inner reef flat, beaches, mangroves, and other habitats protected by the bulwark. Biological accretion is necessary not only to maintain this structure against erosion, but also to keep pace with sea level, which is rising at a rate of 1-2 mm/yr and may accelerate within a few years (Gornitz et al. 1982, Barnett 1983, Cubit 1985). The effects of reducing the relative height of the reef flat edge are amplified by the relationship that the maximum amount of wave energy passing over a structure increases as a square of the depth of the water over the structure (Bascom 19__).

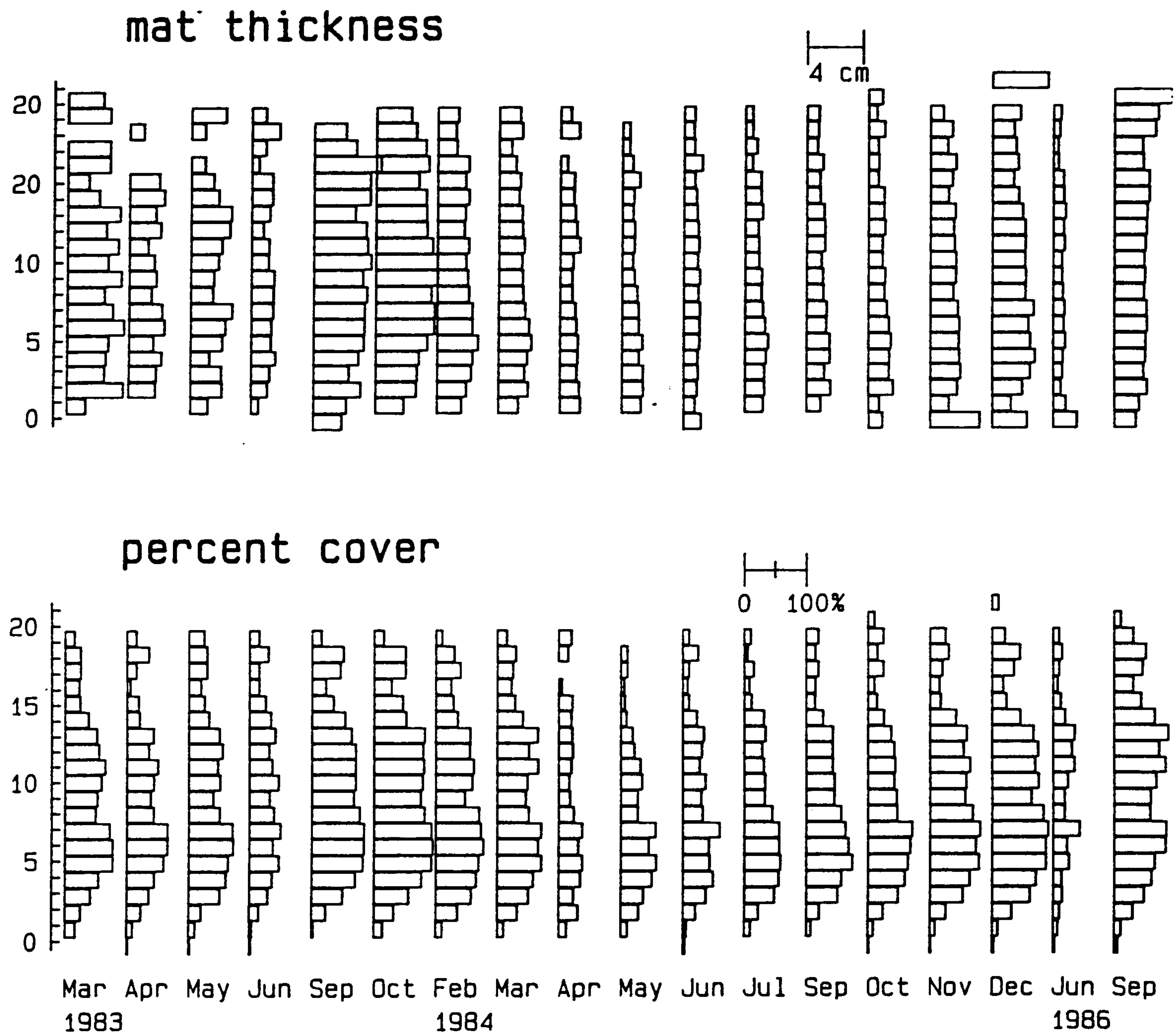
Although the coralline algae had increased to pre-spill abundances by December 1986, the narrow band of corals had not yet recovered. Persistence of the coralline algae and reestablishment of the corals may depend on removal of the microalgae and control of *Laurencia* turf by herbivores (Dart 197__, Vine 197__, Adey and Vassar 1975, Lubchenco and Cubit 1980). Thus, the recovery of some reef flat populations may not just be a function of disappearance of the of oil or arrival of propagules, but also the reconstruction of biological interactions that existed before the spill.


(orange is reef-edge subsection)
areas
transects
Sector 2a
Reef edge transect
Laurencia bed pl
between pylons
Thalassia bed plots
Thalassia bed transect
Sector 2f
Bohio plots are outside map area (6 total)
Sector 1 flat
East reef flat transect
East reef plots
Sector 4
SECTOR ONE
SECTOR FOUR

does not include Dec 86



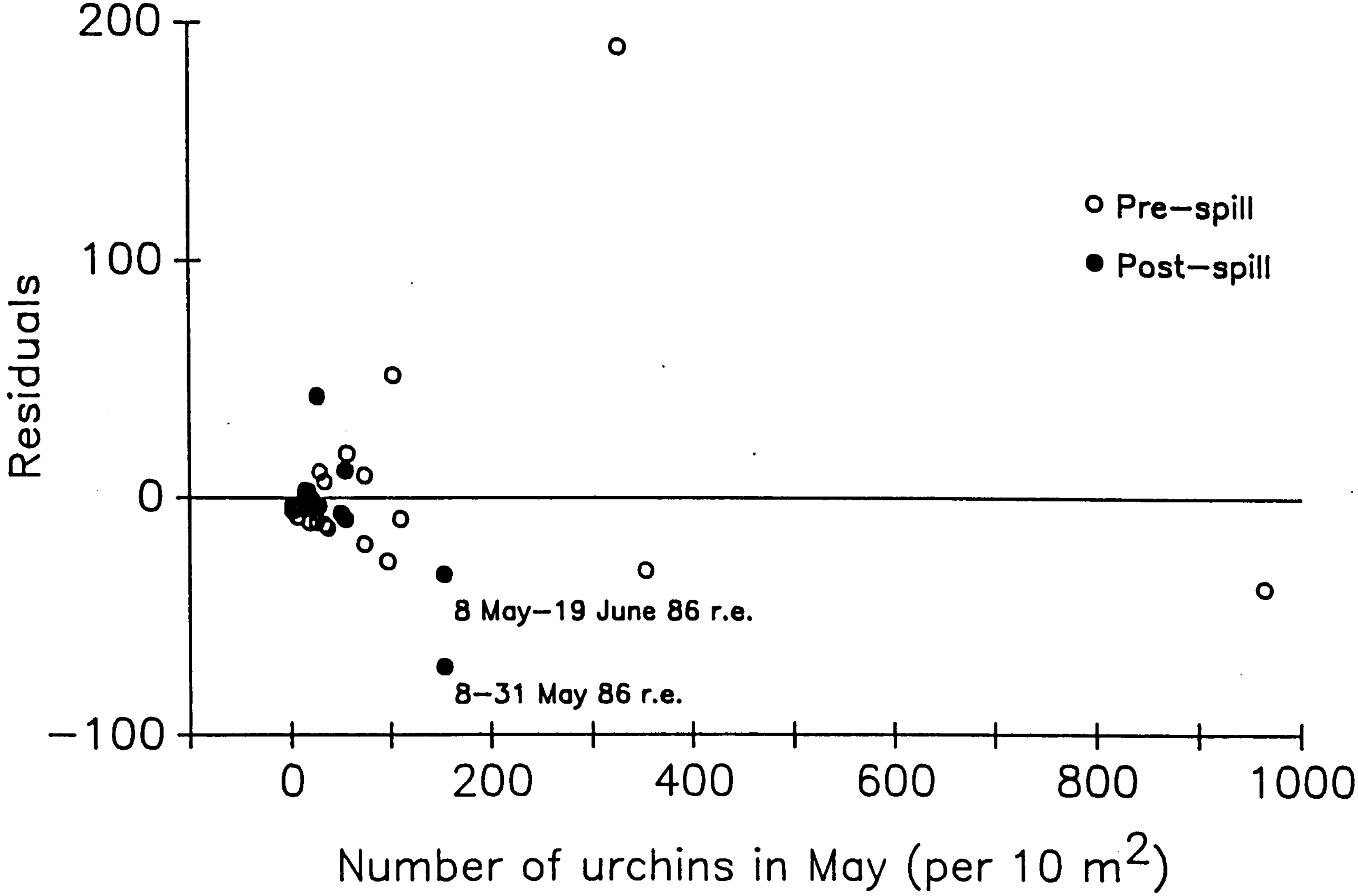
Laurencia papillosa

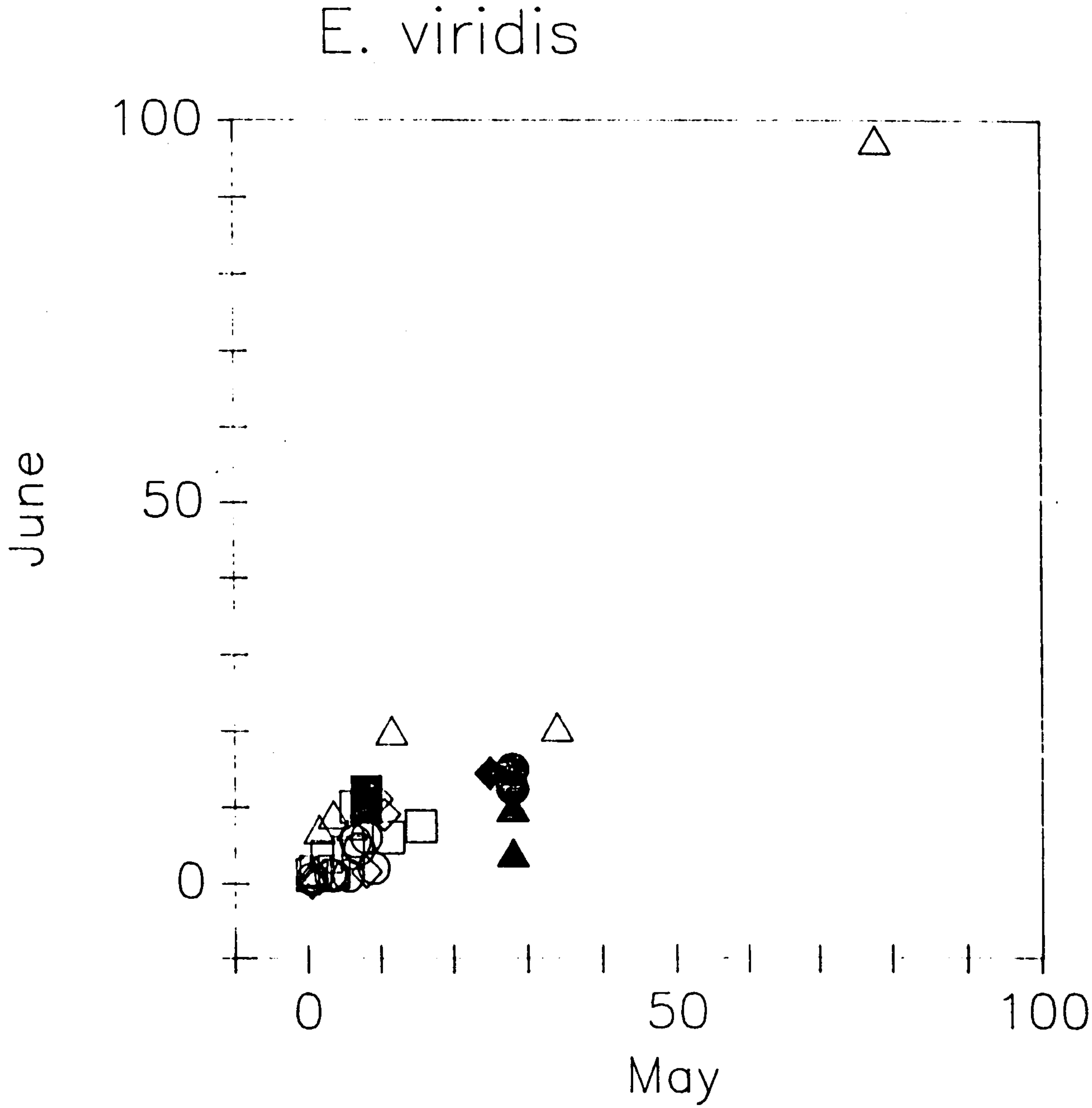


Echinometra lucunter: residuals from May–June regressions

Years 1978–1986

(N=41, r^2=0.88, p<0.001)




E. viridis
100
50
0
June
0
50
100
May

E. lucunter

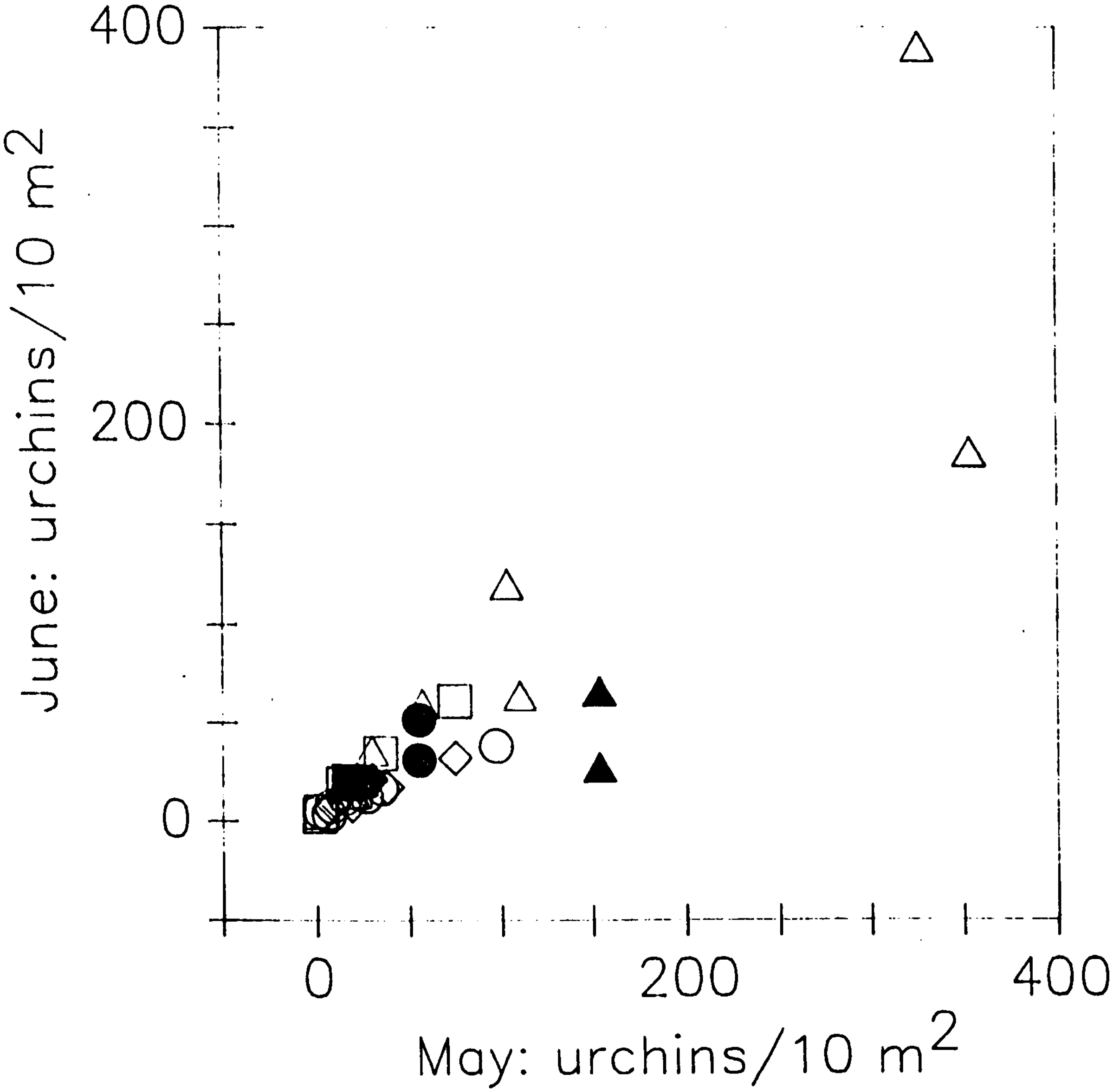


Fig M. - Reef flat

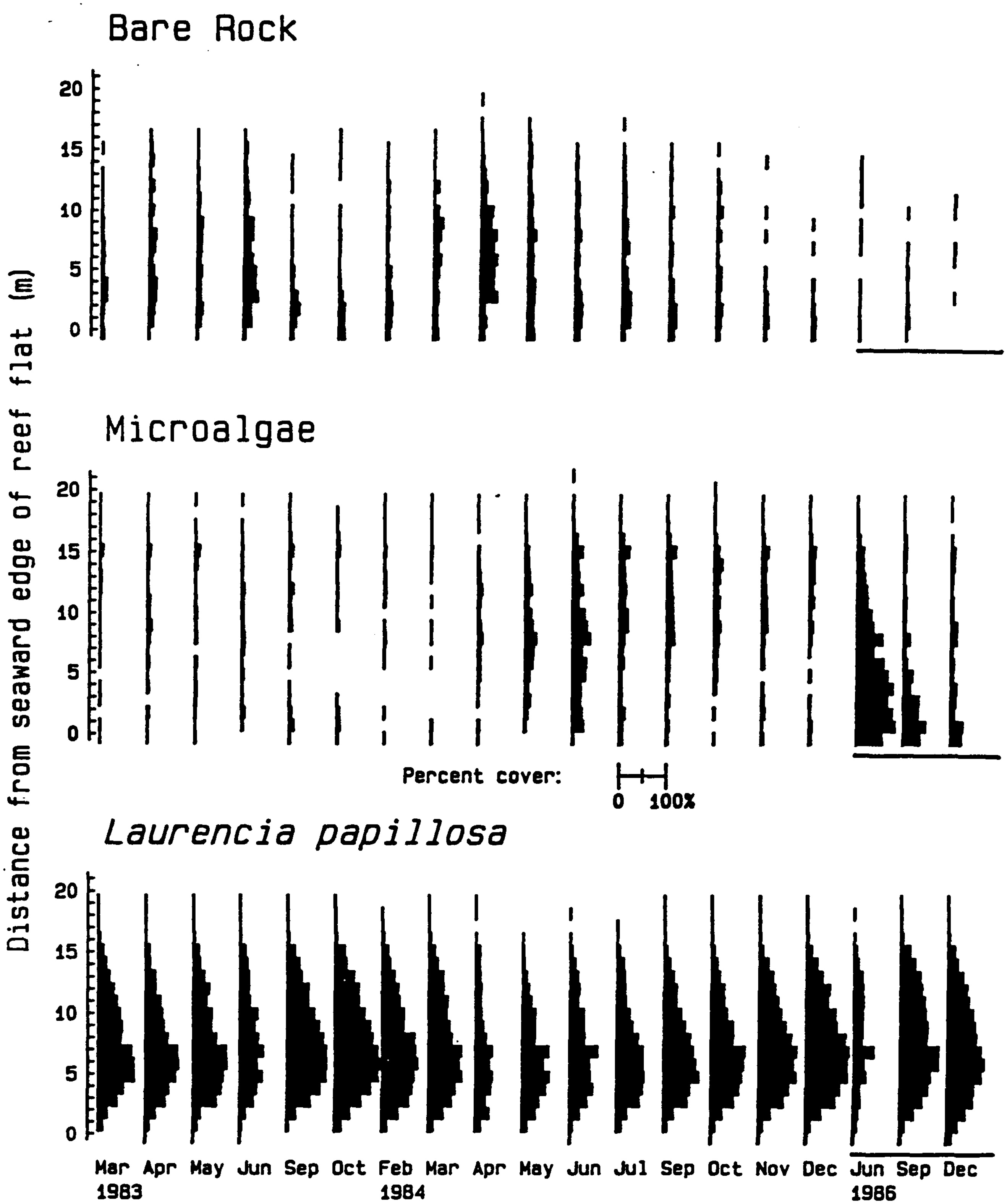
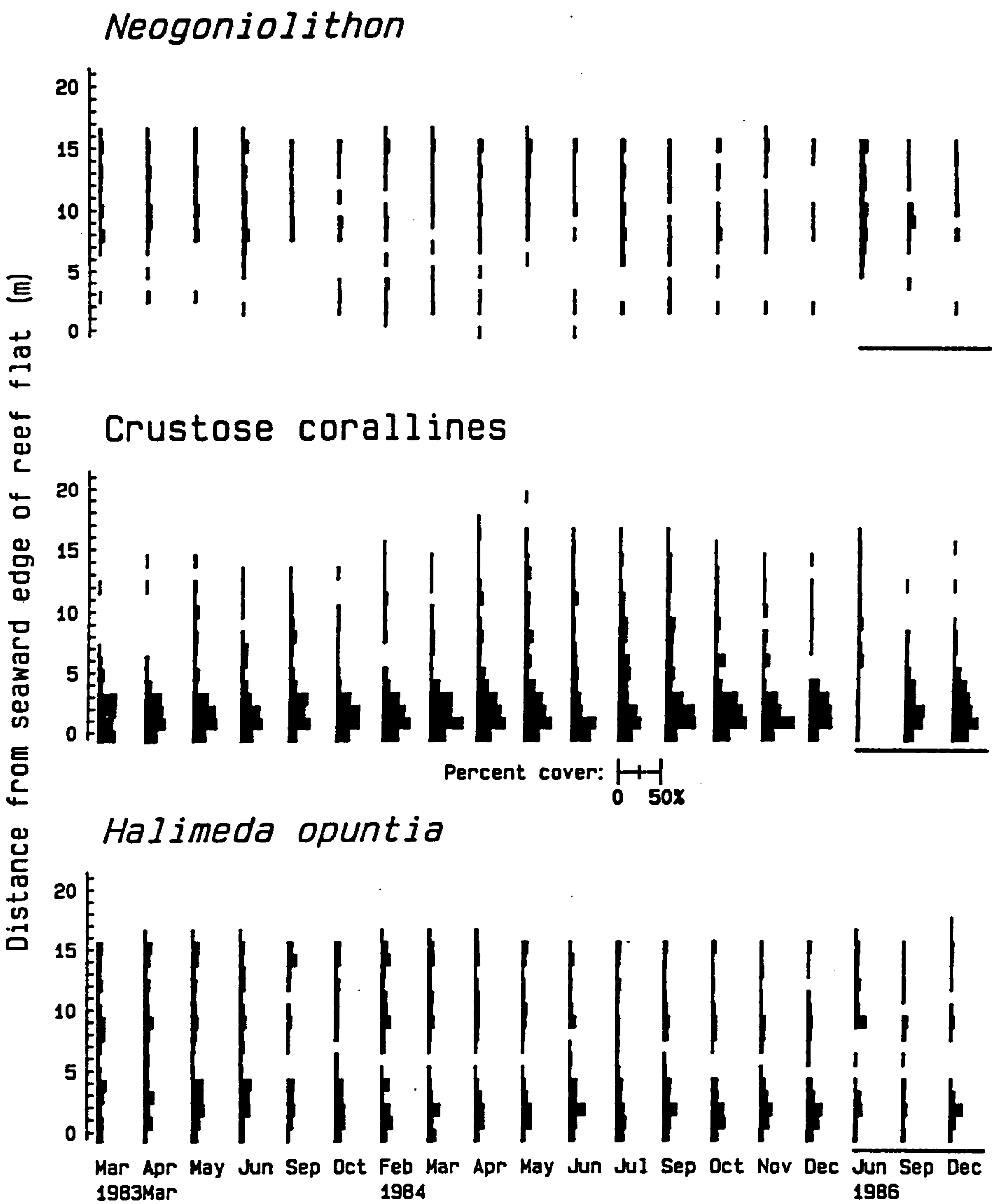


Fig M. – Reef flat



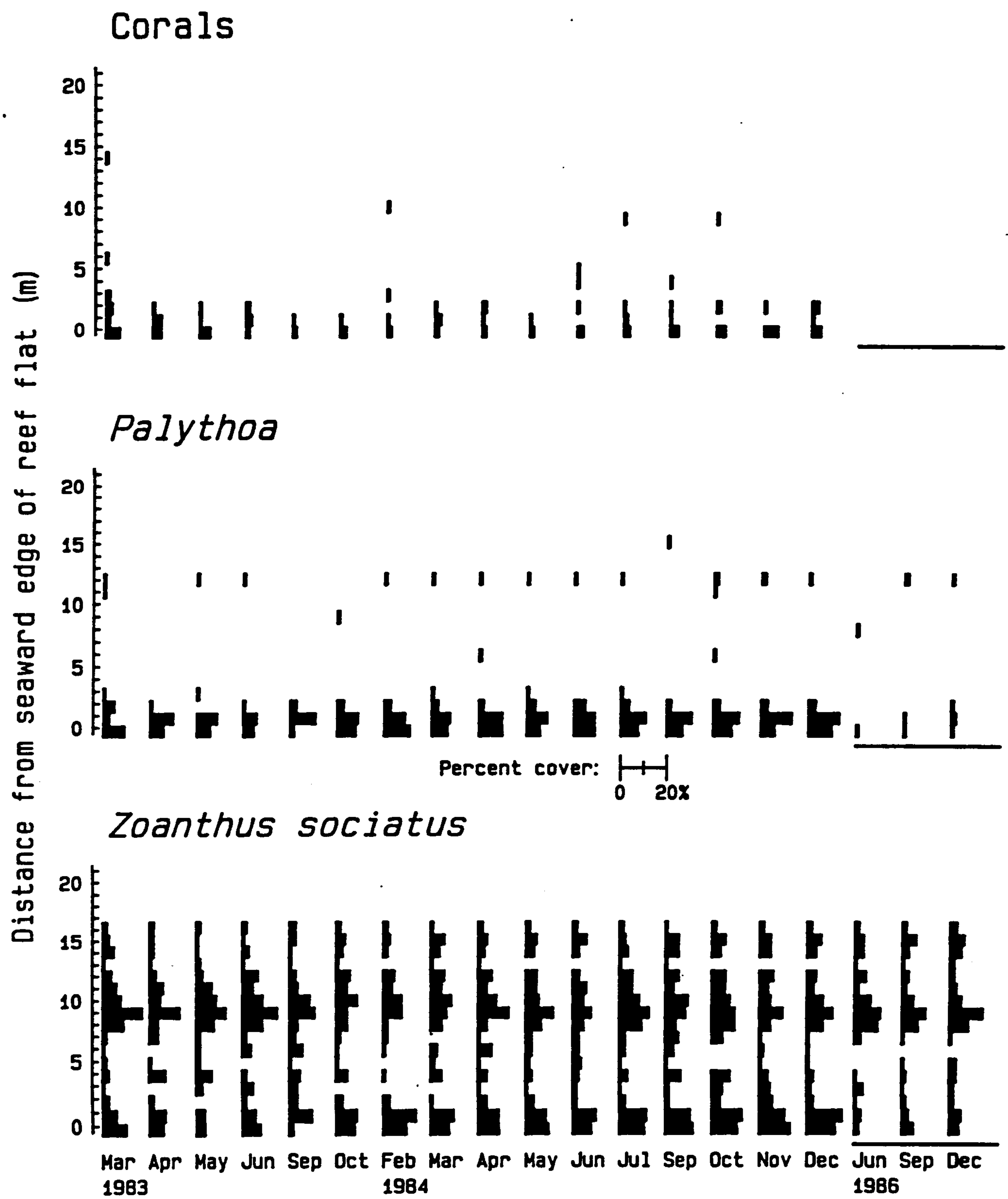
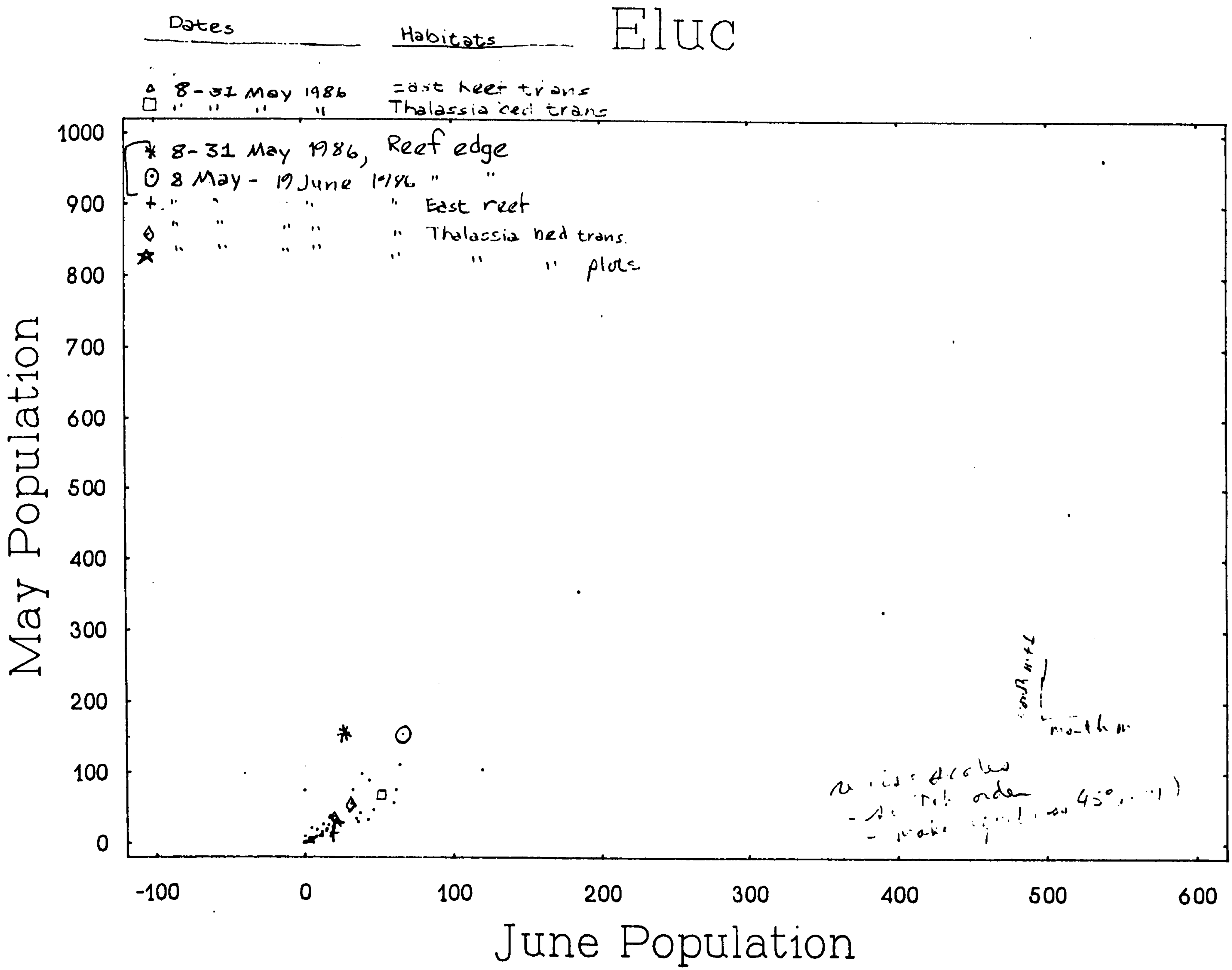
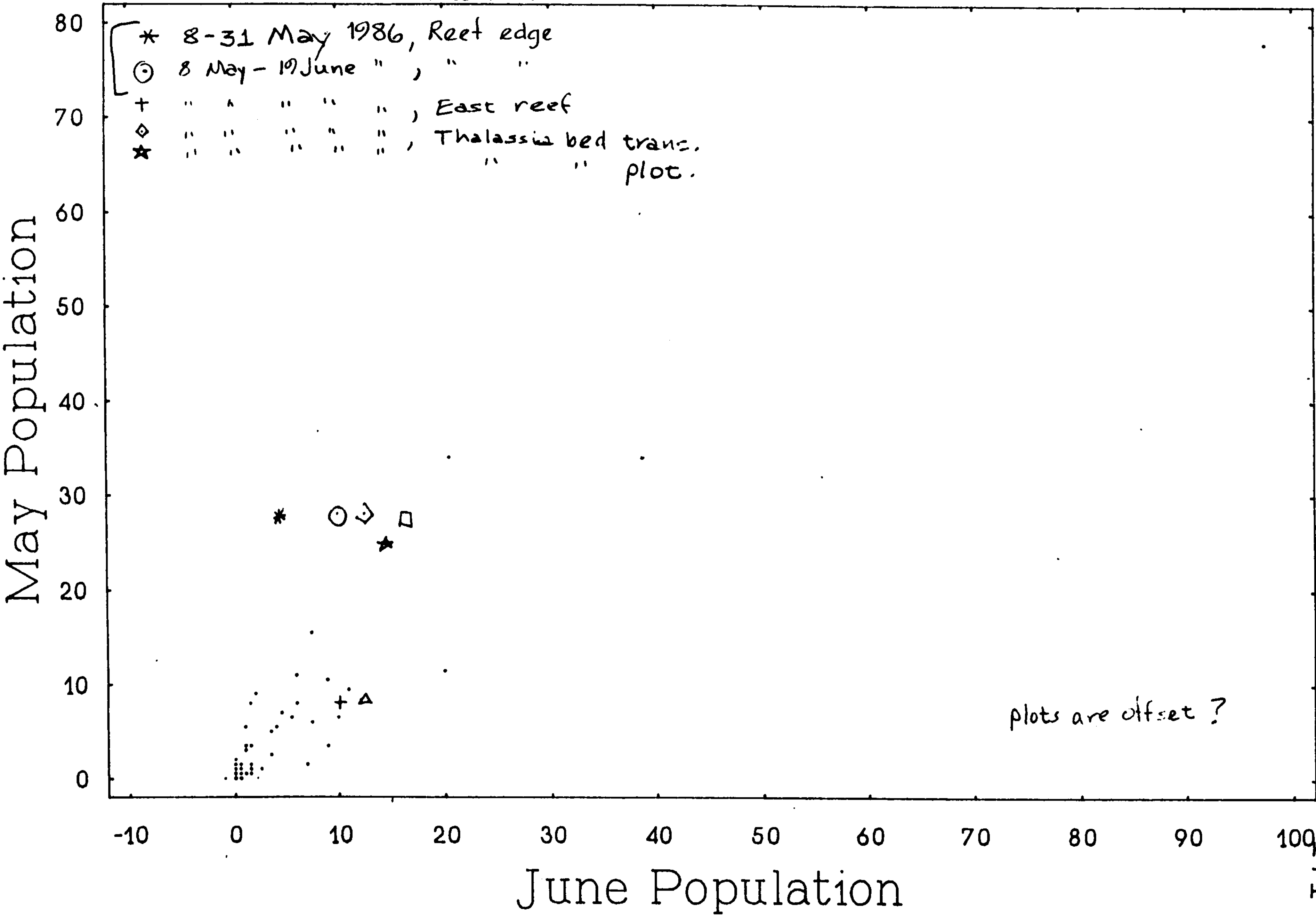


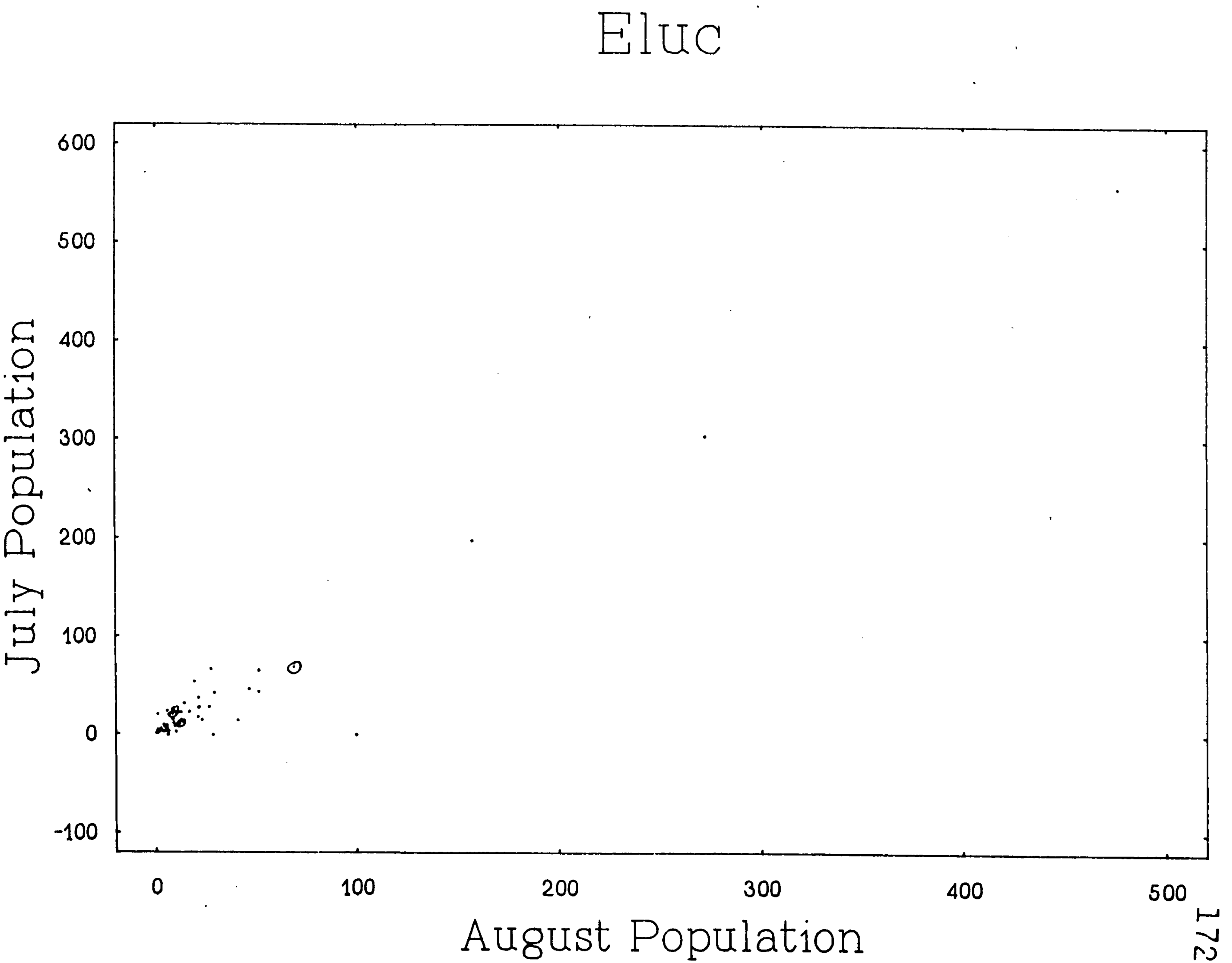
Fig. M. - Reef flat

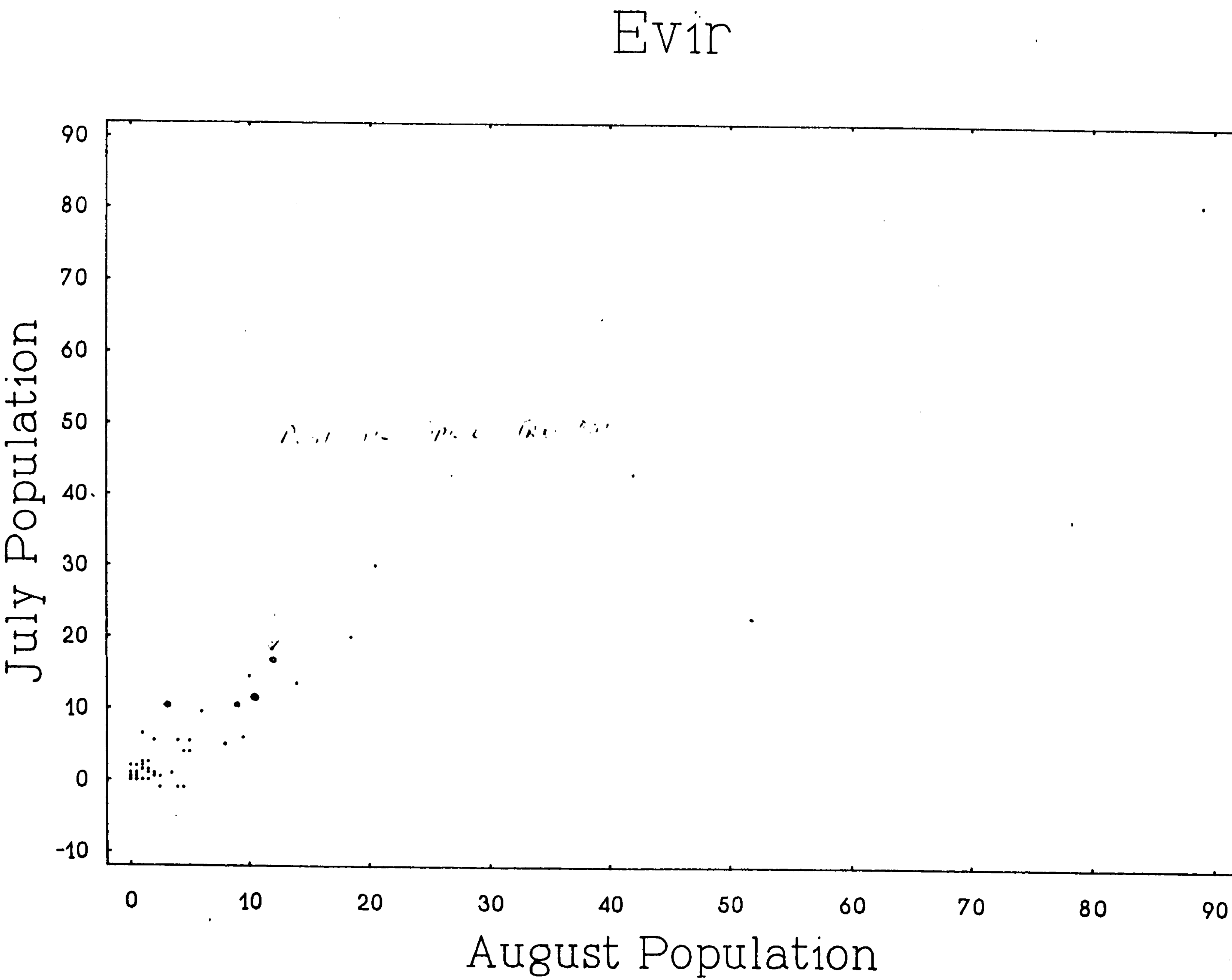

Eluc
Dates
Habitats
8-31 May 1986 East reef trans
" " " " Thalassia bed trans
8-31 May 1986, Reef edge
8 May - 19 June 1986 " "
" " " " " East reef
" " " " " Thalassia bed trans.
" " " " " " " plots
May Population
1000
900
800
700
600
500
400
300
200
100
0
-100
0
100
200
300
400
500
600
June Population

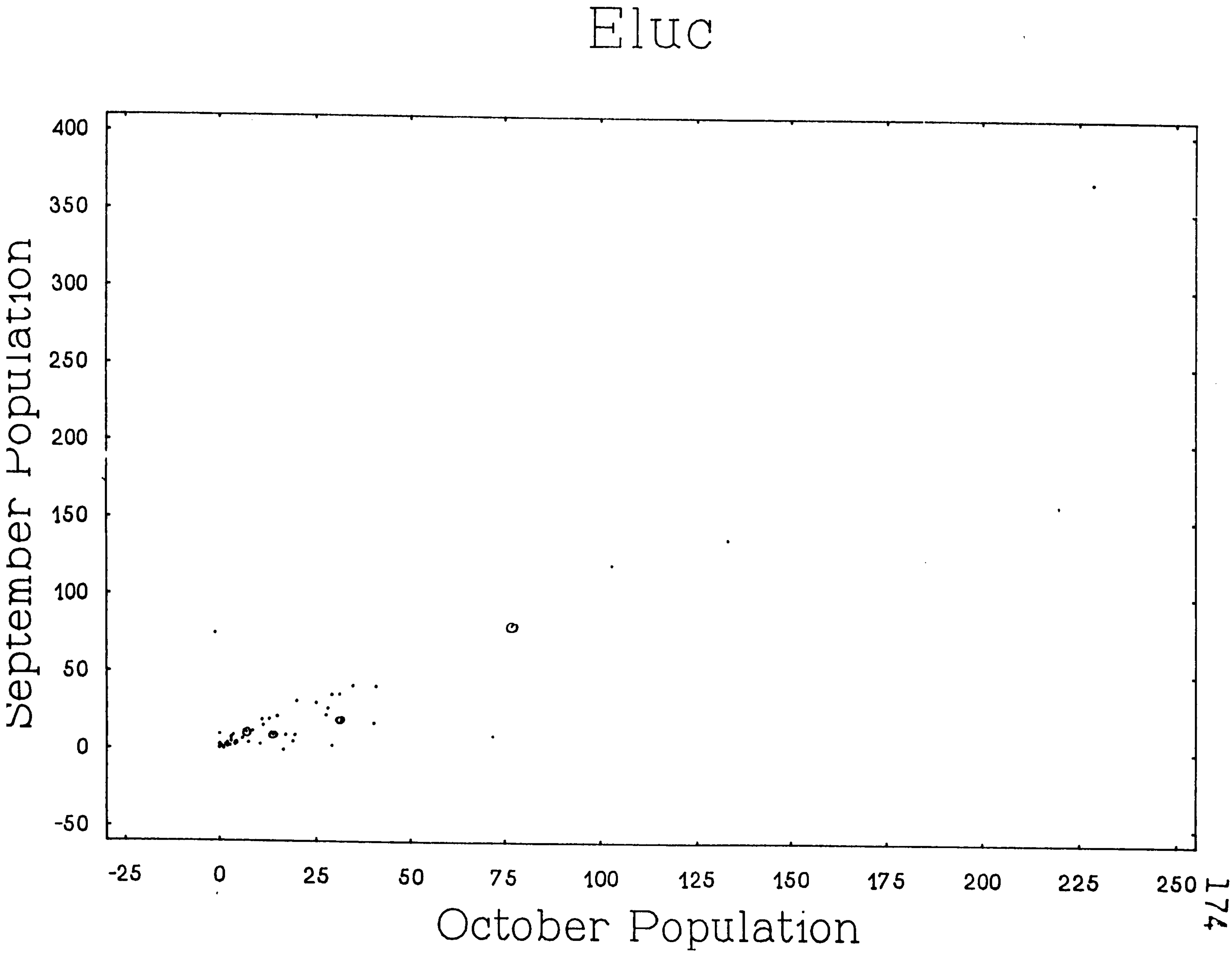
Dates Habitats Evir

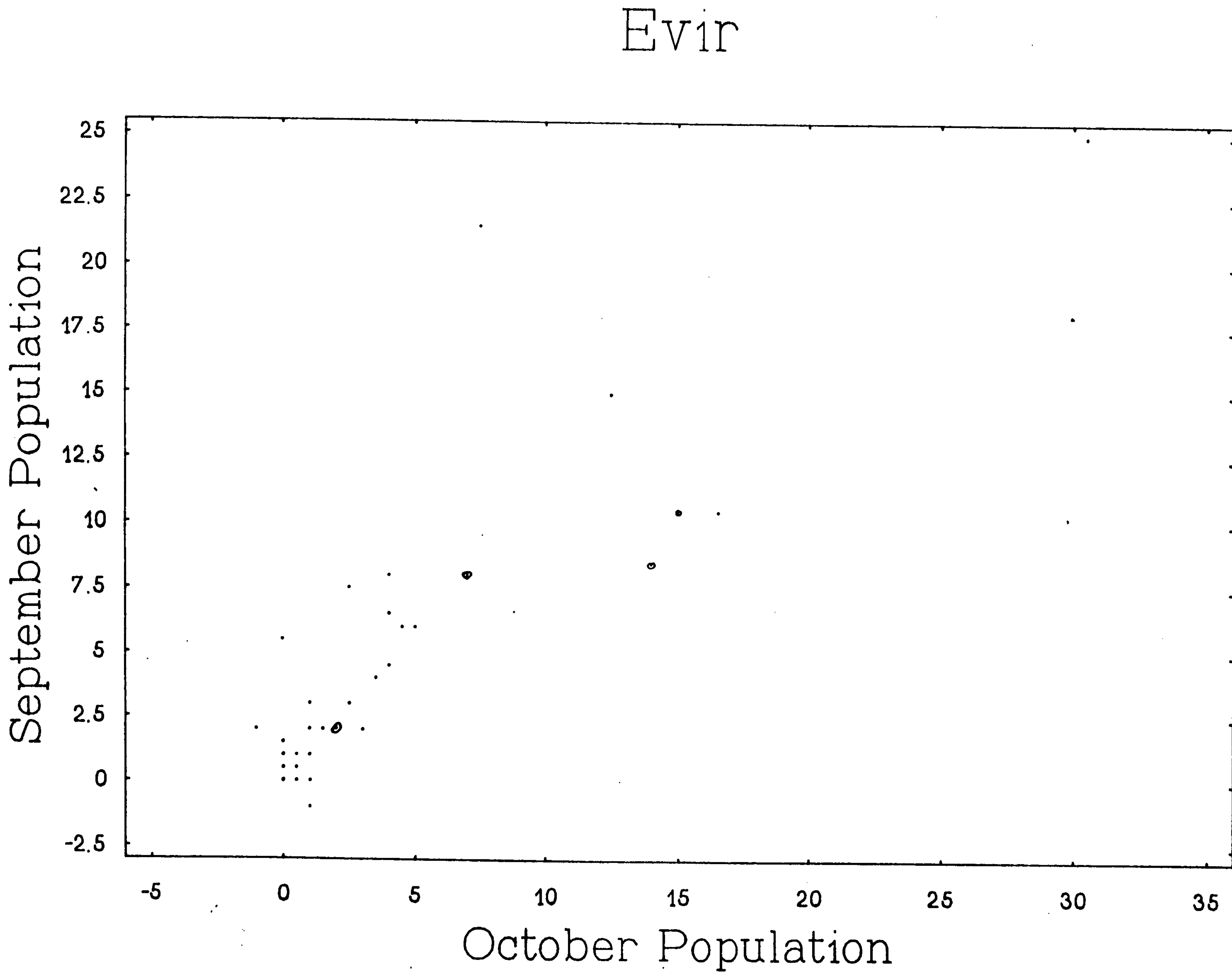
+ 8–31 May 1986 East Reef trans.
□ " " " " Thalassia bed trans.




Eluc
July Population
600
500
400
300
200
100
0
-100
0
100
200
300
400
500
August Population


Evir
July Population
90
80
70
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
70
80
90
August Population


Eluc
September Population
400
350
300
250
200
150
100
50
0
-50
-25
0
25
50
75
100
125
150
175
200
225
250
October Population


Evir
September Population
25
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
-2.5
-5
0
5
10
15
20
25
30
35
October Population

Zonal distribution of organisms and unoccupied substrate at the seaward edge of the reef flat at Punta Galeta. Data are percent covers versus the landward distance ("smtr") along a series of permanent transects perpendicular to the reef edge. The numbers 8303 to 8612 designate years and months of the surveys (e.g., "8612" is December 1986). Disregard means – they are not corrected for variations in number of meters sampled in each meter represented

rosstab average pcti for yrmon by smtr from pctcovg where +
p eq Mic

mtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	1	1	2	0	2	2	1	2	2	0	2	6	2	1	4	4	55	35	23	7
1	2	1	1	3	10	6	0	3	4	2	24	7	5	0	1	6	83	47	26	12
2	0	4	2	7	5	5	1	0	0	6	21	12	2	2	7	2	77	32	8	10
3	2	0	3	2	2	1	0	0	2	12	18	5	6	0	5	3	67	33	11	9
4	1	3	3	1	1	0	0	0	2	7	18	4	2	4	3	0	78	15	12	8
5	0	1	2	4	0	0	0	0	6	10	27	4	5	7	0	3	67	20	5	8
6	1	4	4	1	2	0	1	1	6	17	29	9	6	6	5	0	58	8	7	8
7	1	2	0	5	1	0	1	0	6	19	21	7	7	8	4	1	37	4	4	6
8	1	5	4	6	0	0	3	1	10	24	37	10	16	10	5	4	54	13	12	11
9	1	9	3	4	6	4	1	2	7	17	31	18	15	14	12	8	36	4	13	10
10	1	5	5	4	5	1	0	0	4	14	26	18	14	9	12	4	32	5	5	8
11	1	6	3	4	4	2	3	1	7	8	14	12	14	13	11	10	24	6	5	7
12	3	2	2	6	9	2	4	0	10	15	22	14	11	8	9	6	22	4	2	7
13	4	2	2	2	1	1	4	1	6	11	15	12	11	13	8	11	18	1	4	6
14	2	4	6	3	4	1	2	2	4	9	13	11	10	18	10	11	15	5	7	7
15	8	7	11	3	9	6	4	3	3	8	22	21	20	11	15	13	15	6	8	10
16	1	2	2	2	4	4	1	1	0	3	10	9	7	5	5	5	7	5	2	3
17	1	1	1	1	2	1	1	1	2	2	3	2	3	1	2	2	3	1	0	1
18	1	1	0	0	1	1	1	1	1	2	2	2	2	2	2	1	3	1	1	1
19	1	1	1	1	1	0	1	1	1	1	2	2	2	2	2	2	2	1	1	1
20	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
eans:	1	2	2	2	3	1	1	0	3	8	16	8	7	6	5	4	34	11	7	6

These are meter corrected data in CTPCT.TAB

rosstab average pcti for yrmon by smtr from pctcovg where +
p eq Ac

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
3	1	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	2	0	4	0
4	2	0	1	0	2	0	1	2	0	1	1	1	2	0	9	4	4	3	7	2
5	0	0	1	0	2	0	4	2	0	1	2	2	0	1	9	3	1	0	7	1
6	0	0	0	0	1	0	5	3	0	1	1	1	0	0	7	3	7	2	8	2
7	1	0	0	0	2	1	2	4	0	1	0	4	1	0	5	0	1	5	6	1
8	3	2	3	0	3	0	2	1	0	0	1	0	0	0	3	0	2	5	3	1
9	0	0	1	0	1	0	4	0	0	0	0	0	0	2	6	3	1	1	0	1
10	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2	0	2	0	0
12	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0
13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
15	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0
20	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	1	1	2	0

These are meter corrected data in CTPCT.TAB

crosstab average pcti for yrmon by satr from pctcovg where +
rp eq L

satr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	0	1	1	1	0	0	0	0	0	0	2	0	0	1	1	2	2	4	11	1
1	10	7	8	3	2	13	10	10	12	10	5	9	7	8	8	9	7	10	23	9
2	20	21	16	12	18	31	35	32	30	28	20	22	21	24	25	31	10	29	39	24
3	40	42	50	29	49	55	58	50	23	36	37	48	50	48	52	61	15	47	55	44
4	53	49	60	36	69	76	65	58	34	50	48	55	56	59	63	71	14	59	57	54
5	76	63	64	47	81	92	69	71	37	57	43	58	74	64	78	87	26	64	72	64
6	76	69	72	37	83	94	77	66	31	45	42	56	68	68	73	87	23	81	78	64
7	71	67	71	50	83	92	73	71	37	56	59	56	63	71	80	91	43	82	72	67
8	48	47	50	39	76	81	70	51	24	27	32	45	56	47	68	83	19	57	62	51
9	51	39	40	32	67	75	47	46	18	27	30	33	45	46	56	64	19	58	59	44
10	47	36	41	38	57	63	48	40	14	28	30	27	37	34	47	61	20	54	55	40
11	41	32	30	23	45	51	39	42	13	20	18	20	27	28	41	45	22	52	46	33
12	34	22	35	20	45	50	35	33	14	14	20	18	27	27	34	48	20	46	42	30
13	25	21	25	20	31	40	27	32	11	9	17	17	21	18	29	33	18	42	33	24
14	18	10	16	17	26	25	18	20	10	4	11	15	13	13	20	22	10	31	22	16
15	12	9	13	13	17	22	14	14	11	3	5	6	7	7	8	11	6	21	16	11
16	4	1	3	2	4	4	4	4	1	1	1	1	2	2	2	3	1	5	4	2
17	1	1	1	1	2	2	2	1	0	0	0	1	1	1	1	1	0	2	2	1
18	1	1	1	1	2	2	1	1	1	0	1	0	1	1	1	2	1	2	2	1
19	1	1	1	1	1	1	0	1	1	0	0	0	1	1	1	1	0	1	1	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	28	24	27	19	34	39	31	29	14	18	19	22	26	25	31	36	12	33	34	26

These are meter corrected data in CTPCT.TAB

papillosa

Zonation of average thickness in mm of Laurencia mat at edge of the reef flat. Smtr is distance in meters from seaward end of transects. Dates of surveys are shown as four digits (e.g., 8303 is March 1983). In surveys 8303 through 8309 thickness was sampled at 2 points per meter interval; in all subsequent surveys the sampling density was 10 points per meter. Avg is calculated ...

crosstab average pthicmm by trmonyr for seameter +
from ltrans

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612
0	--	--	--	--	20	--	--	--	--	--	12	--	--	10	35	25	17	15	18
1	12	25	20	--	--	20	17	14	14	13	8	12	10	7	13	13	9	17	21
2	48	20	25	12	28	28	21	21	13	15	9	13	17	17	19	21	5	22	28
3	32	19	25	11	22	29	24	18	11	15	10	13	12	14	21	27	6	20	26
4	26	24	18	11	33	30	25	20	12	12	10	15	16	15	20	30	7	21	26
5	32	16	21	11	37	36	29	23	12	14	11	16	16	16	20	27	8	22	24
6	40	24	21	18	35	41	25	21	11	12	11	14	13	14	20	26	7	23	20
7	32	21	22	13	36	42	25	19	10	11	11	12	14	13	19	30	8	22	23
8	26	15	16	15	38	39	22	17	8	10	10	11	11	11	16	23	7	21	17
9	38	22	22	19	35	44	22	17	8	8	11	11	11	12	18	24	6	21	18
10	25	18	27	10	41	44	20	16	9	7	10	10	10	10	18	23	6	21	19
11	30	15	23	15	36	40	22	18	14	8	11	9	13	10	17	23	8	22	20
12	28	19	21	18	35	36	19	17	11	8	10	9	13	12	16	23	7	22	21
13	28	19	24	13	30	36	20	16	10	7	9	12	12	11	17	21	9	23	18
14	16	25	18	12	40	35	22	14	9	8	9	11	9	11	13	18	7	24	17
15	16	17	12	11	31	30	20	15	10	12	7	11	9	7	15	15	7	24	14
16	30	--	10	5	47	37	22	12	5	7	13	5	11	7	18	18	3	20	20
17	30	--	--	10	30	35	13	9	--	5	7	8	7	7	12	17	3	20	19
18	--	10	10	20	22	28	13	16	13	5	7	5	8	11	15	15	4	29	25
19	30	--	25	10	--	25	15	15	7	--	7	5	8	6	9	20	5	30	31
20	25	--	--	--	--	--	--	--	--	--	--	--	--	10	--	--	--	40	--
21	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	40	--	--	--
Means:	30	20	21	13	35	37	23	18	11	11	10	12	13	13	18	25	7	22	21

:rosstab average pcti for yrmon by smtr from pctcovg where +
rp eq Fleshy

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	2	4	4	1	2	2	3	2	4	2	2	1	2	2	6	5	2	6	11	3
1	11	10	10	3	2	13	11	12	13	14	5	9	10	12	13	12	7	10	27	10
2	26	27	21	12	19	32	36	39	34	28	21	24	24	26	34	38	10	30	41	27
3	48	46	51	29	50	61	61	50	24	36	37	50	51	49	56	62	17	47	59	46
4	59	53	61	36	71	76	67	61	34	52	50	56	59	60	76	76	18	62	64	57
5	76	65	65	47	83	92	73	73	39	58	46	61	75	67	87	90	27	64	79	66
6	77	69	73	38	84	94	83	69	31	48	43	61	69	70	80	91	31	83	88	67
7	75	68	71	51	85	93	75	76	37	57	60	60	65	73	85	91	44	87	78	70
8	53	49	53	39	79	81	72	52	24	27	33	45	56	47	71	83	21	62	65	53
9	52	41	43	32	68	75	51	46	19	27	30	34	45	48	62	68	20	59	60	46
10	47	36	41	38	57	63	49	40	14	28	30	27	37	34	50	63	20	57	55	41
11	41	32	30	23	45	51	39	42	14	20	18	20	27	29	41	45	22	52	46	33
12	34	23	37	21	46	50	37	33	14	14	21	18	30	27	37	48	20	46	42	31
13	25	21	25	20	31	40	27	32	11	5	17	17	22	18	29	33	18	42	33	24
14	19	10	16	18	26	26	18	20	10	4	13	15	14	13	22	22	10	32	22	17
15	14	10	14	13	17	23	17	15	11	3	5	6	7	7	8	11	6	22	16	11
16	4	1	4	2	4	4	4	4	1	1	1	1	2	2	2	3	1	5	4	2
17	1	1	1	1	2	2	2	1	0	0	0	1	1	1	1	1	0	2	2	1
18	1	1	1	1	2	2	2	1	1	0	1	0	1	1	1	2	1	2	2	1
19	1	1	1	1	1	2	2	1	1	0	1	1	1	1	1	1	0	2	2	1
20	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	30	25	28	19	35	40	33	30	15	13	19	23	27	26	34	38	13	35	36	27

These are meter corrected data in CTPCT.TAB

:rosstab average pcti for yrmon by smtr from pctcovg where +
:p eq Fleshyc

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
2	0	0	0	0	0	0	0	0	0	2	1	0	0	1	0	0	0	1	0	0
3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
4	0	0	0	0	0	0	0	1	2	0	1	2	1	1	0	0	0	1	2	0
5	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Means:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

These are meter corrected data in CTPCT.TAB

crosstab average pcti for yrmon by smtr from pctcovg where +
sp eq CorB

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	3	3	1	3	1	0	0	2	2	1	1	1	2	3	1	2	0	1	2	1
1	3	5	1	5	0	3	3	3	1	2	1	1	1	1	3	0	0	0	2	1
2	6	6	3	3	2	0	2	3	1	2	0	0	1	0	1	2	0	1	3	1
3	2	0	0	0	0	0	0	1	0	0	3	1	1	2	0	0	0	1	1	0
4	2	2	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
5	0	1	0	1	0	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0
6	0	1	1	2	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0
7	3	0	0	1	0	0	1	0	0	0	1	0	1	2	1	0	2	0	1	0
8	4	0	1	1	0	0	0	0	0	2	1	1	1	2	1	0	0	1	0	0
9	1	0	0	0	0	0	1	1	1	1	1	1	3	2	2	0	1	3	2	1
10	1	3	0	3	1	0	1	0	1	0	2	1	1	3	0	1	1	1	3	1
11	2	0	0	2	0	0	1	0	1	2	0	2	2	2	2	1	1	0	0	0
12	1	1	1	0	0	0	0	1	1	0	0	3	1	2	2	0	1	0	0	0
13	2	2	3	1	1	1	1	0	1	1	3	1	1	4	3	1	1	0	1	1
14	3	1	1	0	2	4	4	1	1	1	3	2	3	3	3	1	0	1	1	1
15	3	2	3	0	3	1	2	3	1	1	0	3	1	6	4	4	0	2	2	2
16	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	1	1	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0

These are meter corrected data in CTPCT.TAB

crosstab average pcti for yrmon by smtr from pctcovg where +
sp eq Cw

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	1	2	2	1	0	1	2	1	1	1	1	0	0	1	0
3	1	2	1	0	0	2	1	1	2	0	1	0	1	0	0	0	0	0	0	0
4	0	0	0	0	0	1	4	1	0	0	0	0	1	0	0	0	0	2	0	0
5	0	1	0	2	0	0	0	1	2	0	0	0	0	1	0	0	2	0	0	0
6	0	0	0	2	0	0	2	0	0	1	0	3	1	0	0	0	3	0	0	0
7	1	1	0	3	0	0	0	1	2	0	0	2	1	1	1	0	5	1	0	1
8	5	3	4	7	3	3	2	0	2	2	1	5	2	5	3	1	7	2	3	3
9	1	5	3	4	3	4	3	1	1	2	0	2	1	2	2	1	6	8	0	2
10	4	5	4	3	1	0	1	2	3	3	3	4	0	2	2	1	8	5	3	2
11	1	2	2	4	2	2	0	1	2	2	1	1	1	0	1	0	3	0	2	1
12	2	3	2	2	1	0	1	1	1	2	1	3	2	2	0	0	6	2	2	1
13	3	4	3	4	1	1	1	1	3	4	1	4	1	3	1	0	5	1	1	2
14	2	2	1	1	1	1	2	1	1	4	1	1	1	0	2	1	4	1	2	1
15	4	3	2	6	2	3	5	3	4	6	3	4	1	4	4	2	8	1	1	3
16	2	1	2	1	0	0	1	1	0	1	0	0	0	0	1	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	1	1	1	2	0	0	1	0	1	1	0	1	0	1	0	0	3	1	0	1

These are meter corrected data in CTPCT.TAB

rosstab average pcti for yrmon by smtr from pctcovg where +
p eq Cor

mtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	20	14	15	14	9	15	19	19	17	18	22	16	13	18	14	10	1	10	18	14
1	17	23	27	24	24	27	32	39	33	32	28	26	34	37	37	25	2	20	29	27
2	26	20	25	21	18	27	26	26	28	25	12	21	32	32	21	24	1	22	22	22
3	21	18	17	11	21	16	19	26	23	21	10	11	19	26	17	21	1	11	19	17
4	4	6	4	7	8	4	7	11	13	12	6	10	6	8	3	10	1	11	15	7
5	6	2	6	2	5	2	4	2	9	4	7	13	9	3	1	0	1	5	8	4
6	3	2	2	6	2	1	0	1	3	7	5	11	6	11	7	0	5	2	1	3
7	1	0	3	7	3	1	0	4	4	4	4	5	6	2	2	1	3	2	3	2
8	0	0	4	2	7	1	3	4	6	9	2	8	7	3	4	1	1	3	3	3
9	0	0	2	0	4	2	2	2	4	4	3	9	9	5	0	2	4	0	1	2
10	0	0	5	2	2	2	2	2	1	4	1	5	2	3	4	1	2	0	0	2
11	0	0	1	1	2	0	4	0	6	5	6	5	2	3	1	1	2	0	0	2
12	1	1	2	1	1	0	1	1	3	1	2	2	4	3	2	1	1	1	1	1
13	0	0	0	1	1	1	1	1	1	6	1	1	4	3	1	0	1	0	0	1
14	0	1	2	0	0	0	1	1	1	3	1	3	4	1	1	1	2	0	0	1
15	0	0	0	0	0	0	1	0	1	1	2	1	1	1	0	0	2	0	1	0
16	0	0	0	0	0	0	0	0	2	2	1	1	1	0	0	0	1	0	0	0
17	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	4	3	5	4	4	4	5	6	7	7	5	6	7	7	5	4	1	3	5	5

These are meter corrected data in CTPCT.TAB

crosstab average pcti for yrmon by smtr from pctcovg where +
sp eq CorC

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	20	14	15	14	9	15	19	19	18	18	22	16	13	18	14	10	1	10	18	14
1	17	23	27	24	24	27	33	39	33	32	28	26	34	37	37	25	2	20	29	27
2	20	20	25	22	18	28	28	28	29	25	13	23	33	33	22	25	1	22	23	23
3	22	20	18	11	21	18	20	27	25	21	11	11	20	26	17	21	1	11	19	17
4	4	6	4	7	8	5	11	12	13	12	6	10	7	8	3	10	1	13	15	8
5	6	3	6	4	5	2	4	3	11	4	7	13	9	4	1	0	3	5	8	5
6	3	2	2	8	2	1	2	1	3	8	5	14	7	11	7	0	8	2	1	4
7	2	1	3	10	3	1	0	5	6	4	4	7	7	3	3	1	8	3	3	3
8	5	3	8	9	10	4	5	4	8	11	3	13	9	8	7	2	8	5	6	6
9	1	5	5	4	7	6	5	3	5	6	3	11	10	7	2	3	10	8	1	5
10	4	5	8	5	3	2	3	4	4	6	4	8	2	5	5	2	10	5	3	4
11	1	2	3	5	3	2	4	1	7	7	6	6	3	3	2	1	5	0	2	3
12	2	4	3	3	2	0	2	2	4	3	2	5	6	5	2	1	6	3	3	3
13	3	4	3	4	2	2	1	2	4	10	2	5	6	6	2	0	6	1	1	3
14	2	3	3	1	1	1	4	1	3	6	1	4	5	1	3	2	6	1	2	2
15	4	3	2	6	2	3	6	3	5	7	5	5	2	4	4	2	10	1	2	4
16	2	1	2	2	0	0	1	1	2	3	1	1	1	1	1	0	1	0	0	1
17	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	5	5	6	6	5	5	6	7	8	8	5	8	7	8	6	4	3	5	6	6

These are meter corrected data in CTPCT.TAB

crosstab average pcti for yrmon by smtr from pctcovg where +
sp eq H

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	6	2	6	5	1	7	6	9	5	3	6	9	6	7	4	7	2	3	2	5
1	7	9	9	5	5	11	13	6	11	11	8	11	8	15	11	13	2	2	6	8
2	5	6	14	12	8	11	10	14	11	11	18	9	15	14	14	17	8	5	14	11
3	8	11	13	11	6	9	2	5	8	6	8	6	7	7	9	8	6	2	5	7
4	11	5	13	13	7	9	9	3	4	3	8	7	8	6	6	5	1	3	1	6
5	4	4	2	3	0	3	1	2	1	1	1	3	2	0	2	0	0	0	0	1
6	2	5	1	2	0	3	0	0	0	0	2	1	1	0	0	2	1	1	0	1
7	5	4	3	5	1	0	4	2	2	1	1	2	0	1	3	2	0	0	0	1
8	9	6	5	4	1	3	4	3	4	2	0	2	4	5	5	3	0	3	1	3
9	9	10	7	7	4	4	11	7	5	4	7	3	6	5	6	5	12	5	4	6
10	5	5	5	5	2	4	7	5	5	5	3	1	3	3	2	3	4	0	2	3
11	2	4	4	3	0	4	6	6	5	2	1	2	2	1	2	2	2	1	0	2
12	6	6	5	6	2	5	2	3	3	2	2	4	1	2	1	0	5	2	2	3
13	4	2	3	6	3	2	4	3	1	1	1	1	1	1	3	1	2	1	1	2
14	5	6	7	4	10	6	10	7	5	4	4	3	2	1	2	1	3	1	2	4
15	6	8	8	5	5	6	7	6	4	6	1	4	3	4	2	3	4	1	3	4
16	0	1	1	1	0	0	1	2	3	0	0	0	0	0	0	0	1	0	1	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	4	4	4	4	2	3	4	3	3	2	3	3	3	3	3	3	2	1	2	3

These are meter corrected data in CTPCT.TAB

rosstab average pcti for yrmon by mtr from pctcovg where +
p eq GrnC

mtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	6	2	7	5	1	7	6	9	5	3	6	10	6	7	4	7	2	3	2	5
1	7	9	11	5	5	11	13	6	11	11	8	12	8	15	12	13	2	2	7	8
2	5	6	15	12	9	11	10	14	11	11	19	9	15	14	14	17	8	5	14	11
3	8	12	13	11	6	9	2	5	8	6	8	6	7	7	9	8	6	2	5	7
4	12	5	13	13	7	9	9	4	4	3	8	7	8	7	6	5	1	3	1	6
5	4	4	2	3	0	3	1	3	1	2	1	3	3	2	2	0	0	0	0	1
6	2	5	1	2	0	3	0	0	0	0	2	1	1	0	0	2	1	1	0	1
7	5	4	3	5	1	0	4	2	2	1	1	2	0	1	3	2	0	0	0	1
8	9	6	5	4	1	3	4	3	4	2	0	2	4	5	5	3	0	3	1	3
9	9	10	7	7	4	4	11	7	5	5	7	3	6	5	6	5	12	7	4	6
10	5	5	5	5	2	4	7	5	5	5	3	1	3	3	2	3	4	0	2	3
11	2	4	4	3	0	4	6	6	6	2	1	2	2	1	2	2	2	1	0	2
12	6	6	5	6	2	5	2	3	3	2	2	4	1	2	1	0	5	2	3	3
13	4	2	3	6	3	2	4	3	1	1	1	1	1	1	3	1	2	1	1	2
14	5	7	7	4	10	6	10	7	5	4	4	3	2	1	3	1	3	1	2	4
15	6	8	8	5	5	6	7	6	4	6	2	4	3	4	3	3	4	1	3	4
16	0	1	1	1	0	0	1	3	3	0	0	0	0	1	0	0	1	0	1	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
18	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	4	4	5	4	2	3	4	3	3	2	3	3	3	3	3	3	2	1	2	3

These are meter corected data in CTPCT.TAB

osstab average pcti for yrmon by smtr from pctcovg where +
 eq grass

tr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
14	1	3	2	1	2	2	3	2	2	3	1	3	1	2	0	2	3	1	2	1
15	4	4	4	5	4	1	3	5	4	4	4	4	3	4	4	5	4	5	6	4
16	4	3	2	2	4	3	3	4	3	2	0	1	1	3	3	4	2	2	2	2
17	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0
19	0	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	0	1	0	0
20	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
21	1	0	0	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	0
Means:	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1

These are meter brrected data in CTPCT.TAB

crosstab average pcti for yrmon by smtr from pctcovg where +
sp eq Zs

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	10	6	4	8	2	8	10	8	9	10	8	11	12	11	13	12	2	5	4	8
1	6	7	4	6	10	9	14	10	9	9	10	12	11	13	11	15	3	3	5	8
2	3	2	0	2	4	3	3	1	4	4	2	3	2	4	6	3	1	2	2	2
3	1	0	3	5	4	0	0	0	1	1	2	1	2	5	5	2	4	1	2	2
4	3	7	7	2	5	5	1	5	4	3	3	4	7	8	4	3	1	2	3	4
5	2	1	2	0	1	1	0	2	1	2	4	1	1	0	1	1	0	1	3	1
6	1	0	2	4	6	1	1	3	6	3	3	3	4	0	2	1	0	0	0	2
7	2	4	2	2	3	2	2	0	1	3	3	3	6	5	1	1	3	1	1	2
8	9	4	8	9	4	5	2	5	4	7	5	10	5	10	5	7	10	7	8	6
9	17	13	13	15	11	5	8	7	13	12	8	13	9	10	10	11	11	10	14	11
10	8	5	9	9	9	9	8	9	8	6	5	9	10	8	5	7	7	5	5	7
11	6	6	7	5	4	5	4	5	4	5	6	6	4	6	4	3	2	2	3	4
12	4	3	3	7	3	6	5	6	6	5	3	6	6	6	6	4	5	3	2	4
13	1	1	2	1	1	1	0	1	1	0	0	1	1	0	0	0	1	1	2	0
14	5	2	1	3	1	3	2	4	3	4	3	4	6	4	5	4	4	3	5	3
15	3	2	1	1	3	4	3	6	4	5	6	3	6	6	5	6	4	6	6	4
16	2	2	2	2	3	2	2	1	2	2	2	2	1	2	2	2	2	2	3	2
Means:	4	3	4	4	4	4	3	4	4	4	4	5	5	5	5	4	3	3	4	4

crosstab average pcti for yrmon by smtr from pctcovg where +
sp eq Pt

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	9	6	6	5	2	8	11	7	10	6	9	8	7	8	6	10	1	1	1	6
1	3	10	9	6	11	9	9	8	10	9	9	11	11	11	13	13	0	1	2	8
2	5	1	0	1	3	3	3	3	2	4	5	4	2	3	3	3	0	0	1	2
3	1	0	1	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
9	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
12	1	0	1	1	0	0	1	1	1	1	1	1	0	2	2	1	0	2	1	0
15	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Means:	2	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	0	0	0	1

These are meter corrected data in CTPCT.TAB

crosstab average pcti for yrmon by smtr from pctcovg where +
sp eq Cni

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	19	13	11	16	3	17	22	15	18	18	17	19	21	19	20	22	2	6	5	14
1	11	18	14	14	22	19	23	18	19	18	19	23	22	24	24	28	3	4	7	17
2	8	3	0	3	6	8	6	4	7	8	7	7	4	7	11	6	1	3	4	5
3	2	0	4	5	5	0	0	1	1	2	2	2	2	5	5	2	5	1	2	2
4	3	7	7	2	5	5	1	5	4	3	3	4	7	8	4	4	1	2	3	4
5	2	1	2	0	1	1	0	2	1	2	4	2	2	0	2	3	0	1	3	1
6	1	1	2	4	6	1	1	3	7	3	3	3	4	1	2	1	0	0	0	2
7	2	4	2	2	3	2	2	0	1	3	3	4	7	5	1	1	3	1	1	2
8	9	4	8	9	4	5	2	5	4	7	5	10	5	10	6	7	11	7	10	6
9	17	13	13	15	11	7	8	7	13	12	8	13	10	11	11	11	12	10	15	11
10	9	5	10	9	9	9	8	9	8	7	6	11	10	9	5	7	7	7	6	7
11	8	6	7	5	4	5	4	5	4	5	6	6	4	6	5	3	3	3	4	4
12	6	3	4	8	3	6	6	6	6	6	4	6	6	8	7	5	5	6	5	5
13	1	1	2	1	1	1	0	1	1	0	0	1	1	0	0	0	1	1	2	0
14	5	2	1	3	1	3	2	4	3	4	4	4	6	4	5	4	4	3	5	3
15	3	2	1	1	3	4	3	6	4	5	6	3	7	6	5	6	4	6	6	4
16	2	2	2	2	3	2	2	1	2	2	2	2	1	2	2	2	2	2	3	2
Means:	6	5	5	5	5	5	5	5	6	6	5	7	7	7	6	6	3	3	4	5

crosstab average pcti for yrmon by smtr from pctcovg where +
sp eq CniCal

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	6	4	5	2	2	3	2	2	2	2	3	3	4	4	6	4	0	0	0	2
1	2	4	1	3	1	1	1	3	1	1	0	2	1	0	0	1	0	0	0	1
2	3	1	1	2	0	0	0	1	2	0	1	1	1	2	1	3	0	0	0	1
3	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
10	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

These are meter corrected data in CTPCT.TAB

crosstab average pcti for yrmon by smtr from pctcovg where +
sp eq 8po

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
13	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
15	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

crosstab average pcti for yrmon by smtr from pctcovg where +
sp eq 8ub

smtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612	(Row mean)
0	8	8	4	8	6	17	10	14	14	19	10	8	13	10	9	10	2	2	3	9
1	6	12	16	25	18	19	16	16	18	20	15	20	18	11	10	15	3	16	2	14
2	13	14	14	22	23	16	17	11	16	18	17	24	20	15	10	7	3	6	7	14
3	14	22	11	42	15	11	16	16	40	23	20	25	13	11	8	4	4	4	3	15
4	19	24	11	41	7	5	12	17	41	23	13	17	14	12	8	5	1	4	3	14
5	12	25	23	41	11	2	21	19	42	23	12	16	5	20	7	4	3	9	5	16
6	15	18	17	45	6	1	13	26	52	21	18	10	13	12	5	6	2	6	4	15
7	12	21	21	26	7	4	17	17	47	16	10	19	13	8	3	4	6	5	13	14
8	19	33	21	32	6	7	14	35	50	27	20	18	9	18	5	1	6	9	6	17
9	19	22	29	38	4	4	23	34	50	32	20	19	11	12	5	5	9	9	5	18
10	15	22	11	19	5	3	13	23	45	21	11	15	15	19	7	2	7	5	7	13
11	10	15	16	22	8	1	6	10	26	20	19	16	12	10	2	2	7	2	8	11
12	12	25	13	20	3	1	14	18	26	23	14	14	9	13	5	4	5	3	8	12
13	10	17	12	15	8	3	11	10	25	18	11	12	8	8	4	4	5	2	8	10
14	11	20	13	19	2	6	8	11	21	17	10	8	8	8	4	6	8	4	7	10
15	9	13	8	17	6	4	8	8	17	16	5	4	6	6	6	6	6	6	6	8
16	3	6	4	5	1	1	3	2	5	6	2	2	3	3	2	2	2	2	2	2
17	1	1	2	1	0	1	0	2	2	2	0	1	0	2	0	0	0	0	1	0
18	2	1	2	2	0	0	0	2	2	1	1	1	1	1	1	1	0	0	0	0
19	1	1	1	1	0	0	0	1	1	1	0	0	1	1	0	0	2	0	1	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means:	9	14	11	20	6	4	10	13	24	15	10	11	8	9	4	4	3	4	4	10

These are meter corrected data in CTPCT.TAB

ROCKPCT2.TAB (crosstab sum pcti for yrmon by mtr from rcovg)

Percent of substrate as bare rock listed for survey by meter from seaward end of transects.

mtr	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612
0	6	1	3	5	6	13	8	12	10	16	10	6	11	7	4	6	2	1	0
1	4	9	10	18	12	12	12	10	15	14	15	18	16	10	9	8	1	7	0
2	6	12	14	17	19	13	14	10	11	14	17	20	16	13	7	5	1	5	0
3	12	15	9	31	14	8	12	12	37	16	14	19	9	6	6	1	1	3	1
4	13	16	9	26	5	3	8	9	30	17	10	13	9	9	1	4	1	2	0
5	5	11	12	27	7	2	11	13	31	12	6	11	3	10	3	0	0	4	0
6	6	7	8	20	3	1	4	17	37	13	9	5	6	3	0	0	0	1	1
7	5	12	10	14	2	2	2	11	29	11	6	14	6	1	0	1	1	2	2
8	3	15	11	20	2	3	4	16	35	18	12	9	2	8	2	0	2	0	0
9	4	4	13	21	1	1	6	21	24	11	8	11	2	3	0	1	1	0	0
10	2	9	5	8	2	2	5	11	27	9	6	6	8	11	1	0	0	1	1
11	1	3	6	11	0	0	2	1	11	9	8	6	2	3	0	0	2	0	2
12	1	9	2	8	1	0	5	11	14	6	6	6	1	6	0	0	1	0	0
13	1	2	4	6	1	1	1	1	10	5	3	4	3	1	0	0	1	0	0
14	0	7	1	4	1	1	1	1	6	7	4	4	2	0	1	0	1	0	0
15	1	4	1	6	0	1	1	1	3	6	2	1	1	1	0	0	0	0	0
16	0	2	1	1	0	1	0	1	2	3	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tots	70	138	119	243	76	64	96	158	334	188	136	154	97	92	34	26	15	26	7

Table Consurv

Ctablc.tab.
Percent covers (primary only) of sessile organisms on the reef flat at Galeta, from whole reef-flat surveys.
N=9700-10000 points per survey.

	Pre-spill surveys				Post-spill		
sp#	Jun81	Sep81	Jun82	Sep82	Jun86	Sep86	Notes
4			.02	.02		.02	
7						.17	
8	.01		.74				
14	.91						
19	.03		.22				
25			.03	.53		.02	
27	5.85	5.62	4.88	4.60	3.52	2.77	Halimeda opunti
30	.01	.04	.21	.35	.99	.50	
42			.01			.02	
45		.17	.01	.66			
46	.03	.11	.05	.16	.10	.37	
53	.01			.02			
56		.06	.08	.07	.01	.21	
62				.01			
65						.20	
66		.02	.01	.17	.01	.08	
67				.62		.04	
68				.01			
87						.04	
88	.03	.42	.23	.71		.57	
90					.21	.12	
91				.02			
94						.01	
206				.03		.04	
212	1.07	1.03	1.57	.45	1.24	.13	
216	.40	.39	.07	.08			
227	.02		.01	.03	.01		
237						1.58	
240						.02	
241	.51	.85	.66	1.15			
246				.11	.29	.35	
252	1.95	7.19	2.42	1.98	2.10	.36	Crustose corallines
253	2.43	4.43	1.36	1.66	4.07	1.79	Neogoniolithon w-i
277		.03	.05	.08			
282	.04	.13		.03	.22	.06	
298				.02		.08	
299			.06	.01	.01		
300	.01		.03	.26		.19	
304							
313	.01		.18	.01		.01	
319		.01					
321		.05			.18		
323						.01	

324				.10	.04	.22	
325		.01				.05	
346	.01	2.67	1.27	7.04	2.43	9.84	
353			.06	.19	.03	.05	
354	8.02	16.69	19.14	34.48	16.64	25.80	Laurencia papillosa
355		.01	.05	.08			
356				.01			
361			.06			.02	
387			.05	.07			
388				.06			
389							
400	15.43	22.06	15.10	16.71	13.08	19.55	Thalassia
406	22.80	8.94	19.84	9.82	24.64	14.73	Bare rock
407	25.17	16.46	19.84	8.13	17.61	9.57	sand
408	10.25	8.29	8.34	5.07	5.93	3.44	Loose rubble
411		.01		.01		.01	
416	.73	.37	.40	.56	.38	.67	
420			.01		.01		
430		.01					
456	2.94	3.17	2.40	3.35	5.98	5.35	Zoanthus
461	.02		.02				
462		.35	.17	.08	.04	.05	
469	.24	.38	.24	.17	.22	.69	
476	.02			.16		.13	
479	.03		.03	.04		.01	
480	.01		.06				
481			.01			.01	
485				.01	.01		
490			.01				
491		.02					
496						.05	
503	.01						
564				.01			

sp	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612
Ac	1	1	1	0	1	1	2	1	0	0	0	1	1	0	4	1	2	2	3
Amp	3	2	1	2	1	1	1	1	1	1	1	1	2	2	2	1	0	0	0
ana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANEMONE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
BCor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BRCOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BRCRUST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BROWNSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caulr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[redacted]				8	8	7	8	9	12	11	8	10	11	11	8	7	2	6	8
Cr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[redacted]				3	1	1	2	1	2	2	1	2	1	2	2	1	4	2	1
Cx	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dasya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dx	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dy	1	1	1	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0
Er	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Galax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gel	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0
Gem	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GREENFUZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H	7	8	8	[redacted]	4	7	8	6	6	5	5	5	5	5	5	5	[redacted]	2	3
Hp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ht	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
[redacted]				31	56	62	49	46	22	28	29	34	40	39	48	57	20	54	53
Lint	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lob	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Penicil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peys	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POR	1	1	0	1	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0
Pt	2	1	1	1	1	2	2	1	2	2	2	2	2	2	2	2	0	0	0
R	5	10	9	17	6	5	7	11	23	14	9	11	7	7	2	2	1	2	0
REDCRUST	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
REDFUZZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rub	4	5	4	5	2	1	3	4	7	6	2	3	1	2	1	1	0	1	2
S	8	10	7	11	3	2	6	7	10	7	5	5	7	7	5	4	6	4	6
Sarg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCZ	3	6	5	5	7	4	3	2	7	14	28	16	14	12	11	9	54	18	12
SPONGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Struv	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sx	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Th	2	2	2	2	2	2	2	2	2	2	1	2	1	1	2	2	1	2	2
UN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zs	6	5	5	6	6	5	5	5	6	6	6	7	7	7	6	6	4	4	5

Total percent covers in reefedge surveys estimated from point-intercept sampling. 1510 to 1560 points were examined per survey.

sp	8303	8304	8305	8306	8309	8310	8402	8403	8404	8405	8406	8407	8409	8410	8411	8412	8606	8609	8612
Cni	8	7	7	8	7	7	7	7	8	8	7	9	9	9	8	8	5	5	6
CniCal	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0
CorB	3	2	1	2	1	1	2	1	1	1	1	1	2	3	2	1	1	1	2
CorC	9	9	11	11	9	8	10	11	13	14	9	12	12	12	9	7	7	8	9
FLESHY	49	41	45	31	58	63	52	48	24	29	30	35	42	41	54	60	22	57	57
fleshyc	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
grass	2	2	2	2	2	2	2	2	2	2	1	2	1	2	2	2	1	2	2
GRNC	7	8	9	8	4	7	8	7	6	5	5	5	5	5	5	5	4	3	4
MIC	3	6	5	5	7	4	3	2	7	15	29	16	14	12	11	9	54	19	12
Sponge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUB	17	25	20	34	11	8	16	22	39	27	17	18	15	16	8	7	7	7	9

```
select sp:9 s1:4 s2:4 s3:4 s4:4 s5:4 s6:4 s7:4 s8:4 s9:4 s10:4 s11:4 +
s12:4 s13:4 s14:4 s15:4 s16:4 s17:4 s18:4 s19:4 from pctot
```

ef-edge Transect

rmon	pltdate	Diadema	Ecnon	ELUC	Eucid	EVIR	Lytvar	TRYPN
7712	77.92	1	0	182	10.5	6.5	0	0
7802	78.08	2.5	0	145	14	3	.5	.5
7803	78.17	0	0	143	12	1.5	0	0
7804	78.25	0	1	127.5	9	1.5	0	0
7805	78.33	0	0	103.5	5.5	1.5	0	0
7806	78.42	0	0	120	7	7	0	0
7808	78.58	0	.5	100	8.5	2.5	0	0
7809	78.67	1.5	0	74.5	6	2	0	0
7811	78.83	2	0	36	12	0	1.5	0
7812	78.92	0	0	35.5	3.5	0	.5	0
7901	79.00	1	0	76	10.5	0	0	0
7903	79.17	3.5	0	178	15.5	2.5	.5	1
7904	79.25	1	0	179.5	15	4.5	1	0
7905	79.33	0	0	110.5	5	.5	0	0
7906	79.42	0	0	63.5	3.5	1.5	0	0
7907	79.50	0	0	14	0	2.5	0	0
7908	79.58	.5	0	41	4	1.5	0	0
7909	79.67	0	0	30	5	0	0	0
7910	79.75	0	0	25	5	.5	0	0
7911	79.83	0	0	10.5	3	0	0	0
7912	79.92	0	0	18.5	3	.5	0	0
8001	80.00	.5	0	14	4	.5	0	0
8002	80.08	0	0	11.5	4.5	1	1	0
8003	80.17	.5	0	21	6	.5	5	0
8004	80.25	1.5	0	35	6.5	3	8.5	0
8005	80.33	0	0	23.5	1	3.5	0	0
8006	80.42	0	1	19.5	1	9	0	0
8007	80.50	0	1	65	.5	43	0	0
8008	80.58	1	0	51.5	1.5	42	0	0
8009	80.67	1.5	0	31	1.5	21.5	0	0
8010	80.75	0	0	20	1.5	7.5	0	.5
8011	80.83	0	0	23.5	1.5	18.5	0	0
8101	81.00	.5	0	101.5	3.5	14.5	4.5	0
8102	81.08	0	0	186	3	12	2	0
8103	81.17	2.5	0	352	4.5	39.5	7.5	0
8104	81.25	4	2	514	3	81.5	2	0
8105	81.33	.5	1.5	327	4	78	1	0
8106	81.42	.5	1	390.5	3	97.5	0	0
8107	81.50	0	2	303.5	0	81	0	0
8108	81.58	0	5	272.5	0	89	0	0
8109	81.67	.5	1.5	137	1.5	25	0	0
8110	81.75	0	3	133.5	.5	30.5	0	0
8111	81.83	0	.5	78.5	1	10.5	0	0
8112	81.92	0	0	29	2	7	0	0
8201	82.00	0	.5	37	2	13.5	0	0
8202	82.08	0	0	26.5	1.5	6	0	0
8203	82.17	.5	0	28.5	2	8.5	0	0
8204	82.25	0	2	36.5	1.5	6.5	.5	0
8205	82.33	0	3.5	57	1	6	0	0
8206	82.42	1	4	59.5	.5	7.5	0	0
8207	82.50	0	1.5	66	.5	5.5	0	0
8208	82.58	.5	0	27.5	1	4	0	0
8209	82.67	0	0	26.5	1.5	2	.5	0
8210	82.75	0	0	28	1.5	3	0	0
8211	82.83	.5	1.5	42.5	1	1.5	1.5	.5
8301	83.00	1.5	2	96.5	2.5	7.5	1.5	1
8302	83.08	0	4	100.5	2.5	5.5	2	0
8303	83.17	0	4.5	258.5	2.5	8.5	7.5	1
8304	83.25	0	0	287	4	11.5	3	0

[illegible]	[illegible]	[illegible]	[illegible]					
8308	83.58	0	2.5	157.5	1	20.5	0	0
8309	83.67	1.5	.5	120	1.5	15	0	0
8310	83.75	1	3.5	103	.5	12.5	1	0
8312	83.92	0	2.5	410	3.5	14	6.5	1
8402	84.08	1	2.5	754	2.5	20.5	5	1
8403	84.17	.5	1	1077	3	22.5	2.5	0
8404	84.25	0	3	729.5	2	8.5	0	.5
8405	84.33	0	10	964.5	2.5	11.5	0	0
8406	84.42	0	13	539	.5	20	0	0
8407	84.50	0	18.5	558	1	20	0	0
8408	84.58	0	8	476	1.5	18.5	0	0
8409	84.67	0	9	369.5	2	8	0	0
8410	84.75	0	8.5	228.5	2	4	0	0
8411	84.83	0	2.5	133.5	2.5	4	0	0
8501	85.00	0	1.5	112	3	0	1	0
8502	85.08	0	0	87	1.5	4	1.5	0
8503	85.17	1	3.5	68	4	4.5	3.5	0
8504	85.25	.5	2.5	86	4	4	2	0
8505	85.33	0	6	29.5	1	1	0	0
8506	85.42	0	4.5	35.5	.5	1.5	0	0
8507	85.50	0	8.5	53.5	1	2	0	0
8508	85.58	0	4	19	.5	0	0	0
8509	85.67	0	5.5	35	1	3	0	0
8510	85.75	0	2	29	.5	1	.5	0
8511	85.83	0	1	4.5	0	.5	0	0
8602	86.08	0	1.5	10	2	.5	0	0
8603	86.17	0	3.5	34	1	.5	0	0
8604	86.25	0	2	63.5	2	2.5	1	0
8605.3	86.36	0	5.5	154	2	28	.5	0
8605.6	86.38	0	3.5	27	0	4	0	0
8606	86.42	0	4.5	66	0	10	0	0
8607	86.50	0	.5	68.5	.5	11.5	0	0
8608	86.58	0	1	69	1	10.5	.5	0
8609	86.67	0	2.5	80	1	10.5	0	0
8610	86.75	0	0	77	0	15	1	0
8611	86.83	0	0	75	.5	10	.5	0
8612	86.92	0	1	53.5	1.5	8.5	0	0

199

8604 10 Apr no size
8605.3 8 May 1986 80% [illegible]
8605. 31 May no urchins in black patches
8606 19 June 6 big
07 21 July 7 big

yrmon	pltdate	Diadema	Echon	ELUC	EVIR	Lytvar	Lytwill	TRYP
7712	77.92	.5	0	1.5	.5	11	0	[illegible]
7801	78.00	1	0	11.5	4	41.5	0	3.[illegible]
7803	78.17	0	.5	16.5	1.5	.5	0	[illegible]
7804	78.25	0	2	15	3.5	0	0	[illegible]
7805	78.33	.5	.5	21	7	0	0	[illegible]
7806	78.42	0	1	19.5	4.5	0	0	[illegible]
7808	78.58	1	0	6	4	0	0	[illegible]
7809	78.67	1	.5	4.5	5.5	1	0	.[illegible]
7810	78.75	3	0	4.5	0	34.5	0	[illegible]
7811	78.83	6	0	4	0	20.5	0	
7812	78.92	4	0	3	.5	23	0	.[illegible]
7901	79.00	2.5	0	4.5	.5	7.5	0	[illegible]
7903	79.17	2	0	3	.5	6.5	0	[illegible]
7904	79.25	0	0	1.5	.5	5	0	[illegible]
7905	79.33	0	0	1.5	3	0	0	[illegible]
7906	79.42	0	0	5	1	0	0	[illegible]
7907	79.50	0	0	2	.5	0	0	[illegible]
7908	79.58	0	0	4	.5	0	0	[illegible]
7909	79.67	0	0	.5	0	0	0	[illegible]
7910	79.75	0	0	1	0	1	0	[illegible]
7911	79.83	0	0	.5	0	1	0	[illegible]
7912	79.92	0	0	.5	.5	10.5	0	[illegible]
8001	80.00	.5	0	5.5	.5	3	0	[illegible]
8002	80.08	1.5	1	6	1	30.5	0	
8003	80.17	.5	0	6	4	21.5	0	[illegible]
8004	80.25	1	0	4.5	14	24	0	
8005	80.33	0	0	8	8	0	0	[illegible]
8006	80.42	0	0	7.5	6	0	0	
8007	80.50	0	0	8	13.5	0	0	
8008	80.58	.5	0	5.5	14	0	0	
8009	80.67	1.5	0	3	6.5	19.5	0	
8010	80.75	0	1.5	10.5	4	0	0	
8011	80.83	0	0	24	2.5	0	0	
8101	81.00	.5	.5	108.5	14	70	0	1.
8102	81.08	1.5	0	138.5	26	107.5	0	
8103	81.17	2.5	0	148.5	40.5	63	0	
8104	81.25	0	.5	17.5	3	0	0	
8105	81.33	0	0	35	9	0	0	
8106	81.42	0	0	16.5	2	0	0	
8107	81.50	0	0	23	5.5	0	0	
8108	81.58	0	0	5.5	2	0	0	
8109	81.67	0	0	2.5	1	0	0	
8110	81.75	0	0	2	1	0	0	
8111	81.83	0	0	1	1	0	0	
8112	81.92	.5	0	2.5	.5	0	0	
8201	82.00	0	0	4	.5	13.5	0	
8202	82.08	0	0	1.5	2	27	0	
8203	82.17	1	0	13	3	46.5	0	1.
8204	82.25	0	0	29.5	6	3	0	
8205	82.33	0	0	26.5	3.5	0	0	
8206	82.42	0	0	12.5	1	0	0	
8207	82.50	0	0	9	2	0	0	
8208	82.58	0	0	4	.5	0	0	
8209	82.67	.5	0	9	0	24.5	0	
8210	82.75	.5	0	19.5	.5	70	0	
8211	82.83	[illegible]	0	19	1.5	58.5	0	
8301	83.00	1	0	19	3	31	0	
8302	83.08	1	0	14	3	11	0	
8303	83.17	.5	0	14	5.5	17.5	0	2.
8304	83.25	0	0	16	3.5	0	0	

8307	83.50	0	0	14.5	5.5	0	0	0
8308	83.58	0	0	8.5	5	0	0	0
8309	83.67	2.5	0	9	2	17.5	0	2
8310	83.75	.5	0	72	1.5	326.5	0	5
8312	83.92	.5	0	82	1	245.5	0	8.5
8402	84.08	0	0	65.5	1.5	111.5	0	2
8403	84.17	0	0	40.5	.5	71	0	1
8404	84.25	0	0	95.5	2.5	.5	0	.5
8405	84.33	0	0	97.5	5.5	0	0	0
8406	84.42	0	0	38	1	0	0	0
8407	84.50	0	0	22	1.5	0	0	0
8408	84.58	0	0	16.5	1.5	0	0	0
8409	84.67	0	0	11.5	2	0	0	0
8410	84.75	0	0	8.5	1	0	0	0
8411	84.83	0	0	10	.5	.5	0	0
8412	84.92	0	0	6	0	6.5	0	1
8501	85.00	.5	0	5	0	86.5	0	3.5
8502	85.08	0	0	11	0	80	0	4.5
8503	85.17	0	0	4.5	1	25	0	1
8504	85.25	0	0	8	.5	16.5	0	5
8505	85.33	0	0	6.5	.5	0	0	0
8506	85.42	0	0	3	.5	0	0	0
8507	85.50	0	0	3	0	0	0	0
8508	85.58	0	0	1	0	0	0	0
8509	85.67	0	0	2	0	0	0	0
8510	85.75	0	0	2	0	0	0	0
8511	85.83	0	0	.5	0	0	.5	0
8601	86.00	0	0	10	1.5	26.5	0	6.5
8602	86.08	0	0	49	14.5	31.5	0	16.5
8603	86.17	0	0	45	13	10.5	0	6.5
8604	86.25	0	0	57.5	23.5	0	0	1
8605.3	86.36	0	.5	55.5	28	0	0	0
8605.6	86.38	0	0	51.5	15	0	0	0
8606	86.42	0	0	31	12.5	0	0	0
8607	86.50	.5	0	23.5	10.5	0	0	0
608	86.58	0	0	9	3	0	0	1
609	86.67	0	0	18.5	2	99	0	9.5
610	86.75	0	0	31.5	2	87	0	10
611	86.83	0	0	38.5	2	161	0	12

ast Reef Transect URCHEAST.DAT

rmon	Plotdate	Diadema	ELUC	Eucid	EVIR	Lytvar
7712	77.92	.5	12	0	.5	6.5
7801	78.00	2	27	0	5	22
7803	78.17	0	20.5	.5	2	.5
7804	78.25	0	29.5	0	4	0
7805	78.33	0	34.5	0	3.5	0
7806	78.42	0	34.5	0	1.5	0
7808	78.58	.5	28.5	0	4.5	.5
7809	78.67	.5	21	0	4	1
7810	78.75	0	15	0	3.5	5.5
7812	78.92	4.5	17.5	0	3	12
7903	79.17	.5	16.5	0	3.5	4.5
7904	79.25	0	13.5	.5	3	1
7905	79.33	0	14	0	2.5	0
7906	79.42	0	17.5	0	3.5	0
7907	79.50	0	31	1	1	0
7908	79.58	0	14	0	3.5	0
7909	79.67	0	7.5	.5	1.5	0
7910	79.75	0	3	0	0	.5
7911	79.83	0	3	0	.5	.5
7912	79.92	0	1.5	0	0	0
8001	80.00	0	3.5	0	1	.5
8002	80.08	0	6.5	0	.5	2.5
8003	80.17	5	4	0	1.5	10
8004	80.25	.5	7.5	0	3	6
8005	80.33	0	14.5	0	6.5	0
8006	80.42	0	19	0	10	0
8007	80.50	0	11	0	14.5	0
8008	80.58	.5	9	0	10	0
8009	80.67	.5	10	0	10.5	1
8010	80.75	0	13.5	0	16.5	0
8011	80.83	0	15	0	8	1
8101	81.00	1.5	28	0	14	17.5
8102	81.08	1	21	0	15.5	15
8103	81.17	1	39.5	0	24	17.5
8104	81.25	0	1.5	0	0	0
8105	81.33	0	1.5	0	.5	0
8106	81.42	0	2.5	0	1	0
8107	81.50	0	3	0	.5	0
8108	81.58	0	3	0	2.5	0
8109	81.67	0	7	0	1	0
8110	81.75	0	3	0	0	0
8111	81.83	0	4.5	0	0	0
8112	81.92	0	3.5	0	.5	0
8201	82.00	0	.5	0	.5	0
8202	82.08	.5	2	0	.5	0
8203	82.17	1	2	0	0	.5
8204	82.25	0	1.5	0	1.5	.5
8205	82.33	0	2.5	0	1	0
8206	82.42	0	4.5	0	1.5	0
8207	82.50	0	4	0	0	0
8208	82.58	0	1	0	0	0
8209	82.67	0	1	0	0	0
8210	82.75	0	2	0	0	.5
8211	82.83	0	3	0	.5	10.5
8301	83.00	0	5	0	.5	5.5
8302	83.08	.5	8.5	0	.5	4.5
8303	83.17	0	8.5	0	2.5	0
8304	83.25	[illegible]	12.5	0	4	0
[illegible]	[illegible]	0	17	0	11	5

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8308	83.58	0	23	0	8	0
8309	83.67	0	9	0	6	1
8310	83.75	.5	17	0	5	26.5
8312	83.92	.5	25.5	0	3	113.5
8402	84.08	.5	35.5	0	7.5	83.5
8403	84.17	.5	44.5	0	9.5	57.5
8404	84.25	0	64.5	0	12	.5
8405	84.33	0	75	0	15.5	0
8406	84.42	0	61	0	7.5	0
8407	84.50	0	42	0	9.5	0
8408	84.58	0	29	0	6	0
8409	84.67	0	22	0	6	0
8410	84.75	0	27.5	0	4.5	0
8411	84.83	0	17	0	4.5	0
8501	85.00	0	20.5	0	3.5	2.5
8502	85.08	0	12	0	4	18
8503	85.17	0	13	0	5.5	9.5
8504	85.25	0	16.5	.5	7	11.5
8505	85.33	0	20	0	5.5	0
8506	85.42	0	15	0	4	0
8507	85.50	0	13.5	0	4	.5
8508	85.58	0	14	0	4.5	0
8509	85.67	0	11	0	4.5	0
8510	85.75	0	8	0	4	0
8511	85.83	0	7.5	0	4	0
8601	86.00	0	9	0	3	0
8602	86.08	0	9	0	2	2
8603	86.17	.5	10.5	0	1.5	2.5
8604	86.25	0	12	0	4	.5
8605.5	86.36	0	17.5	0	8	0
8605.6	86.38	0	20.5	0	12	0
8606	86.42	0	19	0	10	0
8607	86.50	0	10	0	10.5	0
8608	86.58	0	12	0	9	0
8609	86.67	0	10.5	0	8	0
8610	86.75	0	7	0	7	4
8611	86.83	0	9.5	0	5.5	29.5

URBXEMRE.DAT (E)

Thalassia bed plots

East mid-reef plots

yrmon	Pltdate	DIADEMA (M)	ECHON (M)	ELUC	EUCID	EVIR	LYTVAR	LYTWILL (M)	~~OTHER~~	TRYPN (M)
7810	78.75	.00	.00	6.00	.00	.50	12.00	.00	.00	.00
7901	79.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
7902	79.08	.00	.00	5.50	.00	1.00	.50	.00	.00	.00
7903	79.17	.50	.00	6.00	.00	2.00	1.50	.00	.00	.50
7904	79.25	.00	.00	8.50	.00	3.00	4.50	.00	.00	.00
7905	79.33	.00	.00	6.00	.00	1.50	.00	.00	.00	.00
7906	79.42	.00	.00	6.00	.00	.50	.00	.00	.00	.00
7907	79.50	.00	.00	5.00	.00	.00	.00	.00	.00	.00
7908	79.58	.00	.00	2.50	.00	.50	.00	.00	.00	.00
7909	79.67	.00	.00	4.50	.00	.50	.00	.00	.00	.00
7910	79.75	.00	.00	3.00	.00	.50	.00	.00	.00	.00
7911	79.83	.00	.00	.00	.00	.00	.00	.00	.00	.00
7912	79.92	.00	.00	.00	.00	.00	.00	.00	.00	.00
8002	80.08	1.50	.00	2.00	.00	.50	17.00	.00	.00	.00
8004	80.25	.50	.50	15.00	.00	18.00	19.50	.00	.00	.00
8005	80.33	.00	.00	9.00	.00	10.50	.00	.00	.00	.00
8006	80.42	.00	.50	8.00	.00	9.00	.00	.00	.00	.00
8007	80.50	.00	.00	2.50	.00	6.00	.00	.00	.00	.00
8008	80.58	.00	.00	5.00	.00	9.50	.00	.00	.00	.00
8009	80.67	.00	.00	2.00	.00	7.50	13.00	.00	.00	.00
8010	80.75	.00	.00	29.00	.00	2.50	.00	.00	.00	.00
8011	80.83	.00	.00	30.50	.00	2.50	.00	.00	.00	.00
8101	81.00	2.00	.00	98.50	.00	17.50	58.00	.00	.00	.00
8103	81.17	.00	.00	120.00	.00	28.00	75.50	.00	.00	.50
8104	81.25	.00	.00	40.00	.00	8.00	.00	.00	.00	.00
8105	81.33	.00	.00	38.00	.00	9.50	.00	.00	.00	.00
8106	81.42	.00	.00	17.00	.00	11.00	.00	.00	.00	.00
8107	81.50	.00	.00	14.50	.00	6.50	.00	.00	.00	.00
8108	81.58	.00	.00	8.00	.00	1.00	.00	.00	.00	.00
8109	81.67	.00	.00	5.00	.00	.00	.00	.00	.00	.00
8110	81.75	.00	.00	3.00	.00	.00	.00	.00	.00	.00
8111	81.83	.00	.00	2.00	.00	.00	.00	.00	.00	.00
8112	81.92	.00	.00	4.00	.00	.00	.00	.00	.00	.00
8201	82.00	.00	.00	2.50	.00	.00	.50	.00	.00	.00
8202	82.08	.00	.00	1.00	.00	.00	2.00	.00	.00	.00
8203	82.17	.00	.00	5.00	.00	1.50	17.50	.00	.00	.00
8204	82.25	.00	.00	15.00	.00	.50	4.00	.00	.00	.00
8205	82.33	.00	.00	19.00	.00	.50	.00	.00	.00	.00
8206	82.42	.00	.00	8.00	.00	.00	.00	.00	.00	.00
8207	82.50	.00	.00	20.00	.00	.50	.00	.00	.00	.00
8208	82.58	.00	.00	1.00	.00	.00	.00	.00	.00	.00
8209	82.67	.00	.00	5.00	.00	.50	11.00	.00	.00	1.00
8210	82.75	.00	.00	19.00	.00	.50	40.00	.00	.00	.50
8211	82.83	.00	.00	16.50	.00	.50	35.00	.00	.00	.00
8301	83.00	.00	.00	22.00	.00	.50	17.00	.00	.00	.00
8302	83.08	.00	.00	39.50	.00	1.00	21.50	.00	.00	.50
8303	83.17	.00	.00	28.00	.00	3.00	.00	.00	.00	.00
8304	83.25	.00	.00	22.50	.00	2.00	.00	.00	.00	.00
8305	83.33	.00	.00	25.50	.00	8.00	.00	.00	.00	.00

8306	83.42	.00	.00	16.00	.00	1.50	.00	.00	.00	.00
8307	83.50	.00	.00	14.00	.00	1.50	.00	.00	.00	.00
8308	83.58	.00	.00	12.50	.00	1.00	.00	.00	.00	.00
8309	83.67	.50	.00	17.00	.00	1.00	9.00	.00	.00	.00
8310	83.75	.00	.00	40.00	.00	1.00	187.50	.00	.00	.00
8312	83.92	.00	.00	82.00	00	2.00	210.00	.00	.00	.50
8402	84.08	.50	.00	87.00	.00	3.50	44.00	.00	.00	.00
8403	84.17	.50	.00	88.00	.00	2.50	24.50	.00	.00	.00
8404	84.25	.00	.00	94.00	.00	3.50	.00	.00	.00	.00
8405	84.33	.00	.00	75.00	.00	3.50	.00	.00	.00	.00
8406	84.42	.00	.00	32.00	.00	1.00	.00	.00	.00	.00
8407	84.50	.00	.00	26.50	.00	1.00	.00	.00	.00	.00
8408	84.58	.00	.00	21.00	.00	2.00	.00	.00	.00	.00
8409	84.67	.00	.00	18.50	.00	.00	.00	.00	.00	.00
8410	84.75	.00	.00	11.00	.00	.00	.00	.00	.00	.00
8411	84.83	.00	.00	9.50	.00	.00	.00	.00	.00	.00
8501	85.00	.00	.00	10.00	.00	.50	19.00	.00	.00	.00
8502	85.08	.00	.00	11.00	.00	.50	45.50	.00	.00	.00
8503	85.17	.00	.00	10.00	.00	.50	15.50	.00	.00	.00
8504	85.25	.00	.00	10.50	.00	.50	16.00	.00	.00	.00
8505	85.33	.00	.00	9.50	.00	.50	.00	.00	.00	.00
8506	85.42	.00	.00	10.00	.00	.50	.00	.00	.00	.00
8507	85.50	.00	.00	8.50	.00	.00	.00	.00	.00	.00
8508	85.58	.00	.00	5.50	.00	.00	.00	.00	.00	.00
8509	85.67	.00	.00	3.50	.00	.00	.00	.00	.00	.00
8510	85.75	.00	.00	4.50	.00	.50	.00	.00	.00	.00
8511	85.83	.00	.00	4.00	.00	.50	.00	.00	.00	.00
8602	86.08	.00	.00	8.50	.00	.00	18.00	.00	.00	.00
8603	86.17	.00	.00	32.00	.00	17.50	7.00	.00	.00	1.00
8604	86.25	.00	.00	22.00	.00	12.50	.00	.00	.00	.00
8605	86.33	.00	.00	29.50	.00	25.00	.00	.00	.00	.00
8606	86.42	.00	.00	21.00	.00	14.50	.00	.00	.00	.00
8607	86.50	.00	.00	20.00	.00	17.00	.00	.00	.00	.00
8608	86.58	.00	.00	8.50	.00	12.00	.00	.00	.00	.50
8609	86.67	.00	.00	9.00	.00	8.50	22.00	.00	.00	1.00
8610	86.75	.00	.00	14.00	.00	14.00	117.50	.00	.00	1.00
8611	86.83	.00	.00	16.50	.00	7.00	103.00	.00	.00	.00

yrmon	PLTDATE	DIADEMA	ECNON	ELUC	EUCID	EVIR	LYTVAR	LYTWILL	TRY
7810	78.75	.00	.00	.00	.00	.00	.00	.00	
7901	79.00	.00	.00	.00	.00	.00	.00	.00	
7902	79.08	.00	.00	.00	.00	.00	.00	.00	
7903	79.17	.00	.00	.00	.00	.00	.00	.00	
7904	79.25	.00	.00	3.00	.00	.00	.00	.00	
7905	79.33	.00	.00	4.50	2.00	.00	.00	.00	
7906	79.42	.00	.00	3.00	1.50	.00	.00	.00	
7907	79.50	1.00	.00	2.00	2.50	.00	.00	.00	
7908	79.58	1.00	.00	10.00	.50	.00	.00	.00	
7909	79.67	.00	.00	3.00	.00	.00	.00	.00	
7910	79.75	.00	.00	.00	.00	.00	.00	.00	
7911	79.83	.00	.00	.00	.00	.00	.00	.00	
7912	79.92	.00	.00	.00	.00	.00	.00	.00	
8002	80.08	.00	.00	.00	.00	.00	.00	.00	
8004	80.25	.00	.00	.00	.00	.00	.00	.00	
8005	80.33	.00	.00	9.00	.00	1.00	.00	.00	
8006	80.42	.00	.00	.00	.00	.50	.00	.00	
8007	80.50	.00	.00	6.00	.50	.00	.00	.00	
8008	80.58	1.00	.00	5.00	.00	1.00	.00	.00	
8009	80.67	3.00	.00	4.00	.50	1.00	.00	.00	
8010	80.75	.00	.00	7.50	1.00	.50	.00	.00	
8011	80.83	.00	.00	4.00	1.00	.50	.00	.00	
8101	81.00	.00	.00	.00	.50	.50	.00	.00	
8103	81.17	1.00	.00	1.00	.50	.50	.00	.00	
8104	81.25	.00	.00	1.50	.00	1.00	.00	.00	
8105	81.33	.00	.00	1.50	1.50	1.50	.00	.00	
8106	81.42	.00	.00	3.50	.00	.50	.00	.00	
8107	81.50	.00	.00	1.50	.00	.00	.00	.00	
8108	81.58	.50	.00	1.50	.50	.50	.00	.00	
8109	81.67	.00	.00	2.50	.00	.00	.00	.00	
8110	81.75	.00	.00	4.00	.50	.00	.00	.00	
8111	81.83	.00	.00	4.50	.50	.50	.00	.00	
8112	81.92	.00	.00	2.50	.00	.00	.00	.00	
8201	82.00	.00	.00	4.50	.00	.50	.00	.00	
8202	82.08	.00	.00	2.00	.00	.50	.00	.00	
8203	82.17	.00	.00	3.50	.00	.50	.00	.00	
8204	82.25	.00	.00	1.50	.00	.00	.00	.00	
8205	82.33	.00	.00	3.00	.00	.00	.00	.00	
8206	82.42	.00	.00	4.50	.00	.00	.00	.00	
8207	82.50	.00	.00	3.00	.00	.00	.00	.00	
8208	82.58	.00	.00	2.00	.00	.00	.00	.00	
8209	82.67	.50	.00	.50	.00	.00	.00	.00	
8210	82.75	.00	.00	.00	.00	.00	.00	.00	
8211	82.83	.00	.00	.00	.00	.00	.00	.00	
8301	83.00	.00	.00	2.00	.00	.00	.00	.00	
8302	83.08	.00	.00	4.50	.00	.00	.00	.00	
8303	83.17	.00	.00	5.50	.00	1.00	.00	.00	
8304	83.25	.00	.00	6.50	.50	.00	.00	.00	
8305	83.33	.00	.00	6.50	.00	1.00	.00	.00	
8306	83.42	.00	.00	4.50	.00	.00	.00	.00	
8307	83.50	.00	.00	6.50	.00	2.50	.00	.00	
8308	83.58	.00	.00	5.50	.00	1.00	.00	.00	
8309	83.67	.00	.00	1.50	.00	.00	.00	.00	
8310	83.75	.00	.00	.50	.00	1.00	.00	.00	
8312	83.92	.00	.00	2.50	.00	.00	.00	.00	
8402	84.08	.00	.00	10.50	.00	1.50	.00	.00	1
8403	84.17	.00	.00	31.50	.00	1.00	.00	.00	
8404	84.25	.00	.00	39.00	.00	.50	.00	.00	
8405	84.33	.00	.00	46.50	.50	1.00	.00	.00	
8406	84.42	.00	.00	46.00	.00	2.50	.00	.00	
8407	84.50	.00	.00	36.50	1.00	2.00	.00	.00	

8409	84.67	.00	.00	40.50	.50	2.00	.00	.00	.00
8410	84.75	.00	.00	40.50	.00	1.50	.00	.00	.00
8411	84.83	.00	.00	16.00	.00	.50	.00	.00	.00
8501	85.00	.00	.00	13.50	.00	.50	.00	.00	.00
8502	85.08	.00	.00	14.50	1.00	.50	.00	.00	.00
8503	85.17	.00	.00	11.50	.00	.00	.00	.00	.00
8504	85.25	.00	.00	10.00	1.00	.00	.00	.00	.00
8505	85.33	.00	.00	.50	.00	.00	.00	.00	.00
8506	85.42	.00	.00	.50	.50	.50	.00	.00	.00
8507	85.50	.00	.00	1.50	.50	.50	.00	.00	.00
8508	85.58	.00	.00	1.00	.00	.00	.00	.00	.00
8509	85.67	.00	.00	2.50	.50	.00	.00	.00	.00
8510	85.75	.00	.00	1.50	.50	.00	.00	.00	.00
8511	85.83	.00	.00	.50	.00	.00	.00	.00	.00
8602	86.08	.00	.00	.00	.00	.00	.00	.00	.00
8603	86.17	.00	.00	.50	.00	.00	.00	.00	.00
8604	86.25	.00	.00	.50	.00	.00	.00	.00	.00
8605	86.33	.00	.00	.00	.00	.00	.00	.00	.00
8607	86.50	.00	.00	.00	.00	.00	.00	.00	.00
8608	86.58	.00	.00	.00	.00	.00	.00	.00	.00
8609	86.67	.00	.00	.00	.00	.00	.00	.00	.00
8610	86.75	.00	.00	.00	.00	.00	.00	.00	.00
8611	86.83	.00	.00	.00	.00	.00	.00	.00	.50

URBXSOET.DAT

208

Southeast Plots

yrmon	Plt-Date	DIADEMA (M)	ECNON (M)	ELUC	EUCID	EVIR	LYTVAR (M)	LYTWILL (M)	TRYPN (M)
7810	78.75	.50	.00	1.50	.00	.00	.00	.00	.00
7901	79.00	.00	.00	.00	.00	.00	.00	.00	.00
7902	79.08	.00	.00	1.50	.00	.00	1.50	.00	.00
7903	79.17	.50	.00	7.50	.50	.00	.50	.00	.00
7904	79.25	.00	.00	10.50	.00	.00	.00	.00	.00
7905	79.33	.00	.00	9.50	.00	.50	.00	.00	.00
7906	79.42	.00	.00	11.50	.00	.00	.00	.00	.00
7907	79.50	.00	.00	7.50	.00	.00	.00	.00	.00
7908	79.58	1.50	.00	11.50	.00	.00	.00	.00	.00
7909	79.67	.00	.00	6.50	.00	.00	.00	.00	.00
7910	79.75	.50	.00	6.00	.00	.00	.00	.00	.00
7911	79.83	.00	.00	5.00	.00	.00	.00	.00	.00
7912	79.92	.00	.00	.00	.00	.00	.00	.00	.00
8002	80.08	.50	.00	2.50	.00	.00	.00	.00	.00
8004	80.25	.50	.00	1.50	.00	.00	.00	.00	.00
8005	80.33	.00	.00	.00	.00	.00	.00	.00	.00
8006	80.42	.00	.00	5.50	.00	.00	.00	.00	.00
8007	80.50	.00	.00	8.00	.00	1.00	.00	.00	.00
8008	80.58	.50	.00	9.50	.00	.00	.00	.00	.00
8009	80.67	.50	.00	4.00	.50	.00	.00	.00	.00
8010	80.75	.00	.00	4.00	.00	.00	.00	.00	.00
8011	80.83	.00	.00	5.00	.00	.50	.00	.00	.00
8101	81.00	.00	.00	1.50	.00	.50	1.00	.00	.00
8103	81.17	.00	.00	8.50	.00	1.00	.00	.00	.00
8104	81.25	.50	.00	27.00	.00	1.50	.00	.00	.00
8105	81.33	.00	.00	42.00	.00	5.00	.00	.00	.00
8106	81.42	.00	.00	37.00	.00	3.50	.00	.00	.00
8107	81.50	.00	.00	46.00	.00	4.00	.00	.00	.00
8108	81.58	1.00	.00	46.50	.00	5.00	.00	.00	.00
8109	81.67	.00	.00	35.50	.00	3.00	.00	.00	.00
8110	81.75	.50	.00	31.00	.00	2.50	.00	.00	.00
8111	81.83	.50	.00	19.00	.00	2.50	.00	.00	.00
8112	81.92	.50	.00	13.00	.00	3.00	.00	.00	.00
8201	82.00	.00	.00	6.50	.00	1.50	.00	.00	.00
8202	82.08	.00	.00	11.00	.00	3.00	.00	.00	.00
8203	82.17	.00	.00	12.00	.50	1.00	.00	.00	.00
8204	82.25	.00	.00	16.00	.50	1.00	.00	.00	.00
8205	82.33	.00	.00	12.00	.00	.00	.00	.00	.00
8206	82.42	.00	.00	11.50	.00	.00	.00	.00	.00
8207	82.50	.00	.00	2.50	.00	.50	.00	.00	.00
8208	82.58	.50	.00	6.50	.00	2.00	.00	.00	.00
8209	82.67	2.50	.00	4.00	.00	1.50	.00	.00	.00
8210	82.75	2.50	.00	2.00	.00	.00	.00	.00	.00
8211	82.83	2.00	.00	2.50	.00	.50	.00	.00	.00
8301	83.00	.00	.00	4.50	.00	.00	.00	.00	.00
8302	83.08	.00	.00	13.50	.00	.00	.00	.00	.00
8303	83.17	.00	.00	12.50	.00	.00	.00	.00	.00
8304	83.25	.00	.00	23.50	.00	.00	.00	.00	.00
8305	83.33	.00	.00	33.00	.00	.50	.00	.00	.00
8306	83.42	.00	1.50	18.50	.00	.00	.00	.00	.00
8307	83.50	.00	1.00	21.50	.00	.50	.00	.00	.00

8308	83.58	.00	.00	12.50	.00	.00	.00	.00	.00
8309	83.67	.00	.00	9.50	.00	.50	.00	.00	.00
8310	83.75	.00	.00	.00	.00	.00	.00	.00	.00
8312	83.92	.00	.00	6.50	.00	.50	.00	.00	.00
8402	84.08	.00	.00	13.50	.50	.00	.00	.00	.00
8403	84.17	.00	.00	20.00	.50	.00	2.00	.00	.00
8404	84.25	.00	.00	97.50	.00	3.00	.00	.00	.00
8405	84.33	.00	.00	88.50	.50	2.00	.00	.00	.00
8406	84.42	.00	.00	43.00	.00	.00	.00	.00	.00
8407	84.50	.00	.00	43.00	.00	.00	.00	.00	.00
8408	84.58	.00	.00	51.50	.00	1.00	.00	.00	.00
8409	84.67	.00	.00	41.00	.00	1.00	.00	.00	.00
8410	84.75	.00	.00	34.50	.00	.00	.00	.00	.00
8411	84.83	.00	.00	16.50	.00	.00	.00	.00	.00
8501	85.00	.00	.00	14.00	.00	.50	1.00	.00	.00
8502	85.08	.00	.00	16.00	1.00	.50	.50	.00	.00
8503	85.17	.00	.00	20.00	.00	.50	.50	.00	.00
8504	85.25	.00	.00	43.50	1.00	.50	1.00	.00	.00
8505	85.33	.00	1.50	20.00	.00	.00	.00	.00	.00
8506	85.42	.00	.00	19.00	.00	.00	.00	.00	.00
8507	85.50	.00	.00	21.50	.00	.00	.00	.00	.00
8508	85.58	.00	.00	11.50	.00	.00	.00	.00	.00
8509	85.67	.00	.50	19.00	.00	.00	.00	.00	.00
8510	85.75	.00	.00	13.00	.00	.50	.00	.00	.00
8511	85.83	.00	.00	2.00	.00	.00	.00	.00	.00
8602	86.08	.00	.00	1.00	.00	.00	.00	.00	.00
8603	86.17	.00	.00	8.00	.00	.00	.00	.00	.00
8604	86.25	.00	.00	7.00	.00	.50	.00	.00	.00
8605	86.33	.00	.00	.00	.00	.00	.00	.00	.00
8606	86.42	.00	.00	1.00	.00	.00	.00	.00	.00
8607	86.50	.00	.00	2.50	.00	.00	.00	.00	.00
8608	86.58	.00	.00	2.00	.00	.00	.00	.00	.00
8609	86.67	.00	.00	.00	.00	.00	.00	.00	.00
8610	86.75	.00	.00	.00	.00	.00	.00	.00	.00
8611	86.83	.00	.00	.00	.00	.00	.00	.00	.00

yrmon	plotdate	M DIADEMA	M ECNON	ELUC	EUCID	EVIR	M LYTVAR	M LYTHILL	M TRYPN
7810	78.75	.83	.00	6.67	.00	.83	.83	.00	.00
7901	79.00	1.83	.00	22.33	.00	.00	.00	.00	.00
7902	79.08	.00	.00	.00	.00	.00	.00	.00	.00
7903	79.17	.83	.00	28.17	.00	.00	.00	.00	.00
7904	79.25	.83	.00	37.17	.00	.00	.00	.00	.00
7905	79.33	.00	.00	21.17	.00	.00	.00	.00	.00
7906	79.42	.00	.00	4.50	.83	.00	.00	.00	.00
7907	79.50	.00	.00	4.33	.00	.00	.00	.00	.00
7908	79.58	.00	.00	5.50	.00	.00	.00	.00	.00
7909	79.67	.83	.00	1.67	.00	.00	.00	.00	.00
7910	79.75	.00	.00	2.67	.00	.00	.00	.00	.00
7911	79.83	.00	.00	.00	.00	.00	.00	.00	.00
7912	79.92	.00	.00	.83	.00	.00	.00	.00	.00
8002	80.08	.00	.00	.50	.00	.50	.50	.00	.00
8004	80.25	.00	.00	.00	.00	.00	.00	.00	.00
8005	80.33	.00	.00	.00	.00	.00	.00	.00	.00
8006	80.42	.00	.00	.00	.00	.00	.00	.00	.00
8007	80.50	.00	.00	.50	.00	.00	.00	.00	.00
8008	80.58	.00	.00	1.00	.00	.00	.00	.00	.00
8009	80.67	.00	.00	.50	.00	1.00	.00	.00	.00
8010	80.75	.00	.00	.00	.00	.00	.00	.00	.00
8011	80.83	.00	.00	.50	.00	.00	.00	.00	.00
8101	81.00	.00	.00	10.33	.00	1.00	.00	.00	.00
8103	81.17	.00	.00	18.17	.50	1.50	.00	.00	.00
8104	81.25	.50	.00	22.00	.00	.50	.00	.00	.00
8105	81.33	.00	.00	9.67	.00	1.50	.50	.00	.00
8106	81.42	.00	.00	17.33	.50	1.50	.00	00	.00
8107	81.50	.00	.00	17.17	.50	1.00	.00	.00	.00
8108	81.58	.00	.00	21.00	.50	1.50	.00	00	.00
8109	81.67	.00	.00	8.83	.50	.50	.00	.00	.00
8110	81.75	.00	.00	3.50	.00	.00	.00	.00	.00
8111	81.83	.50	.00	3.67	.50	.50	.00	.00	.00
8112	81.92	.50	.00	2.50	.00	.50	.00	.00	.00
8201	82.00	.00	.00	.00	.00	.00	.00	.00	.00
8202	82.08	.50	.00	2.50	.50	.00	.00	.00	.00
8203	82.17	1.00	.00	2.50	.00	.00	.50	.00	.00
8204	82.25	1.00	.00	5.50	.50	.50	.50	.00	.00
8205	82.33	.00	.00	3.50	.00	.00	.00	.00	.00
8206	82.42	1.00	.00	4.00	.00	.50	.00	.00	.00
8207	82.50	.50	.00	7.67	.00	1.00	.00	.00	.00
8208	82.58	.50	.00	4.17	.00	.50	.00	.00	.00
8209	82.67	1.50	.00	2.50	.50	.00	.00	.00	.00
8210	82.75	.00	.00	.00	.00	.00	.00	.00	.00
8211	82.83	.00	.00	10.33	.50	.00	1.00	.00	.00
8301	83.00	.00	.00	42.17	.00	.50	.00	.00	.00
8302	83.08	.00	.00	53.67	.00	.00	1.00	.00	.00
8303	83.17	.00	.00	47.33	.00	1.00	.00	.00	.00
8304	83.25	.00	.00	63.50	.50	2.50	.00	.00	.00
8305	83.33	.00	.00	74.17	.50	1.50	.00	.00	.00
8306	83.42	.00	.00	.00	.00	.00	.00	.00	.00
8307	83.50	.00	.00	27.17	.50	.50	.00	.00	.00
8308	83.58	.00	.00	21.50	.00	.50	.00	.00	.00
8310	83.75	.00	.00	16.50	.00	1.00	2.00	.00	.00
8312	83.92	.00	.00	.00	.00	.00	.00	.00	.00
8402	84.08	.00	.00	372.17	.00	2.50	2.50	.00	.50
8403	84.17	.00	.00	552.17	.00	15.83	D.00	.00	.00
8404	84.25	.00	.00	40.83	.50	.00	.00	.00	.00
8405	84.33	.00	.00	33.00	.50	.50	.00	.00	.00
8406	84.42	.00	.00	42.00	.50	.00	.00	.00	.00
8407	84.50	.00	.00	27.33	.50	.00	00	.00	.00

8410	84.75	.00	.00	11.33	.50	.00	.00	.00	.00
8411	84.83	.00	.00	8.67	.00	.00	.50	.00	.00
8501	85.00	.00	.00	12.83	.50	1.00	.50	.00	.00
8502	85.08	.00	.00	15.00	.50	1.00	.00	.00	.00
8503	85.17	.00	.00	13.50	.50	.50	1.00	.00	.00
8504	85.25	.00	.00	10.33	.50	.50	1.50	.00	.00
8505	85.33	.00	.00	1.50	.00	.00	.00	.00	.00
8506	85.42	.00	.00	3.50	.00	.00	.00	.00	.00
8507	85.50	.00	.00	1.00	.00	.00	.00	.00	.00
8508	85.58	.00	.00	1.00	.00	.00	.00	.00	.00
8509	85.67	.00	.00	.00	.00	.00	.00	.00	.00
8510	85.75	.00	.00	1.00	.00	.00	.00	.00	.00
8511	85.83	.00	.00	.50	.00	.00	.00	.00	.00
8602	86.08	.00	.00	.00	.00	.00	.00	.00	.00
8603	86.17	.00	.00	.00	.00	.50	.00	.00	.00
8604	86.25	.00	.00	1.00	.00	.50	.00	.00	.00
8605	86.33	.00	.00	.50	.00	.00	.00	.00	.00
8607	86.50	.00	.00	1.50	.00	1.00	.00	.00	.00
8608	86.58	.00	.00	1.00	.00	.00	.00	.00	.00
8609	86.67	.00	.00	1.50	.00	.00	.00	.00	.00
8610	86.75	.00	.00	.00	.00	.00	1.50	.00	.00
8611	86.83	.00	.00	1.50	.00	.00	3.00	.00	.00

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.