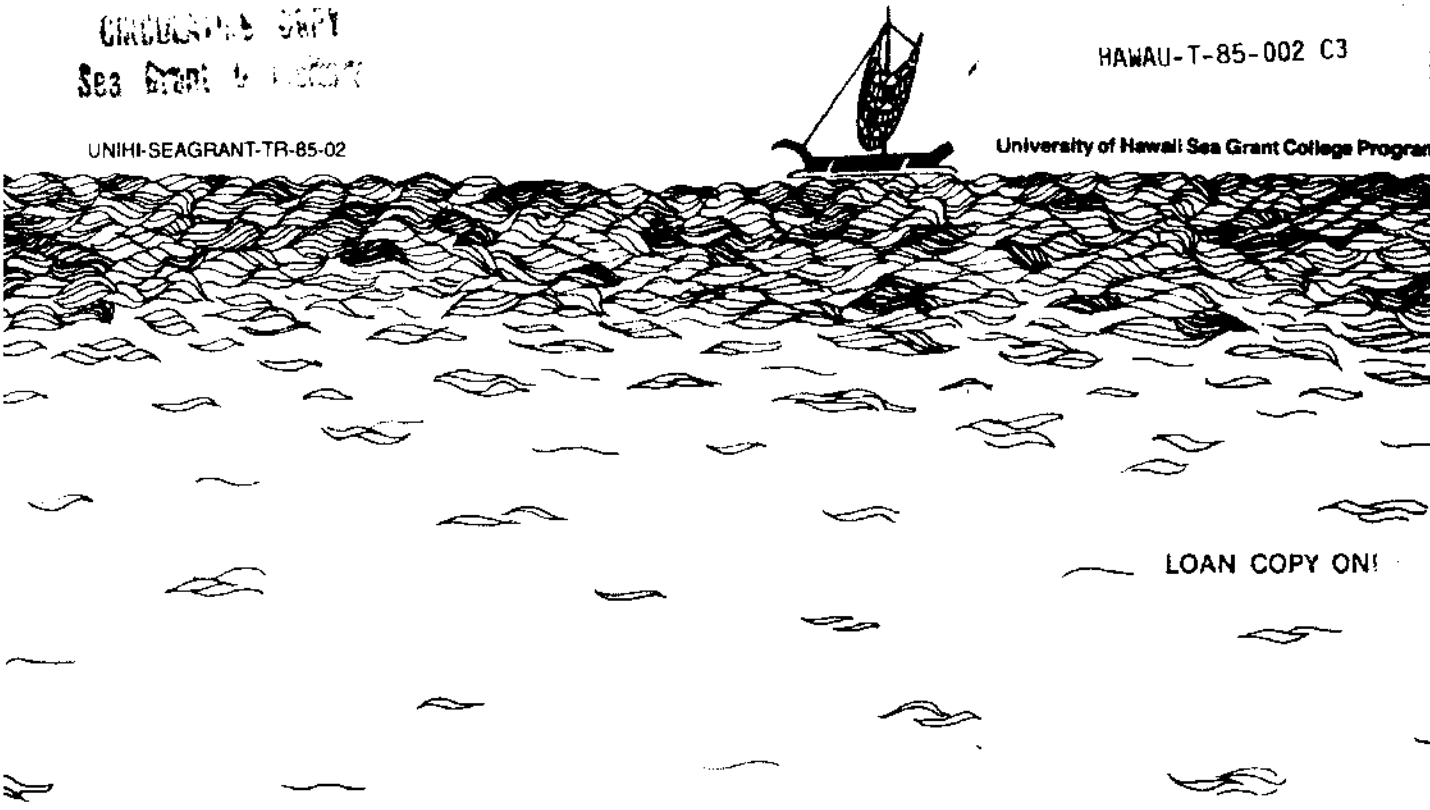
HAWAU-T-85-002 C3

UNIHI-SEAGRANT-TR-85-02

University of Hawaii Sea Grant College Program



LOAN COPY ONLY

Hamakua Coast Sugar Mill Ocean Discharges

Before and After EPA Compliance

Richard W. Grigg

$2.75

HAMAKUA COAST SUGAR MILL OCEAN DISCHARGES
Before and After EPA Compliance

Richard W. Grigg

Sea Grant Technical Report
UNIHI-SEAGRANT-TR-85-02

May 1985

UH Sea Grant College Program
Honolulu, Hawaii

This report was published with funds from "The Publications Program" (PM/P-1) project which is sponsored by the University of Hawaii Sea Grant College Program under Institutional Grant No. NA81AA-D-00070 from NOAA Office of Sea Grant, Department of Commerce. The U.S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon.

About the Author

Richard W. Grigg is a marine biologist with the Hawaii Institute of Marine Biology, University of Hawaii, P.O. Box 1346, Kaneohe, HI 96744; and Sea Grant Scientist, University of Hawaii Sea Grant College Program, 1000 Pope Road, Room 220, Honolulu, HI 96822.

ABSTRACT

In 1971, ecological studies of coral communities along the Hamakua Coast of the island of Hawaii resulted in the instigation of a number of Environmental Protection Agency restrictions regarding ocean disposal by sugar mills. These included, among other things, the elimination of bagasse discharge into the ocean and significant reductions in total suspended solid (TSS). Compliance with EPA standards was achieved in 1979. In 1983, another survey of sugar mill sites including natural streams was conducted to determine the efficacy of EPA standards. The results reported here indicate that differences between 1971 and 1983 are insignificant, suggesting that existing standards are ineffective in reducing zones of impact (0.5 to 1.5 miles). Impacts caused by natural streams are as great as those associated with sugar mills. Were the existing standards for TSS completely relaxed, the increase in coastline impacted would probably be small (~7 percent). Conversely, the cost of completely eliminating mill discharges are prohibitive and not justified by environmental benefits.

ACKNOWLEDGMENTS

I would like to thank C. Brewer & Co., Ltd. and Theo H. Davies & Co., Ltd. for providing the underlying support for this study. Garvie Hall of T.H. Davies supplied important data on tonnage of cane processed and sediment discharged by the mills and helped administer the project. John Bedish of the U.S. Soil Conservation Service helped to calculate sediment discharge volumes from natural streams along the Hamakua Coast during wet and dry years. Field assistance for the study was generously and competently provided by Patrick Tani and Ben Marantan of Hilo and Steve Dollar of the University of Hawaii. I also thank the publications staff, Karen Tanoue and Joan Yamada, of the University of Hawaii Sea Grant College Program, for their excellence in preparing this report for publication.

TABLE OF CONTENTS

LIST OF FIGURES

Figure

LIST OF TABLES

Table

INTRODUCTION

Since 1965, five major studies have been conducted on the marine environment o the Hamakua Coast sugar mills on the island of Hawaii. The first two of these — complete in 1967 and 1969 and known as the Kennedy Engineers study and the Burm report, respec tively — were concerned almost exclusively with the quality of the effluent water of th sugar mills and the receiving water in the ocean off the mill sites (Kennedy Engineers, 196 Environmental Protection Agency, 1971). The major finding of both studies was that "ino ganic suspended solids were the single most distinguishing characteristic of sugar factor waste waters."

The third study, carried out in 1971, was conducted off the entire Hamakua Coast i order to evaluate environmental impacts to marine life associated with the sugar mills (Grig 1972). The results showed that significant reductions in reef corals and fish had occurre off the mill sites, but that impacts were highly localized, being restricted to shallow zone within 1 mile of the mill discharge sites. Within zones of impact, sedimentation was dete mined to be the major cause of biotic depletion.

The fourth study, carried out in 1975, was also undertaken by Grigg. It was concerne with the question of thermal loading and biological oxygen demand (BOD) and their com bined impacts on nearshore marine communities (Grigg, unpublished manuscript). Thes study results showed that no significant changes in temperature occurred in the receivin waters off Pepeekeo, Papaikou, and Ookala sugar mills; however, levels of oxygen concer tration were on occasion slightly depressed. The lowest value of oxygen concentratio recorded was 87 percent saturation. Low values occurred on calm days in the immediat vicinity of the mill discharges. Oxygen depletion levels of this order pose no actual or poter tial ecological threat to marine life (Prosser and Brown, 1965). Critical oxygen levels var widely, ranging from 18 percent saturation for most aquatic vertebrates to about 63 percer for very sensitive species such as oysters. Critical levels are defined as threshold values fc inducing stress. Lethal levels are usually much lower than critical values.

The fifth study, conducted in 1983, was essentially a repeat of the 1971 survey by Grig The results of this study are discussed in detail below following a brief summary of th developments affecting the sugar industry both legally and economically in the 1970s.

During the 1970s, the combined results of the first four studies led to several majc changes in wastewater management by the sugar mills located along the Hamakua Coas All trash, bagasse, and fibrous material were removed from all discharges during 1973-7 In 1976, because of the lack of environmental impact associated with BOD, standards fc BOD were completely relaxed. Conversely, because significant impacts were associated wit sedimentation patterns resulting from the mill operations, strict guidelines for dischargin TSS were developed by the EPA and imposed upon the industry in late 1979. The preser standards include guidelines of 9.9 pounds of TSS maximum per 1,000 pounds gross can processed for any 1 day and 3.6 pounds of TSS average per 1,000 pounds gross can processed for a period of 30 consecutive days. Gross cane is defined as the total quanti of sugarcane, soil, and associated debris received at the mill for processing. Another EP standard is for a zone of mixing for each mill. These zones range outward from the mil from 1 to 2 miles in radius.

During the early 1980s, economic conditions for the sugar industry changed drasti ally. A worldwide recession occurred in 1981-82, during which time the demand for sug was reduced. This resulted in a tremendous loss in sales, compounded by the problem record surpluses. Demand for sugar was also reduced in these years due to the appearanc of high fructose corn syrup on world markets. Corn syrup will most likely continue to mal inroads on the demand for sugar until about 1985 when the situation is expected to stabilize (In *litt.*, 1983, William Case and Francis Morgan). In spite of the Federal Farm Act which provides price supports for domestic production, the Hamakua Coast mills collectively lost $140 million in 1981 and 1982.

In light of the existing economic climate, the sugar industry is currently examining all possible means of cutting operational costs. Without substantial success in this effort, the industry islandwide may eventually be forced into bankruptcy. One means of cutting costs for the Hamakua Coast mills is convincing the EPA to relax its standards regarding the discharge of mill wash water into the ocean. Regarding this effort, perhaps the most relevant question to ask is, Are the present EPA guidelines effective in minimizing environmental impact, and, if so, to what extent? The purpose of the 1983 survey was to provide an answer to this question. The approach was to repeat the survey done in 1971 (Grigg, 1972) in an identical manner so as to determine if zones of impact produced by pre-1980 discharge levels have been significantly reduced as a result of compliance with the EPA standards. The results are detailed in this technical report. An attempt is also made to estimate the size of the plumes and zones of impact that would develop should the standards for total suspended solids be completely relaxed at some time in the future.

METHODS

Stations were selected at locations directly off Pepeekeo, Ookala, and Haina sugar mills and at sites situated at progressively greater distances away from each mill until normal (background) conditions were encountered. Where possible, stations selected for the 1983 survey were the same as those used in the 1971 survey (Figure 1).

Pepeekeo, Ookala, and Haina sugar mills are the only mills operating along the Hamakua Coast at the present time. Since the 1971 study was completed, consolidation of sugar mills has resulted in the closure of five operations: Hamakua and Paauhau sugar mills in 1972, Hakalau Sugar Mill in 1974, Wainaku Sugar Mill in 1976, and Papaikou Sugar Mill in 1978. Although considerable consolidation has taken place, the amount of acreage devoted to sugarcane cultivation is roughly the same today as it was in 1971 (Tables 1, 2, and 3). Therefore, the total amount of sugarcane currently processed by the three mills combined is roughly equivalent to the volume harvested in 1971.

In addition to the sites off the three operating sugar mills, stations off Kolekole Stream and Hakalau and Papaaloa sugar mills were also surveyed. The station off Kolekole Stream was surveyed in order to compare the effects of sedimentation from natural run-off with impacts associated with sugar mill discharges. Since Hakalau and Papaaloa mills have been shut down for 8.5 and 17 years, respectively, these stations were surveyed to provide independent estimates of the rate of recovery of reef ecosystems along the Hamakua Coast.

At each station, data were collected on coral cover, coral and fish species diversity, and fish biomass. Methods used were the same as those employed in the 1971 survey (Grigg, 1972). Also, water quality in the vicinity of the mills was analyzed but not at pre-established stations. Stations for water quality were fixed according to the size and shape of plumes at the time the surveys were conducted. The plumes generated by mill discharges vary constantly in time and space according to tide, wind, swell, land run-off from rainfall, and possibly other factors. Water quality factors measured include temperature, salinity, oxygen concentration, oxygen saturation, turbidity (Secchi disk readings), and total suspended solids at the surface. Methods used for defining the plumes and sampling were the same as those employed in the 1975 BOD study by Grigg (unpublished manuscript).

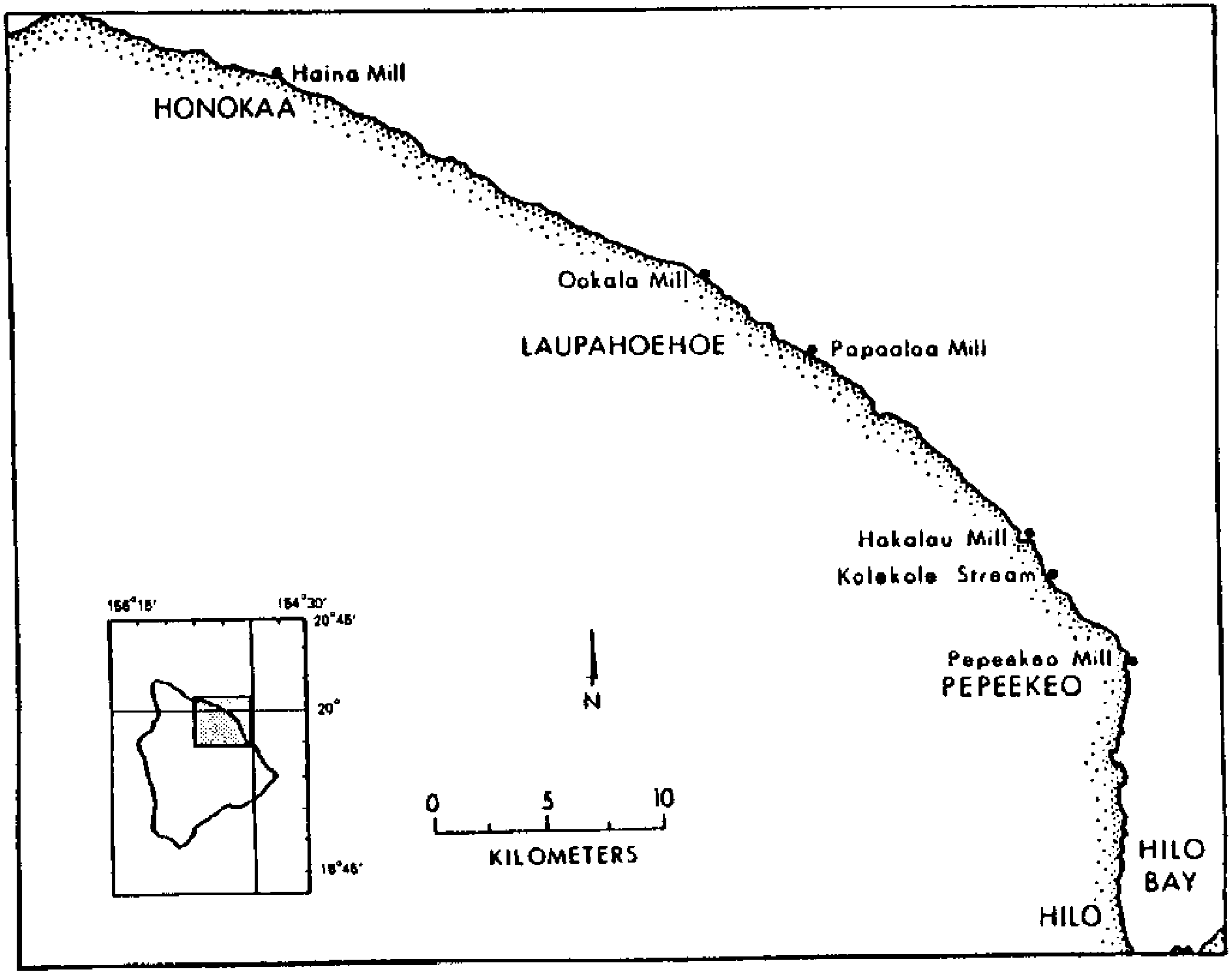


Figure 1. Location of mill and control sites used in the 1983 survey along the Hamakua Coast, Hawaii

TABLE 1. ANNUAL CANE PROCESSED AND SEDIMENT DISCHARGED BY PEPEEKEO SUGAR MILL BETWEEN 1971 AND 1982

Year	Cane (T)	Sediment Potential for Discharge (T)*	Actual Discharge	Actual / Potential	Percent Sediment Removed from Effluent
1971	705,189	56,415	--	--	0
1972	691,740	55,339	--	--	0
1973	579,600	46,368	--	--	0
1974	622,124	49,769	--	--	0
1975	994,968	79,597	--	--	0
1976	1,304,599	104,368	--	--	0
1977	1,555,710	124,456	--	--	0
1978	1,921,223	211,224	211,840	1.00	0
1979†	2,258,567	248,442	28,897	0.12	88
1980	1,968,903	216,579	14,075	0.06	94
1981	2,015,857	221,744	6,563	0.03	97
1982	2,242,156	246,637	48,056	0.19	81

*Based on 11 percent by weight of gross cane (Garvie Hall, T.H. Davies: personal communication)
†Year compliance with TSS guidelines went into effect

TABLE 2. ANNUAL GROSS CANE PROCESSED BY T.H. DAVIES HAMAKUA COAST SUGAR MILLS BETWEEN 1965 AND 1982

Year	Laupahoehoe*	Papaaloa	Hamakua	Paauhau	Honokaa†	Total
1965	291,000	280,000	478,000	392,000	587,000	2,028,000
1966	234,000	360,000	487,000	442,000	670,000	1,523,000
1967	681,000	--	470,000	437,000	583,000	2,171,000
1968	592,000	--	476,000	449,000	620,000	2,137,000
1969	588,000	--	396,000	375,000	610,000	1,969,000
1970	628,000	--	455,000	448,000	726,000	2,257,000
1971	634,000	--	424,000	372,000	579,000	2,009,000
1972	656,000	--	335,000	368,000	549,000	1,908,000
1973§	1,077,000	--	--	--	895,000	1,972,000
1974	945,000	--	--	--	879,000	1,824,000
1975	1,103,000	--	--	--	811,000	1,914,000
1976	1,184,000	--	--	--	933,000	2,117,000
1977	1,074,000	--	--	--	1,142,000	2,215,000
1978	1,362,000	--	--	--	1,400,000	2,762,000
1979	1,210,000	--	--	--	1,449,000	2,659,000
1980	1,079,000	--	--	--	1,500,000	2,579,000
1981#	889,000	--	--	--	1,006,000	1,183,000
1982**	1,206,000	--	--	--	1,440,000	2,646,000

*Ookala Sugar Mill after 1979
†Now known as Haina Sugar Mill
§Year Hamakua Sugar Mill consolidated with Laupahoehoe Sugar Mill and Paauhau Sugar Mill consolidated with Honokaa Sugar Mill to form Haina Sugar Mill
#Dry year
**Wet year

TABLE 3. ANNUAL SEDIMENT DISCHARGE* OF T.H. DAVIES HAMAKUA COAST SUGAR MILLS BETWEEN 1965 AND 1982

Year	Laupahoehoe†	Papaaloa	Hamakua	Paauhau	Honokaa§	Total
1965	26,190	25,200	43,020	35,280	52,830	182,520
1966	21,060	32,400	43,830	39,780	60,300	137,070
1967	61,290	--	42,300	39,330	52,470	195,390
1968	53,280	--	42,840	40,410	55,800	192,330
1969	52,920	--	35,640	33,750	54,900	177,210
1970	56,520	--	40,950	40,320	65,340	203,130
1971	57,060	--	38,160	33,480	52,111	180,810
1972	59,040	--	30,150	33,120	49,410	171,720
1973#	96,930	--	--	--	80,550	177,480
1974	85,050	--	--	--	79,110	164,160
1975	99,270	--	--	--	72,990	172,260
1976	106,560	--	--	--	83,970	190,530
1977	96,570	--	--	--	102,780	199,350
1978	122,580	--	--	--	126,000	248,580
1979	108,900	--	--	--	130,410	239,310
1980**	3,884	--	--	--	5,400	9,284
1981††	3,200	--	--	--	3,621	4,258
1982§§	4,341	--	--	--	5,184	9,525

*Based on 9 percent gross cane except after 1980 when compliance with EPA standards went into effect
†Ookala Sugar Mill after 1979
§Now known as Haina Sugar Mill
#Year Hamakua Sugar Mill consolidated with Laupahoehoe Sugar Mill and Paauhau Sugar Mill consolidated with Honokaa Sugar Mill to form Haina Sugar Mill
**Year compliance went into effect
††Dry year
§§Wet year

Bathymetric profiles were taken using a standard depth recorder off Kolekole Stream and Pepeekeo and Hakalau mills in order to compare the offshore slopes and sedimentation patterns of a natural stream with those associated with sugar mill discharges.

Interviews with fishermen residing in the Hamakua area were conducted in order to assess the effects of mill discharges in terms of social impacts on commercial and recreational fishing interests. Responses are presented in the Appendix.

All data presented in this report were collected between June and August 1983. Dates of specific surveys are given in the text, tables, and figures.

RESULTS

Benthic ecosystems, plume dimensions, and offshore bathymetry

Measures of coral cover, coral and fish diversity, and fish biomass all showed clear and consistent patterns around the three operating sugar mills (Figures 2, 3, and 4). Each index exhibited a gradient of biotic depletion extending outward and along the coast for approximately 1 mile or less, ranging from essentially zero off the mill sites to background values at the perimeter of influence. Along the Hamakua Coast normal levels for the number of coral species and common fish are about 10 and 40 species, respectively. Normal

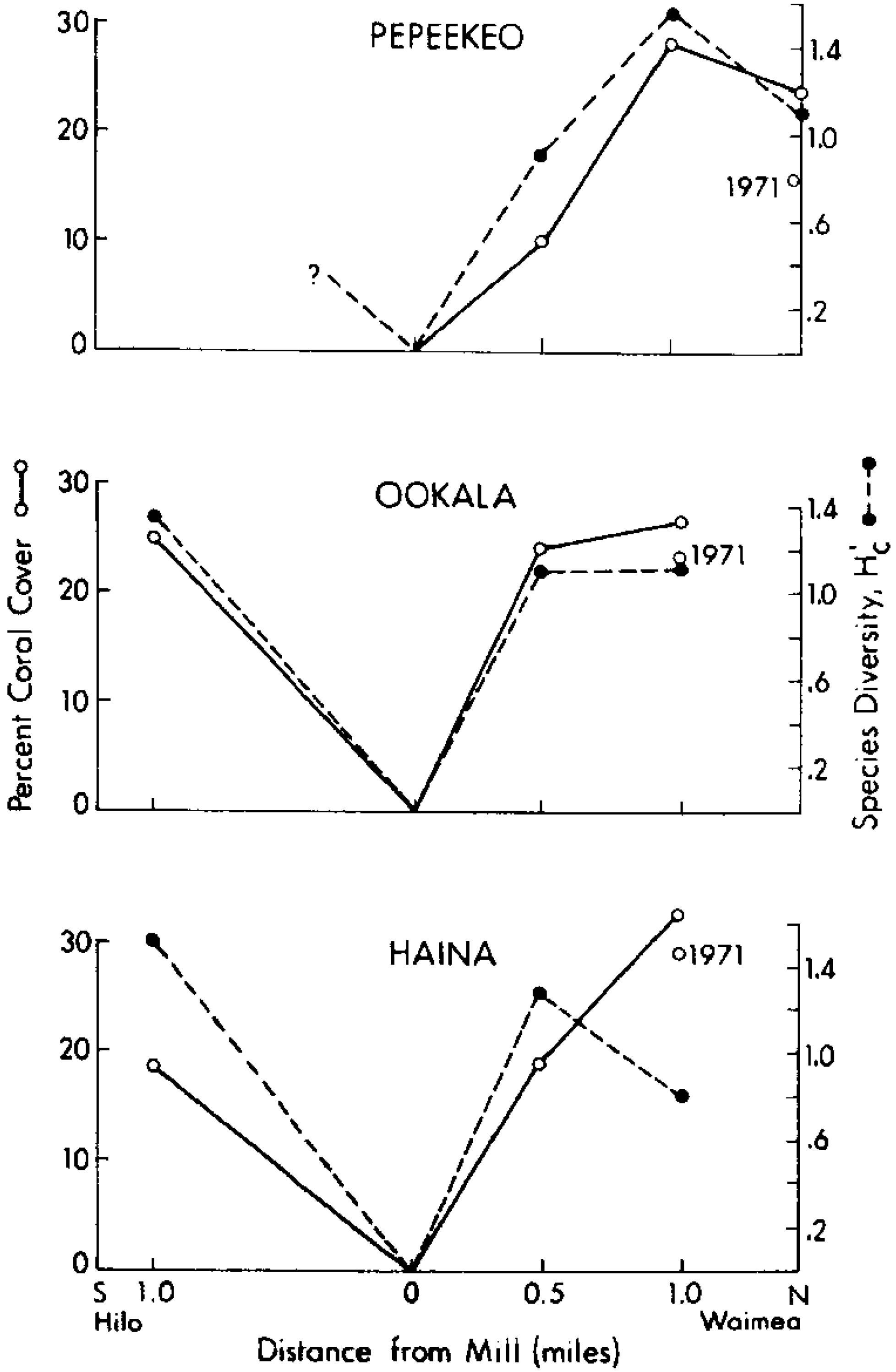


Figure 2. Percent coral cover and diversity of coral for Pepeekeo, Ookala, and Haina stations in 1983 (all stations). Values for 1971 are given only for coral cover at control stations to show differences between the 1971 and 1983 surveys.

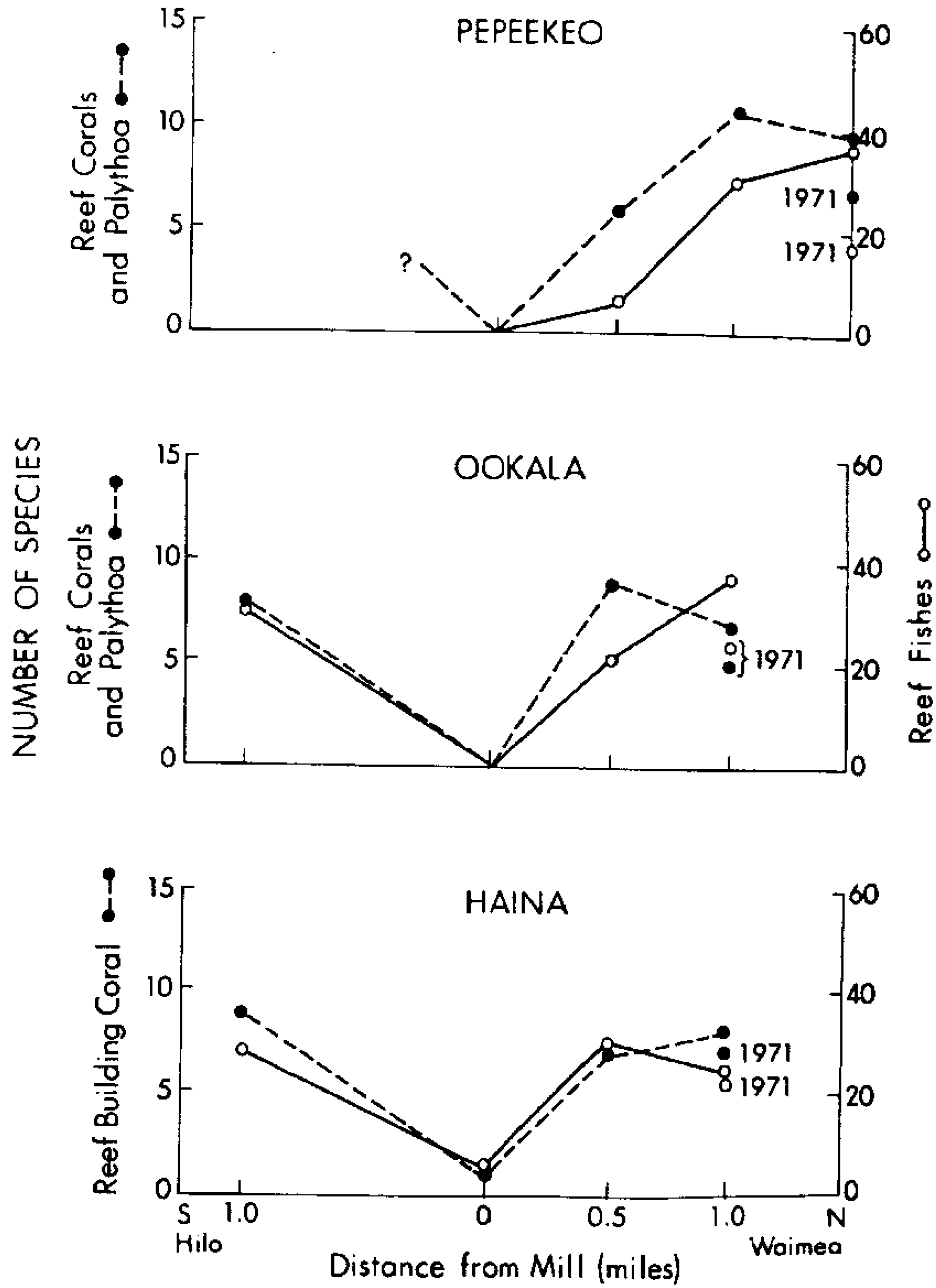


Figure 3. Number of species of coral and fish off Pepeekeo, Ookala, and Haina stations in 1983 (all stations). Values for 1971 are given only for control stations to show differences between the 1971 and 1983 surveys.

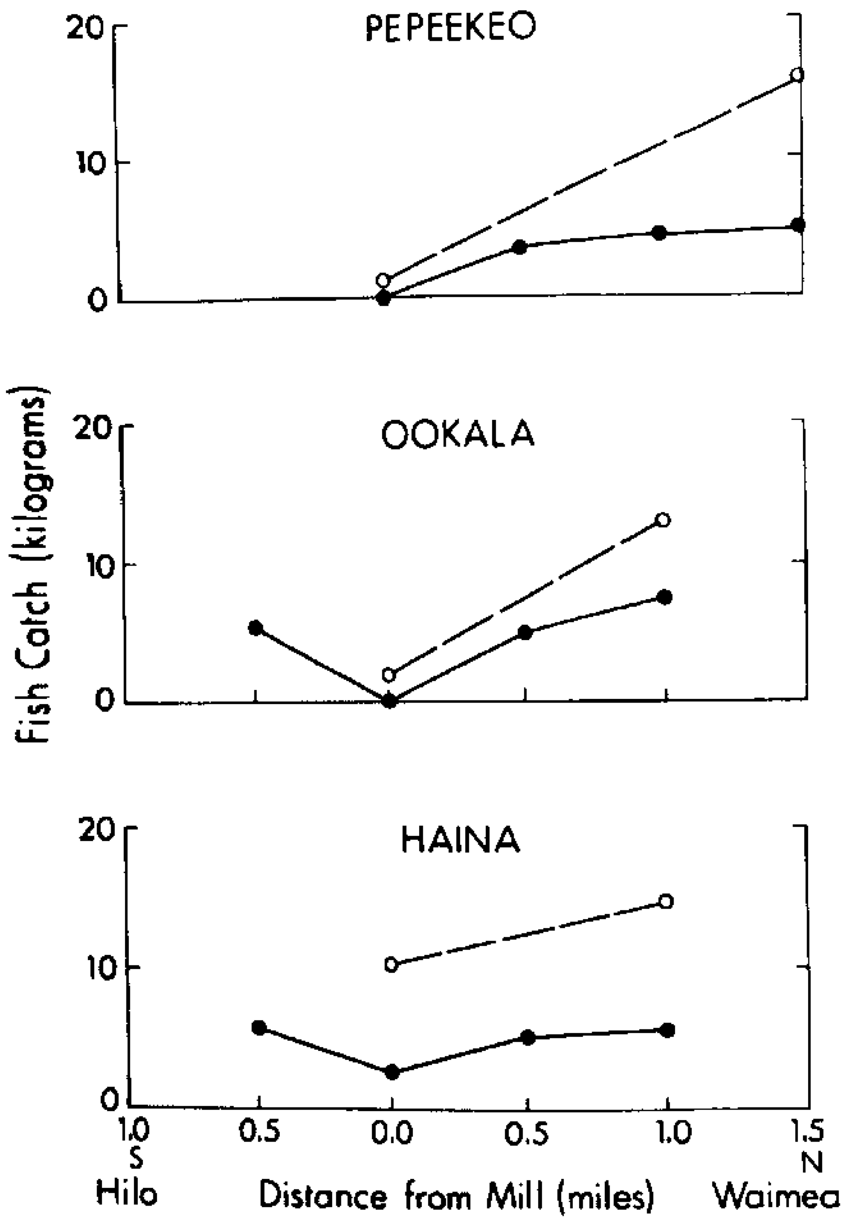


Figure 4. Catch of reef fish off Pepeekeo, Ookala, and Haina stations in 1971 and 1983

coral cover in the areas unaffected by discharges from mills or natural streams is quite variable, but averages about 30 percent. These numbers can be taken as representative of background values that would exist along the coast if the mills were not present. Hence, they can be used as standards against which patterns of biotic depletion can be compared.

The zone of measurable impact off Pepeekeo mill was measured only along the coast to the north. An equivalent zone to the south was not measured because the habitat south of Pepeekeo mill changes from open coast (Hamakua Coast) to sheltered coast (Hilo Bay). Moving north from the discharge site, the number of species of coral and fish, as well as coral cover and fish biomass, gradually increased until normal values were encountered at a distance of about 1 mile. A pattern similar to the one off Pepeekeo mill was found off Ookala and Haina mills, with zones of measurable impact ranging from 0.5 to 1.0 mile on both sides of each mill. Impacts off both Ookala and Haina mills were more pronounced on their northwest side (downcoast) (Figures 2, 3, and 4).

Comparing the Ookala and Haina data for coral cover, coral diversity, coral and fish species number, and fish biomass with the same parameters for Pepeekeo mill showed that the zones of measurable impact for the former two mills are slightly smaller than that for the latter (between 0.5 and 1.0 mile compared with 1.0 mile).

Visual observations of sediment accumulation on the bottom were made at each station. The only areas where thick sediment deposits were observed were directly off the mill sites and natural streams. No trash, bagasse, or other fibrous material was observed at any site during the 1983 survey. Neither were anerobic muds nor methane-producing deposits found off the mill sites as they were in 1971 (Grigg, 1972). The degree of biotic depletion within zones of mill impact correlated well with the thickness of sediment accumulations on outcropping rocks. Where accumulations were thick, benthic communities were severely reduced. Conversely, where sediments were sparse, benthic communities were healthy and abundant.

Plume boundaries associated with all three operating sugar mills rarely extended beyond 1.0 mile (Figures 5, 6, 7, 8, and 9). A plume boundary was defined as the point in the plume where the concentration of TSS is 10 percent of the values immediately off the discharge site. The shape of the plumes was highly variable, depending primarily on tidal stage and wind. During ebb tide, the plume off Pepeekeo mill trends toward Hilo, but at a sluggish rate (~5 cm/sec). As the tide begins to flood, the flow reverses direction and is more vigorous. It generally follows the coast to the north or drifts out to the northeast, moving at an average speed of about 10 cm/sec. The same pattern exists off Ookala and Haina mills, although it is even more asymmetric in favor of northwesterly flow down the coast. During periods of strong tradewind the flow toward Hilo during ebb tide may not develop at all, apparently because the wind-driven component of the longshore current to the northwest is stronger than the tidal component.

Within the plumes, no significant changes occurred in water temperature, salinity, oxygen concentration, and/or oxygen saturation. Often there were slight elevations in temperature (~1.0 degree C), depressions in salinity (1 to 5 ppt), and decreases in oxygen concentration (0 to 7 percent oxygen saturation) in the immediate vicinity of the mills (within 200 m of the discharge); but none of these changes is significant in terms of inducing stress to marine life (see Grigg, unpublished manuscript, for a more complete discussion). In contrast, levels of suspended solids (up to 10 times background levels) were very significant within the plumes; they impacted the nearshore benthic biota by causing increased rates of sedimentation and a marked reduction in light. Secchi disk readings within the plumes often varied between 0 and 15 feet compared with readings of more than 50 feet in unaffected

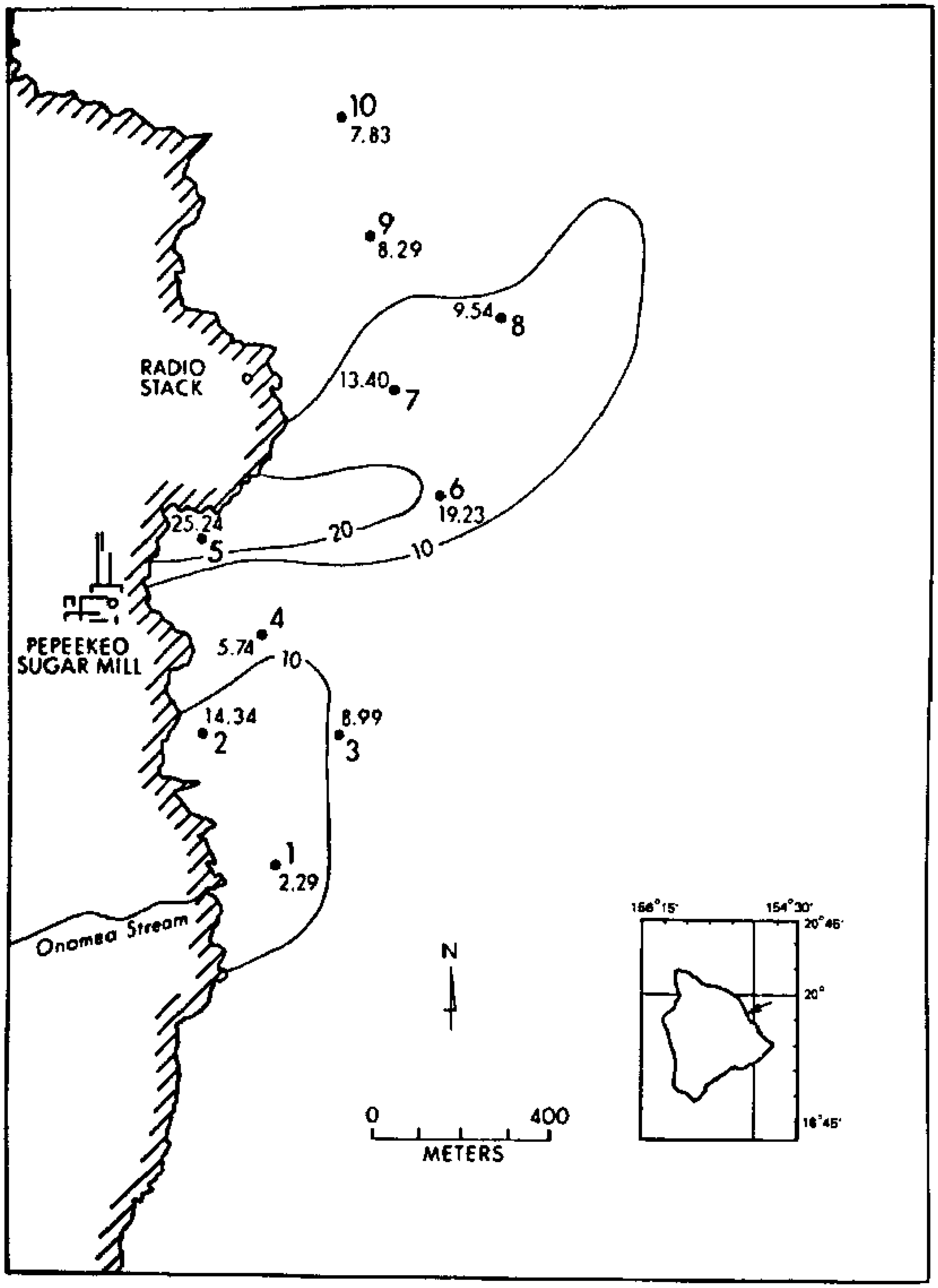


Figure 5. Total suspended solids (mg/l) off Pepeekeo Sugar Mill, June 29, 1983; also shown is influence from Onomea Stream south of mill

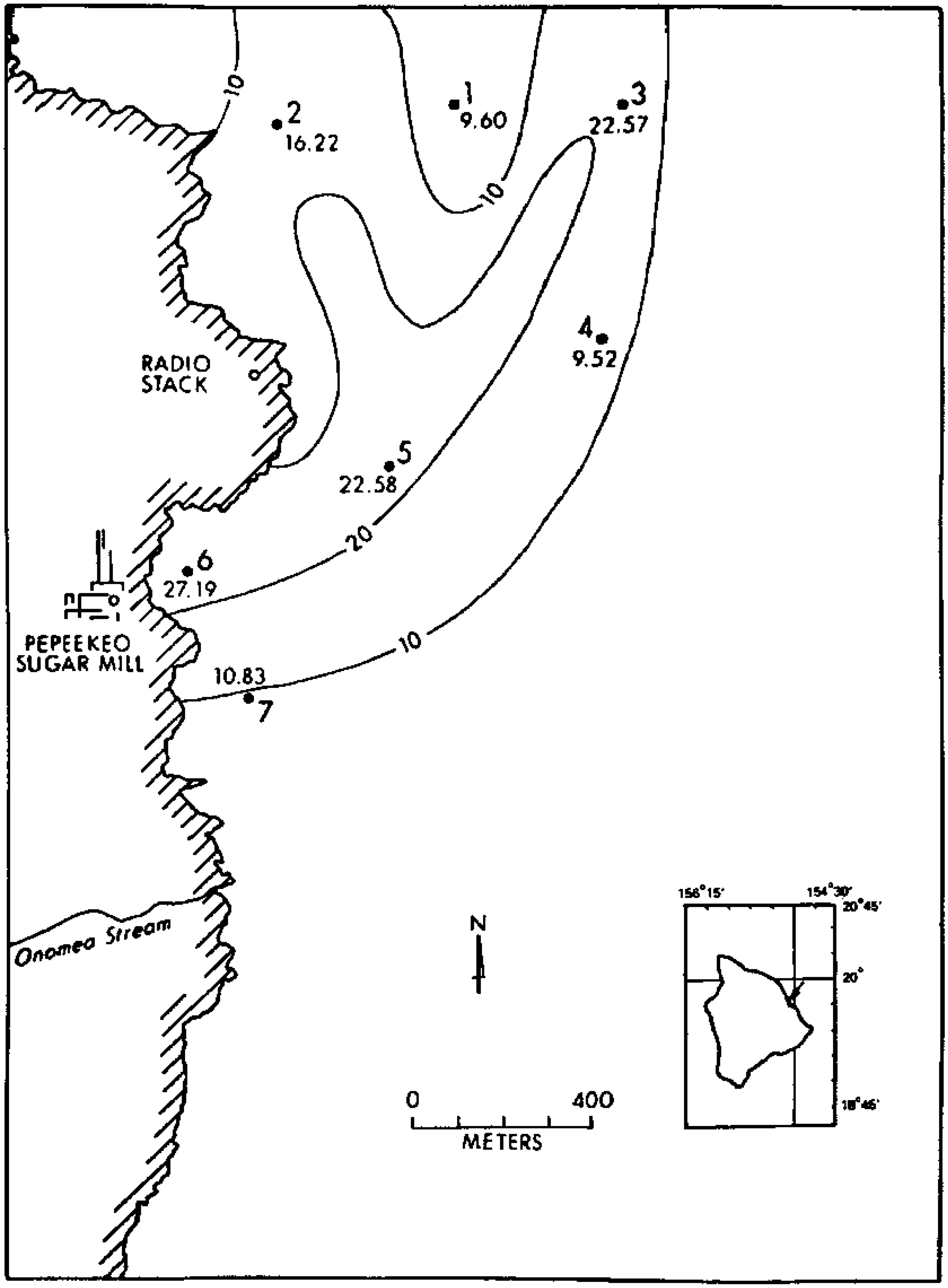


Figure 6. Total suspended solids (mg/l) off Pepeekeo Sugar Mill, July 2, 1983

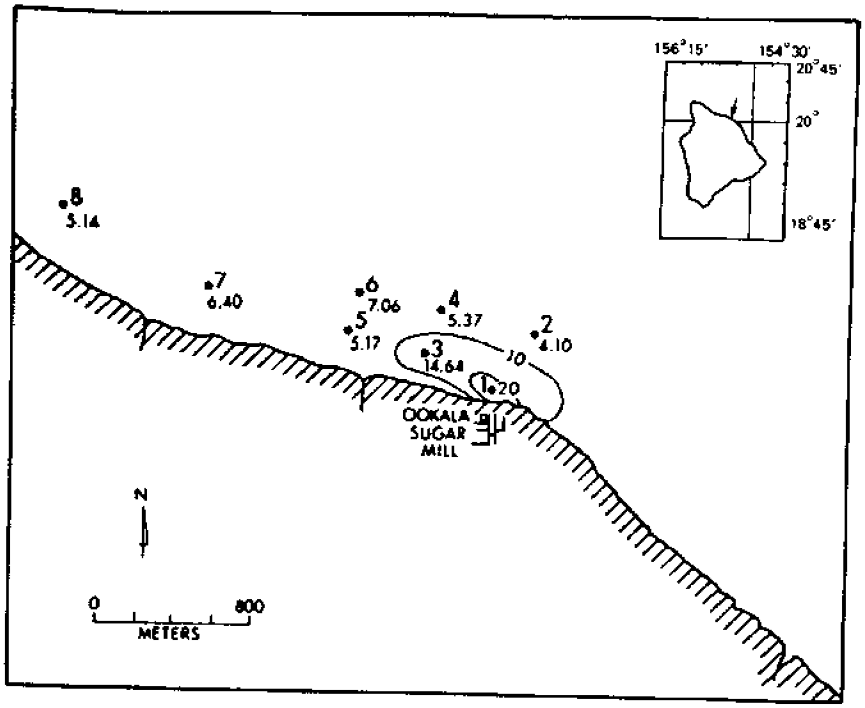


Figure 7. Total suspended solids (mg/l) off Ookala Sugar Mill, June 4, 1983

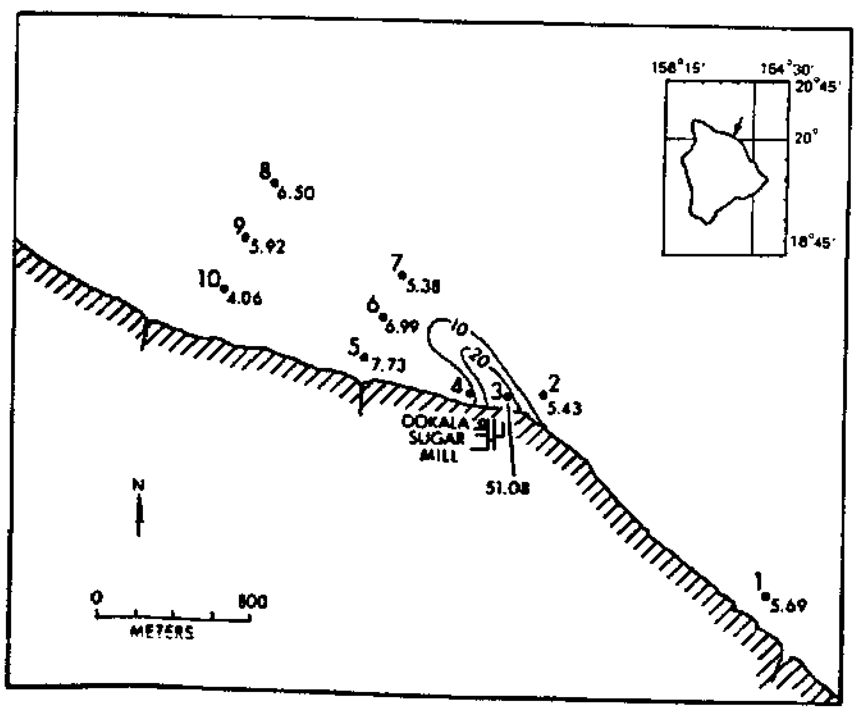


Figure 8. Total suspended solids (mg/l) off Ookala Sugar Mill, June 30, 1983

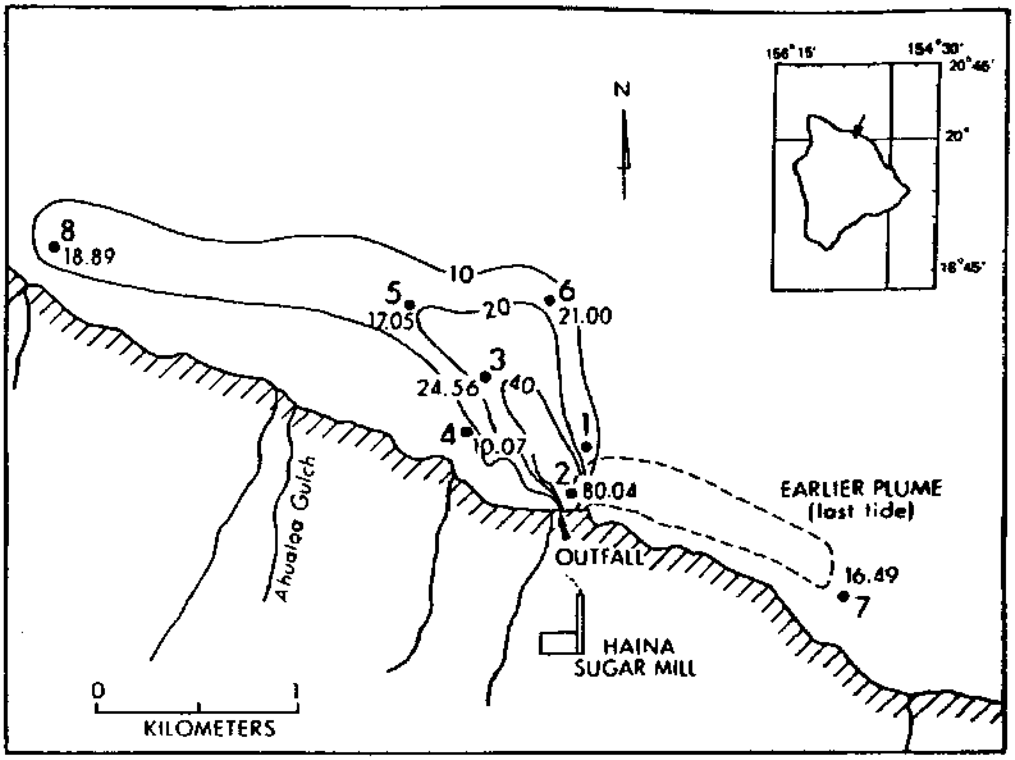


Figure 9. Total suspended solids (mg/l) off Haina Sugar Mill, July 1, 1983

water (Tables 4, 5, and 6). Zones of measurable benthic impact along the coast roughly corresponded to the average position and intensity of the overlying plume water, suggesting a cause-and-effect relationship.

The plumes tended to be somewhat stratified due to slight temperature elevations and salinity depressions, both of which serve to reduce the density of the surface layer. Suspended solids (concentration) consistently decreased with depth. Oxygen concentration also decreased with depth, but not to the extent of approaching critical levels for marine life. Aside from the thin layer of stratified water near the surface, the water column within the plumes was generally well mixed. These features of the plumes are also described in the Kennedy Engineers report (1967), the Burm report (EPA, 1971), and the Grigg 1975 study (unpublished manuscript).

TABLE 4. WATER QUALITY OFF PEPEEKEO SUGAR MILL, JUNE 29, 1983

Station	Distance from Mill (m)	Direction	Temperature (°C)	(O_2)	Oxygen Saturation	Secchi Disk (ft)	Total Suspended Solids (mg/L)	Salinity (ppt)
1-0	800	SE	24.8	6.72	99.0	50+	--	30.0
1-5			25.1	6.74	99.2			
2-0	400	SSE	24.8	6.71	99.0	30	--	26.5
2-5			24.9	6.67	98.7			
3-0	600	SE	24.8	6.83	100	50	--	29.5
3-5			25.0	6.72	99.1			
4-0	375	SE	24.9	6.71	99.1	15	--	32.5
4-5			25.0	6.63	97.7			
5-0	150	ENE	24.8	6.50	96.0	1.5	--	31.5
5-5			25.0	6.50	96.0			
6-0	700	E	25.1	6.44	95.4	3	--	32.0
6-5			25.1	6.49	96.1			
7-0	800	NE	25.0	6.66	98.8	6	--	33.0
7-5			25.2	6.62	98.2			
8-0	1,000	NE	24.6	6.74	99.1	12	--	33.5
8-5			24.8	6.70	98.6			
9-0	1,000	NNE	24.8	6.73	99.4	28	--	33.5
9-5			24.9	6.68	98.5			
10-0	1,200	NNE	25.0	6.71	98.8	33	--	33.5
10-5			24.9	6.64	97.8			

TABLE 5. WATER QUALITY OFF OOKALA SUGAR MILL, JUNE 30, 1983

Station	Distance from Mill (m)	Direction	Temperature (°C)	(O_2)	Oxygen Saturation	Secchi Disk (ft)	Total Suspended Solids (mg/L)	Salinity (ppt)
1-0	1,600	SE	24.7	6.94	102.3	50	5.69	32.5
1-5			24.8					
2-0	200	NE	25.0	6.48	96.6	33	5.43	33.0
2-5			25.1	6.62	97.5			
3-0	100	N	25.0	6.65	98.3	1.5	51.08	32.0
3-5			24.9	6.68	98.9			
4-0	200	WNW	24.9	6.75	99.5	15	6.18	33.0
4-5			24.8	6.75	99.5			
5-0	750	WNW	25.0	6.70	99.2	21	7.73	33.0
5-5			24.8	6.63	98.1			
6-0	800	WNW	24.8	6.86	100.8	8	6.99	32.5
6-5			24.9	6.81	100.2			
7-0	900	NW	24.9	6.81	100.6	50	5.38	34.5
7-5			24.9	6.76	100.0			
8-0	1,700	NW	24.8	6.82	100.5	50	6.50	34.0
8-5			24.8	6.79	100.0			
9-0	1,600	WNW	24.8	6.74	99.7	16	5.92	32.5
9-5			24.8	6.74	99.7			
10-0	1,700	WNW	24.7	6.81	100.1	50	4.06	32.5
10-5			24.7	6.73	99.3			

TABLE 6. WATER QUALITY OFF HAINA SUGAR MILL, JULY 1, 1983

Station	Distance from Mill (m)	Direction	Temperature (°C)	(O_2)	Oxygen Saturation	Secchi Disk (ft)	Total Suspended Solids (mg/L)	Salinity (ppt)
1-0	400	N	24.1	6.80	98.6	6	13.47	32.5
1-5			24.1	6.70	97.6			
2-0	100	N	24.2	6.74	98.3	1	80.04	28.0
2-5			24.2	6.66	97.3			
3-0	750	NW	24.0	6.74	98.2	4	24.56	32.0
3-5			24.1	6.74	98.2			
4-0	700	W	24.1	6.74	98.3	13	10.07	32.5
4-5			24.1	6.75	98.4			
5-0	1,250	NW	24.2	6.96	101.2	50	17.05	33.0
5-5			24.2	6.82	99.5			
6-0	1,000	N	24.2	6.83	99.8	16	21.00	33.5
6-5			24.3	6.72	98.3			
7-0	1,600	E	24.1	6.83	99.6	50	16.49	32.5
7-5			24.2	6.77	98.8			
8-0	3,000	NW	24.6	6.87	101.1	50	18.89	33.0
8-5			24.6	6.86	100.8			
9-0	1,600	WNW	24.8	6.74	99.7	16	5.92	32.5
9-5			24.8	6.74	99.7			
10-0	1,700	WNW	24.7	6.81	100.1	50	4.06	32.5
10-5			24.7	6.73	99.3			

Plumes associated with natural streams can be as large as those caused by sugar mills. No periods of sampling corresponded with periods of heavy rainfall, so it was not possible to track stream plumes in the same manner as sugar mill plumes. Instead, bathymetric profiles were used. Comparing the nearshore shelves off natural streams with those off mill sites showed that streams contribute enormous quantities of sediment to the ocean (Figure 10). The bottom profile off Kolekole Stream revealed that the bathymetry is gently sloping (~1.5 degrees) and uniform, whereas the profiles off Pepeekeo Sugar Mill and the old Hakalau Sugar Mill sites exhibited much steeper and more irregular terrain. The accumulation of sediment off natural streams has occurred over a much longer period than off the mill sites but, in terms of the relative effect on the environment, the important point to consider is how the environment has been modified. Thicker and more massive sediment aprons exist off large streams than off mill sites. Also, the zone of measurable impact for at least Kolekole Stream is as large as it is for mill sites (Grigg, 1972). Shallow outcrops of rock which supported low standing crops of coral and reef fish observed off Kolekole Stream in 1971 were entirely covered with sediment during the 1983 survey, illustrating the continuous nature of the discharge of sediment from natural streams and its impact on the environment.

Recovery of benthic ecosystems off closed sugar mills

Data collected during the 1971 survey showed that benthic ecosystems off closed sugar mill sites begin recovery almost immediately, given no other source of perturbation (Grigg, 1972). For example, in 1971, corals off Papaaloa mill (closed in 1966) showed about 4.5 years of growth. The Papaaloa site was again analyzed in 1983 and the results indicate that recovery was then complete in terms of percentage of coral cover (29 percent), size of largest colonies of corals, and number of species of coral and fish (8 and 10 respectively).

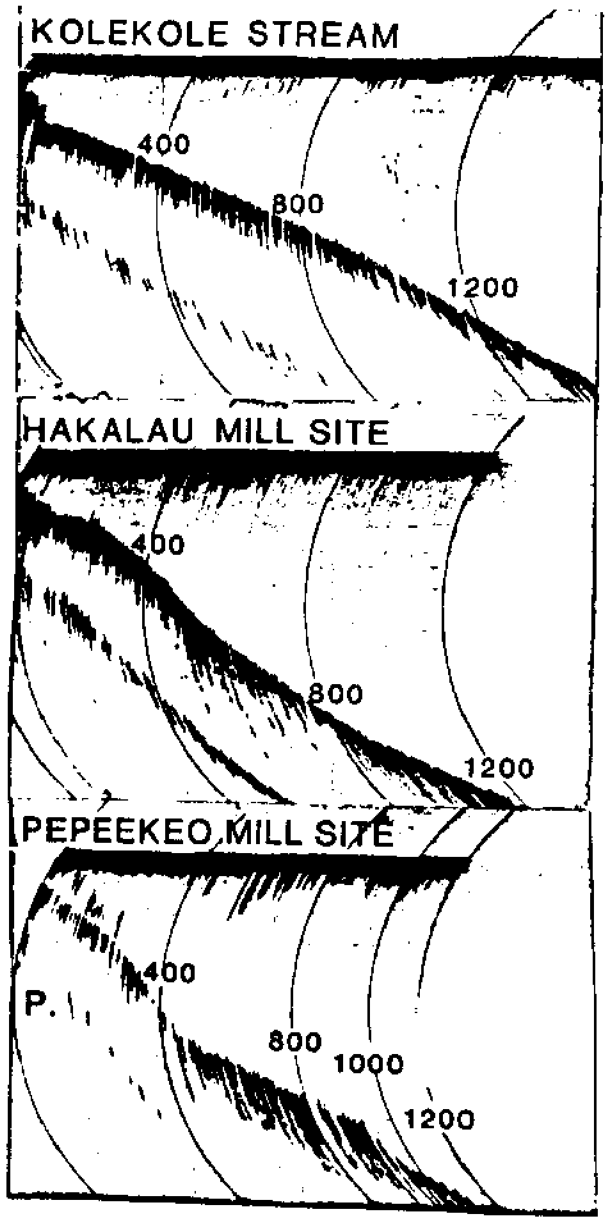


Figure 10. Bathymetric profiles off Kolekole Stream, the old Hakalau Sugar Mill site, and Pepeekeo Sugar Mill. Horizontal scale is 1,600 meters, vertical is 40 fathoms. Of the three sites, sediments off Kolekole Stream are thickest.

Seventeen years had elapsed since Papaaloa Sugar Mill was closed, and, because the recovery process was complete, this figure can be taken as a conservative estimate of the recovery time for benthic ecosystems in this type of habitat. Existing impacts to corals and other benthos, including reef fish, caused by sugar mill discharges along the Hamakua Coast can therefore be viewed as reversible and temporary.

Whether or not a given site actually recovers after mill shutdown depends on the degree to which it is free from natural disturbance. The station off Hakalau is a case of low recovery. Hakalau Sugar Mill was shut down 8.5 years ago and yet almost no recovery has occurred. Coral cover in 1983 was only 6 percent compared with 30 percent which is normal for the Hamakua Coast. After 8.5 years, the numbers of species of coral (8) and fish (25) off Hakalau were also low. The apparent cause of the low rate of recovery at Hakalau is probably the presence of a natural stream whose discharge enters the ocean at almost the same point as the former mill discharge. The bottom off Hakalau continues to be heavily coated with accumulations of sediment.

Reef fish behavior

Patterns of change in overall abundance of fish (species and biomass) are described above in the section on benthic ecosystems. In this section, observations which relate to the behavior of specific fishes relative to the sugar mills are discussed.

In 1971, it was noted that certain species groups of fish were either less or more abundant than normal within zones of mill influence. Various reasons were cited, such as habitat alteration and prey availability (Grigg, 1972). In the 1983 survey the same patterns were evident. Butterflyfish were conspicuously absent near the mills to the extent that the number of species of these fish might serve as an index of the intensity of mill impact. Other species or species groups observed to be absent or rare include the parrotfishes, hawkfishes, damselfishes, wrasses, and squirrelfish.

The most notable species observed to be more abundant than normal were moi (*Polydactylus sexfilis*) and papio (*Caranx ignobilis*). Both of these species may be attracted to the mill plumes by prey which are less abundant elsewhere. According to local fishermen, moi are attracted to mill areas because of the presence of infaunal prey (shrimp) that find mill sediments to be good habitat. Papio apparently are attracted by the abundance of nehu (*Stolephorus purpureus*) and other prey which in turn may seek plume waters for shelter.

In general, the local fishermen look upon the mills along the Hamakua Coast as an added resource (habitat area) for recreational fishing (see Appendix). Without the mills they would have no place to fish for moi and, to a lesser extent, for papio, oio (*Abula vulpes*), and awaawa (*Elops hawaiiensis*). As for other species, they can be caught along the rest of the coastline not impacted by mill plumes.

One fisherman interviewed in 1983 considered offshore bottomfishing for onaga (*Etelis coruscans*) and opakapaka (*Pristipomoides filamentosus*) to be negatively impacted by mill discharges. No data exist to either support or refute this contention. However, it has been determined that, in the last decade, bottomfishing has declined everywhere in the state in an apparent response to overfishing (Ralston, 1984).

With regard to the fish data obtained in 1971, two rather significant differences were evident when compared with the 1983 data. First, fish catches at every station were about 50 percent of what they were in 1971. Second, and in apparent contradiction to the first difference, the number of species of fish increased markedly at normal stations. Neither of these differences, however, appears to be directly related to mill impacts. The first is probably due to a general decline statewide in the abundance of reef fish as a result of overfishing (Division of Aquatic Resources, State of Hawaii, 1979). The author attributes the second difference to observer training, i.e. simply recognizing more species.

DISCUSSION AND CONCLUSIONS

The differences between the zones of measurable impact off Pepeekeo, Ookala, and Haina sugar mills between 1971 and 1983 are very slight (Figures 2, 3, and 4). There have been small increases in coral cover (4 to 8 percent) and the numbers of coral and fish species have increased slightly, but these changes are not considered significant. This result is surprising in view of the rather large changes in the amount of sediment discharged, at least in the cases of Ookala and Haina mills. In 1971, Pepeekeo mill discharged 56,415 tons of sediment compared with 48,056 tons in 1982 (Table 1). The discharge figures for Ookala and Haina mills in 1971 and 1982 are 57,060 tons versus 4,341 tons and 52,111 tons versus 5,184 tons, respectively (Tables 2 and 3). The discharge volumes at Ookala and Haina are down by a factor of 10, which is a consequence of being in compliance with the EPA's 3.6 lb/1,000 lb standard. Compliance at Pepeekeo in 1980 and 1981 was good, but in 1982 wet weather increased the sediment load of the cane substantially.

The lack of difference between the 1971 and 1983 zones of measurable impact off Pepeekeo is not surprising. In fact, this might be expected in view of the similarity in sediment discharge volumes in 1971 and 1983 (actual figures for 1983 are unavailable, therefore 1982 sediment load figures were used). What is surprising is the similarity in zones of measurable impact off Ookala and Haina mills in the 2 comparative years, given the large reduction in discharge (10x) that took place. This finding raises an important question as to the efficacy of the existing standards. Interestingly, the zones of measurable impact in 1971 before the imposition of EPA standards were all (as they are now) within existing zones of mixing established by current permits (Table 7). In 1983 the existing standards had been in effect for almost 3 years and, in view of the rate of recovery experienced off Papaaloa mill (complete recovery in 17 years), one would expect a larger response to be evident if the standards were working. The lack of a significant difference between 1971 and 1983 for Ookala and Haina mills suggests that the existing standards are not effective in reducing zones of impact.

TABLE 7. PERMITS AND EXISTING ZONES OF MIXING FOR HAMAKUA COAST SUGAR MILLS

Mill	Permit	Zone of Mixing
Pepeekeo	HI-0000191	Arc with radius of 1 mile from point of discharge into the ocean
Ookala	HI-0000159	Rectangle 1.5 miles to the northwest, 1.5 miles to the southeast, and 1 mile offshore
Haina	HI-0000256	Rectangle approximately 2 miles to the northwest, 1 mile to the southeast, and 1 mile offshore

The reason for this may be related to the behavior of the plumes and the settling velocities of total suspended solids. In general, it was found that the plumes oscillate in flow direction as a function of tidal state, reversing their direction approximately every 6 hours. Given the average velocity of the plumes (about 10 cm/sec), this means that they travel about 1 mile before reversing direction. After reversal, the plume extremities often drift out to sea while at their origin, the plumes are constantly renewed due to continuous discharge. Thus, in the course of a single day, the trajectory of a given particle would be expected to remain within about 1 mile of the discharge point, and all particles 15 microns and larger in diameter would be expected to settle to the bottom at depths of less than about 20 m (Table 8). This would account for about 60 percent of the sediment discharged (EPA, 1969). The very fine sediments less than 15 microns in diameter remain in suspension for much longer periods (Table 8) and would therefore not be expected to settle out before they reach deep water. This would explain why zones of measurable impact, irrespective of sediment discharge loads, are approximately 1 mile in horizontal extent along the coast. Significant accumulation of sediment on outcropping rocks was observed to be limited to areas within 1 mile of the mill sites, except in instances where large streams were present within the zones of impact.

TABLE 8. SETTLING VELOCITY OF SEDIMENT PARTICLES (QUARTZ SPHERES)

Sediment Type	Size (μ)	Settling Velocity (m/day)
Coarse Sand	1,000	14,400
Medium Sand	250 - 500	3,600
Fine Sand	62 - 125	300
Silt	30	75
	15	20*
	8	5
	4	1.0
Clay	2	0.3
	1	0.07
	0.5	0.02
	0.25	0.004
	0.12	0.001

Source: Sverdrup et al., 1940

*Approximate 1-day threshold for settling in shallow water $<$20 m

The corollary to the above argument is that increasing the sediment load of present discharges may do little to change existing zones of impact. Sediment that would be added — were the standards of TSS to be relaxed — would be that fraction which is currently removed by hydroseparators and settling ponds. It turns out that this fraction of the sediment is the most coarse (heaviest) and would be expected to settle out first. The fine sediments would then be left as they are now to define the existing limits of measurable impact (approximately 1 mile).

If the existing standards were relaxed, the increase in sediment loads of operational mills should also be considered. In the case of Pepeekeo Sugar Mill, the sediment load discharged into the sea would increase by approximately four times the 1971 and present rates. For Ookala and Haina mills, sediment discharge would be about double the 1971 levels (Tables 2 and 3). In view of the behavior of the plumes and the settling velocities of suspended solids as discussed above and the fact that the zone of measurable impact for Ookala and Haina has not changed significantly with a decrease in sediment discharge by a factor of 10, it is unlikely that a doubling or even quadrupling of sediment discharge would lead to a dramatic increase in plume size and zone of impact. At worst, the zone of measurable impact might increase by 50 percent. If this were to occur, the respective zones of impact off Ookala and Haina mills would still be in compliance with existing permit requirements (Table 7). Only at Pepeekeo mill would the zone of impact have to be expanded by 0.5 mile — from 1 to 1.5 miles downcoast.

Should the standards be relaxed, approximately 9 miles of coastline along the Hamakua Coast would be dedicated to the assimilation of sugar mill wastes. This compares with about 16 miles in 1971 when 5 more mills were operating. For the Hamakua Coast, 9 miles is 20 percent of the coastline, but for the coastline of the island of Hawaii (303 miles) it is only 3 percent.

One alternative to relaxation of the EPA standards would be to totally ban the discharge of all sediment into the sea. If taken, this action would result in the restoration of approximately 6 miles of coastline to a normal condition in about 15 years. The added cost of pollution control, however, would probably eventually force the mills into bankruptcy. Were this to happen, about 2,300 people employed by the sugar industry would lose their jobs immediately and about 4,000 others, whose jobs depend indirectly on the industry, would be displaced. Unemployment on the island of Hawaii would jump to about 17 percent (In *litt.*, 1982, Howard Nakamura). Also, if the mills were closed down, the capacity for producing about 40 percent of the electricity for the island would be lost.

Considering the environmental benefits of closing the Hamakua Coast sugar mills, as discussed above, 6 miles of the impacted coastline would eventually revert to normal. In this regard, it is important to distinguish what is normal along the Hamakua Coast as compared with the more luxuriant reefs in sheltered environments along the Kona coast. Hamakua Coast ecosystems are not true reefs but rather consist of thin veneers of coral on volcanic substrates. Coral coverage averages about 30 percent and coral and fish species number about 10 and 40, respectively. As such, Hamakua Coast coral ecosystems must be considered somewhat marginal. This condition is due to the coastline's exposure to high waves and scour from sediments discharged from natural streams.

Along the entire Hamakua Coast, there are 54 major streams which continuously discharge sediment into the sea. Fifty-two of these are bridged by the main highway between Waimea and Hilo. Rainfall along the Hamakua Coast ranges from an average of 150 inches per year at Pepeekeo mill to about 70 inches per year at Haina mill (Department of Geography, University of Hawaii, 1973). Ookala mill averages about 125 inches per year. The discharge of sediment from all of the streams along the Hamakua Coast has been estimated to be about 180,000 tons in an average year (El-Swaify and Cooley, 1980; El-Swaify et al., 1982). In a wet year, sediment discharge by natural streams may exceed 560,000 tons (John Bedish, U.S. Soil Conservation Service: personal communication). These figures can be compared with the total sediment discharged by the mills. In 1978, the year before compliance with EPA standards for TSS went into effect, 459,000 tons of sediment were discharged by Pepeekeo, Ookala, and Haina mills collectively (Tables 1 and 3). Thus, the discharge by natural streams is on the order of one-half the mill discharge in average years, but may exceed mill discharge during wet years. Moreover, discharge by natural streams into the sea is by way of 54 outlets compared with only 3 for the mills. Associated impacts from stream sediment discharge are therefore spread out over the entire coast viz-a-viz only about 6 miles for the mills. Sedimentation from natural streams and wave scour appear to be the major factors limiting the development of reefs to low cover coral crusts along the Hamakua Coast.

In conclusion, the major finding of this study is that, with the exception of bagasse removal, the present discharge regime offers no real or significant ecological advantages or improvement over practices used in 1971. Mats of bagasse no longer clog and smother rocky bottom habitats. Also, mats of bagasse on the ocean surface no longer foul fishing boats and fishing gear.

If the existing standards for total suspended solids (3.6 lb/1,000 lb gross cane, monthly average) were to be completely relaxed, the plumes would probably enlarge slightly and zones of impact might increase from 1 to 1.5 miles downcoast of each mill. This would increase the length of coastline impacted from about 6 miles at present to about 9 miles.

A final consideration regarding the increase of discharge rates for the mills might be the question of health. Mill discharges are known to contain high counts of coliform bacteria (Kennedy Engineers, 1967). However, it was discovered by Kennedy Engineers that dilution and die-off of coliform bacteria are very rapid in the sea. Studies of the Honokaa mill discharge in 1967 (discharge rate = 52,000 tons, Table 3) showed that counts had dropped to background levels within 0.5 mile of the mill. Recreational use of waters within this distance of the mills during periods of grinding is virtually nil. Therefore, the question of health hazard from coliform bacteria does not appear to be a problem.

In summary, the major conclusions of this study are as follows:

1. A gradient of biotic depletion in reef ecosystems extends outward approximately 1 mile along the coast from each sugar mill studied, ranging from essentially zero off the mill sites to background values at the perimeter of influence.

2. The degree of biotic depletion is correlated positively with the thickness of the sediments.

3. Sugar mill plumes rarely extend beyond 1 mile. They are best characterized by suspended solids.

4. Zones of measurable benthic impact roughly correspond to plume dimensions, suggesting a cause and effect relationship.

5. Natural plumes and zones of benthic impact for major streams are as large as for sugar mills.

6. Recovery of benthic ecosystems off Papaaloa mill is complete, 17 years after closure, illustrating that mill impacts are reversible and temporary.

7. Differences in zones of impact in 1983 — 3 years after the guidelines for TSS were imposed by EPA and the state of Hawaii — and in 1971, when no standards were in effect, are insignificant. This suggests that existing standards are ineffective in reducing zones of impact.

8. If the standards for TSS were completely relaxed, the present length of coastline impacted by mill wastes would probably increase from about 6 to 9 miles.

Three miles of additional impacted coastline represent about 7 percent of the Hamakua Coast, or about 1 percent of the island of Hawaii coastline.

9. The socioeconomic cost of completely removing all sediment from mill discharges appears to be prohibitive and is not justified by projected environmental benefits.

REFERENCES CITED

Department of Geography, University of Hawaii. 1973. *Atlas of Hawaii.* Honolulu: University Press of Hawaii.

Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawaii. 1979. *Hawaii fisheries development plan.* Honolulu.

El-Swaify, S.A., and K.R. Cooley. 1980. Soil losses from sugarcane and pineapple lands in Hawaii. In *Assessment of Erosion,* ed. M. De Boodt and D. Gabriels, pp. 327-340. J. Wiley & Sons.

El-Swaify, S.A., E.W. Dangler, and C.L. Armstrong. 1982. *Soil erosion by water in the tropics.* College of Tropical Agriculture, University of Hawaii, Honolulu.

Environmental Protection Agency. 1971. Hawaiian sugar industry waste study. E.P.A. Region IX, San Francisco, California.

Grigg, R.W. 1972. *Some ecological effects of discharged sugar mill wastes on marine life along the Hamakua Coast, Hawaii.* University of Hawaii Water Res. Sem. Series 2:27-45. Water Resources Research Center, University of Hawaii, Honolulu.

Grigg, R.W. Environmental impact of thermal loading and biological oxygen demand of sugar mill wastes off the eastern coast of Hawaii. Unpublished manuscript.

Kennedy Engineers. 1967. Report on Hawaiian sugar factory waste receiving water study. 657 Howard Street, San Francisco, California.

Prosser, C.L., and F.A. Brown. 1965. *Comparative Animal Physiology,* 2nd Edition. Philadelphia: W.B. Sanders Co. p. 118.

Ralston, S. 1984. Biological constraints on production and related management issues in the Hawaiian deep-sea handline fishery. In *Proceedings of the Second Symposium on Resource Investigations in the Northwestern Hawaiian Islands,* ed. R.W. Grigg and K.Y. Tanoue, Vol. 1, pp. 248-264. UNIHI-SEAGRANT-MR-84-01. University of Hawaii Sea Grant College Program, Honolulu.

Sverdrup, H.U., M.W. Johnson, and R.H. Fleming. 1942. *The Oceans.* Englewood Cliffs, N.J.: Prentice Hall, Inc. p. 957.

APPENDIX

INTERVIEWS WITH FISHERMEN, 1983

Name	Age	Years Fishing	Type of Fishing	Area of Fishing	Comments
Ken Kekela	55	30	Shore	Hilo/Hamakua	Used to catch more moi, aholehole, and nehu by the mills when they were dumping soil and bagasse. Does not know why.
Muggs	~52	Long time	Ika-shibi	Pepeekeo/Hilo	Catch about double of last year's, but probably no relation to shore processes.
Tadashi Hiyota	~60	Most of life	Spear	Hilo	Catch near mills of kumu, menpachi, and moana good when water is clear (mills not grinding).
Kiyoshi Murakami	54	Whole life	Shore	Honokaa	Before, when discharge was heavier, catch of moi and papio much better (20 per day vs 2 to 3 now). There is plenty of coastal area unaffected by the mills where other kinds of fish can be caught. Mill discharges diversify recreational opportunities.
Yukio Ishihara	60	Many years	Shore	Honokaa	Moi, nehu, lae, and papio hide in the muddy water. Dumping okay because it improves fishing for these fish. After Paauhau and Hakalau closed, no more moi. Dumping does not affect swimming or surfing because no beaches. Streams cause muddy water, too, but too intermittant for fish to build up.
Wally Sakamoto	51	15	Spear		Shore fishing by mills not as good now, but water clean; better for spear fishing; more diving near mills now.
Earl De Rego	53	45	Shore	Honokaa	Soil in water improves fishing for certain fish near mills; bagasse was bad, before it filled the holes, okay now. Opihi poor everywhere because of overfishing.
Alfred Moniz	51	Many years	Shore	Hamakua Coast	If the mud-water is cut out, it will destroy the moi. Paauhau was one of the best areas before, now no moi.
Mike Hega	34	15	Spear		Fish in general less now than before. Problem is not dirty water but rather overfishing. Mills not too bad because are now consolidated into three and only a small area is affected.
Alika Cooper	55	Lifetime	All types	Hilo	Bottomfishing used to be much better before mechanical harvesting began; believes soil and bagasse ruined bottomfishing off Hamakua Coast, but also says overfishing is a contributing factor; believes that bottomfishing would improve if mills stopped dumping mud and soil.