ENVIRONMENTAL SURVEYS BEFORE, DURING, AND AFTER OFFSHORE MARINE SAND MINING OPERATIONS AT KEAUHOU BAY, HAWAII

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ABSTRACT

Environmental surveys conducted before, during, and after a two-month field test of a new offshore sand mining and delivery system (SSRS) at Keauhou Bay, Hawaii demonstrated that the generation of turbidity and suspended sediment attributed to sand recovery operations was negligible and caused no adverse impact to nearby coral reefs and other marine life. However, incidental impacts from the dragging of anchors and cables and the undermining and collapse of adjacent reef rock were detrimental but can be avoided in future operations provided that proper precautions are taken. Destruction also occurred to mollusks inhabiting the sand and to echinoderms migrating across the sand deposit into the excavation craters. These impacts can be mitigated or largely avoided by conducting adequate field surveys before selecting a site. Additional monitoring studies should be conducted during future sand recovery operations to continue documentation of environmental impacts, and should utilize both qualitative and quantitative methods. Post-sand recovery studies should be conducted to assess long-term impacts.

PREFACE

Offshore submarine sand deposits probably represent Hawaii's greatest future source of commercial sand. Existing resources on land, principally dune and beach deposits, are finite and will be subject to increased uses and demands. Offshore sand deposits, in contrast, are naturally replenished by the breakdown products of coral reefs eroded by waves and other forces. Thus, it seems feasible that some of the submarine sand resource can be utilized on a continuing basis, provided that proper environmental precautions are exercised.

The selection of sites for commercial offshore sand recovery operations must be balanced between environmental and economic considerations. Extraction of sand cannot occur too close to the shoreline where operations and removal of the sand may conflict with recreational, residential, and aesthetic considerations. Neither can extraction occur too distant offshore nor in deep water where engineering problems, economic costs, and the likelihood of encountering poor quality sand are increased. Sites must be chosen where damage to coral reefs and other valuable ecosystems will be avoided.

The ecology of large submerged offshore sand deposits have not been systematically studied for the purpose of assessing and mitigating environmental impacts of sand recovery operations. Furthermore, environmental surveys have not been performed during sand recovery operations. The testing of the Submarine Sand Recovery System (SSRS) at Keauhou Bay, Hawaii represented the first opportunity for an integrated environmental monitoring program before, during, and after testing of a full-scale sand recovery operation. The need for the environmental program was expressed during the processing of permits and the preparation of the federal environmental impact statement (EIS) for the SSRS field test.

The environmental monitoring program was supported by University of Hawaii Sea Grant College Program funds of only $5,000 and required the voluntary participation of a number of students and scientists, some with little or no prior scientific or field experience. At times, coordination of the program and acquisition of equipment were difficult and the study suffered some imperfections. Nevertheless, the results provided valuable insight into the problems of designing and executing monitoring programs and the environmental impacts of the mining operations. The study also raised several concerns and prompts the need to support similar endeavors. The significance and variety of potential environmental impacts of offshore sand mining in Hawaii will also require greater and more regular financial support of environmental monitoring studies by sand mining proponents and greater professional involvement and interest by the scientific community in order that these and other sand recovery technologies are properly tested and applied.

James E. Maragos

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INTRODUCTION

Purpose and Scope

The field testing of the Submarine Sand Recovery System (SSRS) at Keauhou Bay, Hawaii involved assessing the economic, engineering, and environmental feasibility of a new method to extract offshore submarine sand and deliver it onshore. Discussion of the economic and engineering aspects is provided in Casciano (1973, 1976). This report summarizes the environmental feasibility of the SSRS based on field studies before, during, and after testing of the system.

The field environmental monitoring program was divided among several component studies, each of which concentrated on certain environmental parameters. A synopsis of the environmental monitoring program is presented in Table 1.

Studies on algae were designed to assess the impact of possible leaching and runoff of slurry from the deposition and settling basins on tidal and subtidal algal and invertebrate populations. The rates of colonization by benthic algae on pipes and other SSRS structures were also noted.

Water quality measurements were taken on oxygen, nutrients, and turbidity to determine whether sand removal promoted the release or biological utilization of these substances.

Coral observations and surveys conducted before, during, and after the test were designed to assess responses to possible turbidity generation and undermining of the reef framework due to the removal of supporting sand by pumping operations.

Similar studies were also conducted on the echinoderms, particularly to assess the reaction of sea urchins to the possible increases in turbidity. Other observations on sea urchins were made to determine the impact of the excavated sand craters on sea urchins migrating across the deposit. Occasional observations were also made on the behavior of sand dwelling worms uncovered during sand removal operations.

It was suspected that sand dwelling mollusks were among the most common of the invertebrates inhabiting the sand deposit. Studies were designed to acquire estimates of the diversity and abundance of mollusks at the deposit and on the extent of the destruction of mollusks by sand recovery operations.

The fish surveys were designed to assess whether fish populations would would be attracted to or avoid the SSRS operations. In addition, observations were made on the feeding behavior of fishes in sand excavation craters and upon the surfaces mining equipment.

Profiles of the nearest beaches were made before and after the test to determine whether sand recovery operations caused erosion of the beaches. In addition, reconnaissance swims were conducted between the

TABLE 1. SYNOPSIS OF THE ENVIRONMENTAL MONITORING PROGRAM CONDUCTED IN CONJUNCTION WITH THE FIELD TESTING OF THE SSRS AT KEAUHOU BAY, HAWAII

Description	Before	During	After
ALGAE			
Observations of algae colonizing on pipes and other surfaces		X	X
Quadrat surveys offshore from basin and control site	X		X
Quadrat surveys at sand deposit	X		
WATER QUALITY			
Sediment trap experiments at deposit and control site		X	X
Turbidity observations and photographs	X	X	X
O_2, NO_2, NO_3, PO_4, and turbidity measurements at deposit and control station		X	X
Currents and visibility observations	X	X	X
CORALS			
Reconnaissance of perimeter of deposit and control sites	X	X	X
Permanent transect surveys at deposit and control sites	X	X	X
Observations on responses to turbidity generation		X	X
Observations on effects of collapse and slumping of reef rock towards craters			X
ECHINODERMS AND WORMS			
Quadrat surveys of urchins at deposit and control sites	X	X	X
Observations of sea urchins in craters			X
Observations of sand dwelling worms		X	
MOLLUSKS			
Collections and censuses at discharge pipe		X	
Night dive observations	X		X
FISHES			
Censuses along permanent transects at deposit and control sites	X	X	X
Observations at craters and along pipes	X	X	X
SEDIMENTS AND BEACHES			
Beach profiles and reconnaissance swims	X		X
Bathymetric stake surveys	X	X	X
Observations along reef rim and in craters	X	X	X

beaches and the sand deposit to determine whether there were connecting sand channels.

Surveys of bottom sediments at the test deposit were designed to determine the extent of sand migration in and out of the deposit before, during, and after the SSRS test. In addition, observations on the formation of the craters, the resuspension of sediments, and the migration of sand away from the deposit boundary towards the craters were made.

The use of control stations and replicate sampling allowed objective statistical evaluation of the results. Replicates were taken so that the variation within samples and the precision and accuracy of the various methods could be ascertained. Control station studies were performed about 1 km north of the test site at another deposit of similar depth, dimension, and distance from shore so that data variations attributed to natural processes could be differentiated from those caused by SSRS operations. The conducting of studies before, during, and after the field test also allowed an accounting of the changes in environmental conditions with time.

Description of the SSRS Operations and Test Site

The SSRS operations were conducted offshore of Keauhou, about 6 miles south of Kailua-Kona, on the island of Hawaii. The SSRS was designed to maximize the portability of the equipment required to mine offshore sand and to minimize the cost, manpower requirements, and environmental degradation resulting from turbidity and resuspended sediments.

The major components of the SSRS include: (1) a small, twin-hulled platform barge capable of supporting the heavy equipment required to pump and deliver the sand; (2) a suction dredge equipped with a jetting probe which is suspended from the barge above the sand deposit; (3) a long pipeline of 6-inch (16-cm) diameter PVC pipe which is suspended in the ocean slightly below sea level and which extends from the barge to the shoreline; (4) a deposition basin which serves as the onshore collection point for the sand slurry; and (5) a smaller settling basin connected to the deposition basin which collects overflow slurry from the latter and prevents its direct re-entry into the ocean.

The barge is moored over the sand deposit using a system of five anchors and the pipeline is maintained at the proper depth and orientation using a series of buoys and cables anchored to the coral reef substrate. At the shoreline where waves and surge currents could damage PVC, a section of the pipeline consists of steel of the same diameter which is rigidly anchored using heavy concrete anchors and braces. Another length of PVC pipe extends from the onshore end of the steel pipe section to the deposition basin.

The sand recovery procedure is as follows: (1) a pump located on the barge is activated and causes the suction head attached to a flexible pipe to "jet in" (bury itself in the sand); (2) another pump is activated which creates suction in the head causing sand to ascend to the barge at the ocean surface; (3) the sand is passed through a crusher to break up larger rock fragments and is mixed with seawater to form a sand slurry (20 to 30 percent) after entering the head; (4) the slurry is delivered to shore through a pipeline and then discharged in the deposition basin and into the settling basin if there is an overflow. With time, the water in the slurry percolates through the walls and floor of the basin(s) leaving the sand behind.

Sand recovery operations took place between September and November 1974 when approximately 12,000 cubic yards (10,000 m^3) of sand were delivered to shore. The SSRS was capable of pumping 50 to 60 cubic yards (42 to 50 m^3) of sand per hour when operating normally. The sand deposit was located in a depression between depths of 15 and 25 m and was completely surrounded by a flourishing coral reef community. The shallower end of the deposit was located about 120 m offshore. The dimensions of the deposit measured 150 m wide by 300 m long by 6 m deep. Most of the sand mined during the field test was collected at the shallower southeast corner of the deposit. Although sand was mined from depths of 15 to 25 m at Keauhou Bay, the SSRS is capable of pumping sand to a depth of 30 m without design modifications.

Extracting sand from the deposit causes the formation of a cone-shaped crater-like depression. As the head jets in and begins to suck in subsurface sand, sand from shallower adjacent areas begins to slump and descend towards the suction head. If the head does not sink deeper into the deposit, the slumping process continues until the walls of the new depression reach a stable slope angle of 32° when measured from the horizontal. At this point, the probe must be lowered further to precipitate additional pumping and slumping. The probe is lowered until the bottom of the deposit is reached and the pumping of sand from the crater ceases, unless optional equipment is utilized (such as the fluidizing pipe) to increase the sand yield from the crater. Otherwise the probe head must be moved to a new location on the deposit.

The process of shifting the sand mining apparatus from one location to another requires temporary halting of mining operations and the assistance of several people. The suction head is raised off the bottom of the crater and then the barge moorings are shifted to a new site. As much sand as possible is pumped from each location in order to maximize pumping time relative to "down" time.

Normally only two people are required at the SSRS site during pumping operations. One is stationed at the barge to monitor pumps and respond to contingencies while the other periodically checks on the performance of the suction head.

A fluidizing pipe can be used with the SSRS to increase sand yield at individual locations and craters. It is made up of a long 3.8 cm (1.5-inch) diameter PVC pipe capped at one end and connected to a flexible hose and water pump at the other end which is located on the barge. Small 0.6 cm (0.25-inch) diameter holes are located along the PVC pipe. The fluidizing pipe is layed against the sloping crater wall and the pump is activated. The water pumped into the pipe causes water jets to issue from the holes and sediment to slump and cascade down to the suction head at the bottom of the crater. Eventually this process results in the formation of a small "canyon" in the crater wall, and a diver must periodically move the pipe to a new location around the crater perimeter. The use of the fluidizing pipe gives the crater a rosette appearance with irregular walls. The fludizing pipe is an effective tool which extends the distance from which sand can be recovered by the probe and, thus, increases the volume of sand extraction at any one location.

Nine craters were produced during the sand recovery operations at Keauhou Bay. The smallest craters accounted for only 100 cubic yards (84 m^3) of sand while the largest accounted for 4,700 cubic yards (3,930 m^3). The average content of sand extracted from the craters consisted of 2 percent coarse sand, 8 percent medium sand, 55 percent fine sand, 32 percent very fine sand, and 3 percent silt.

METHODS

Bottom Sand Dynamics

A comprehensive field program was undertaken to document changes in volume of and movement of sand in the deposit at the test site and in adjacent areas. The "sand" studies were divided into four objectives:

(1) Documentation of sand erosion, if any, at nearby beaches, attributed to direct and indirect efforts of SSRS operations

(2) Description of the behavior of the sand at the SSRS deposit during recovery operations, including formation of excavation craters

(3) Description of effects of deepening the sand deposit on nearby reef structures and subsequent degeneration of conical depressions after termination of SSRS operations

(4) Documentation of possible sand migration into and out of the boundaries of the SSRS deposit resulting from recovery operations or other causes

The first objective was achieved by periodic evaluation of the morphology, the nearby beaches, Kahaluu and Disappearing Sands (Figure 1). The beach profile method described by Moberly and Chamberlain (1964) was utilized to determine the morphological condition of each before and after the SSRS test.

Profiles were taken perpendicular to the major axis of each beach, usually one profile at each end, in the center, and at any other position of the beach where the major axis deviated noticeably. It was assumed that each tract of beach facing the open sea in a different direction would be affected differently by a prevailing swell condition; thus, the necessity for multiple profiles.

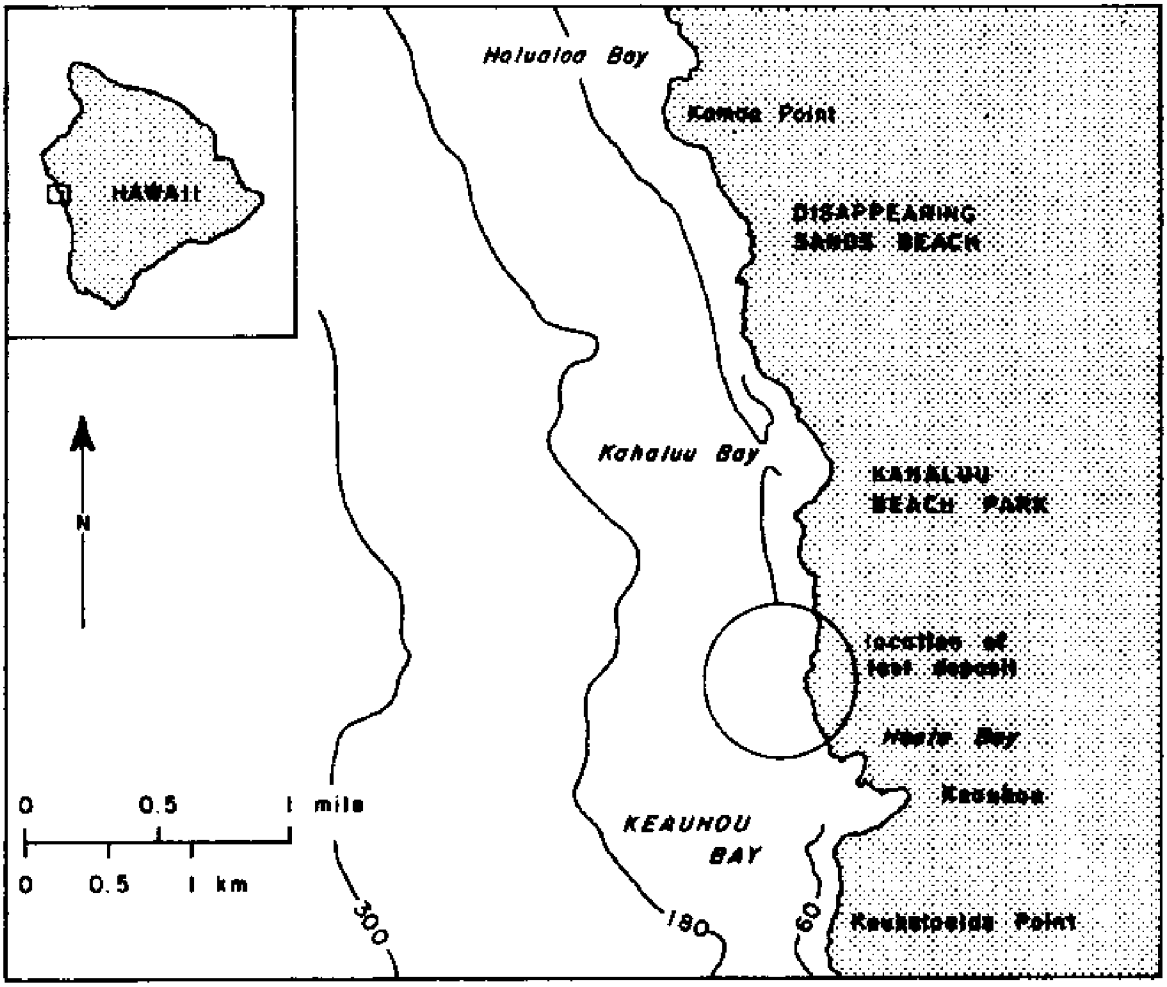


Figure 1. SSRS test site, Keauhou Bay, Hawaii

For Kahaluu Beach Park, three traverses were secured, each facing a different prevailing swell direction (Figure 2). Only one traverse was marked off for Disappearing Sands Beach due to the brevity of the beach length and its small size (Figure 3). The traverse was secured in the center of the beach where the major concentration of sand was located.

In addition to beach profiles, photographs were taken during each beach monitoring visit so as to document more fully the condition of each beach.

Supplementing the beach profile surveys were a series of observation swims to determine whether physical connections existed between the test sand deposit and the nearby sandy beaches and whether sand movement within possible connections was occuring.

Observation dives were conducted at the Keauhou Bay sites on August 27 and 29, September 10 and 21, October 27 and 28, November 30 and 31 in 1974, and March 15 and 16, 1975 to provide comparative surveys throughout the mining operations.

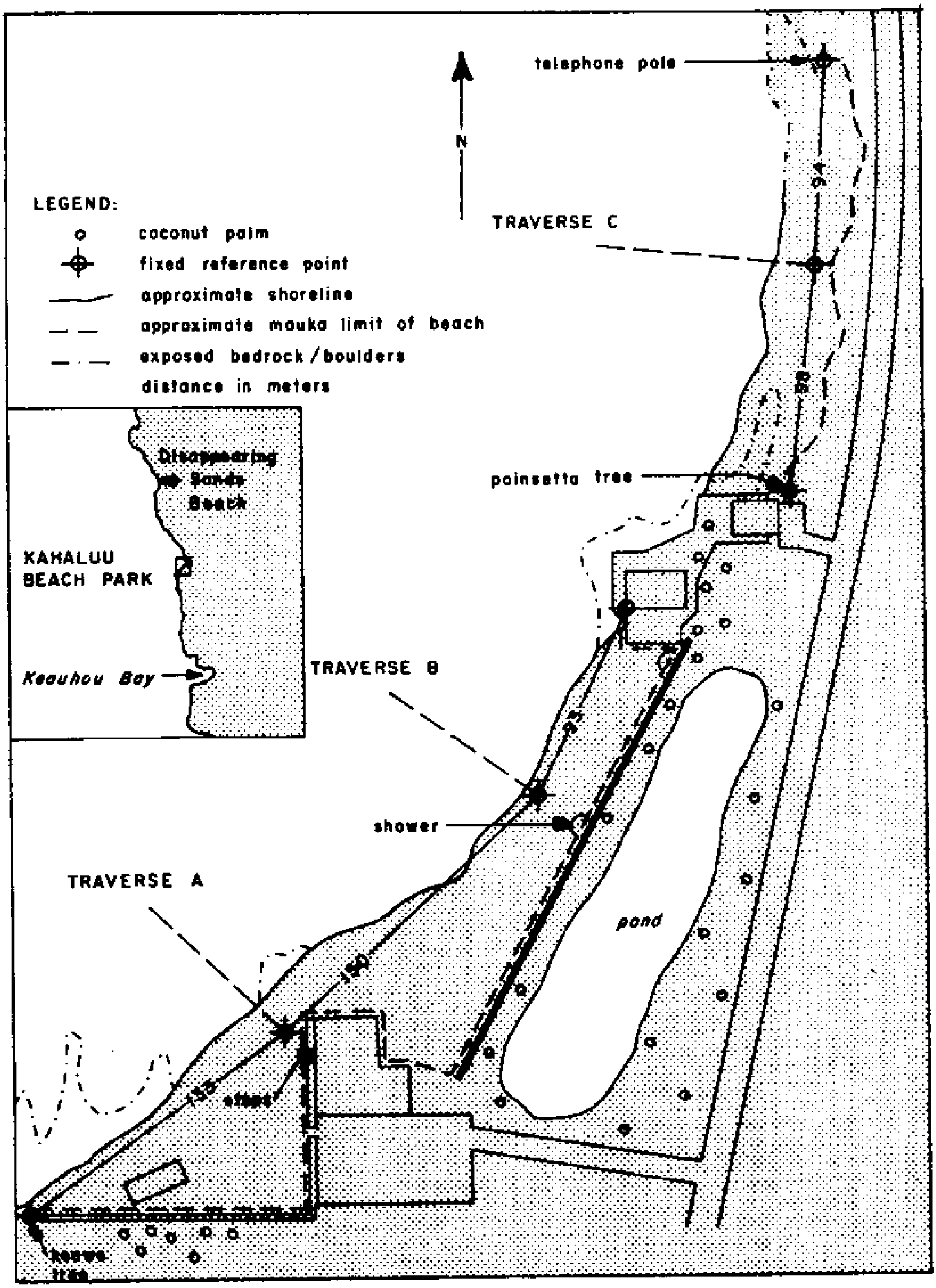


Figure 2. Kahaluu Beach Park

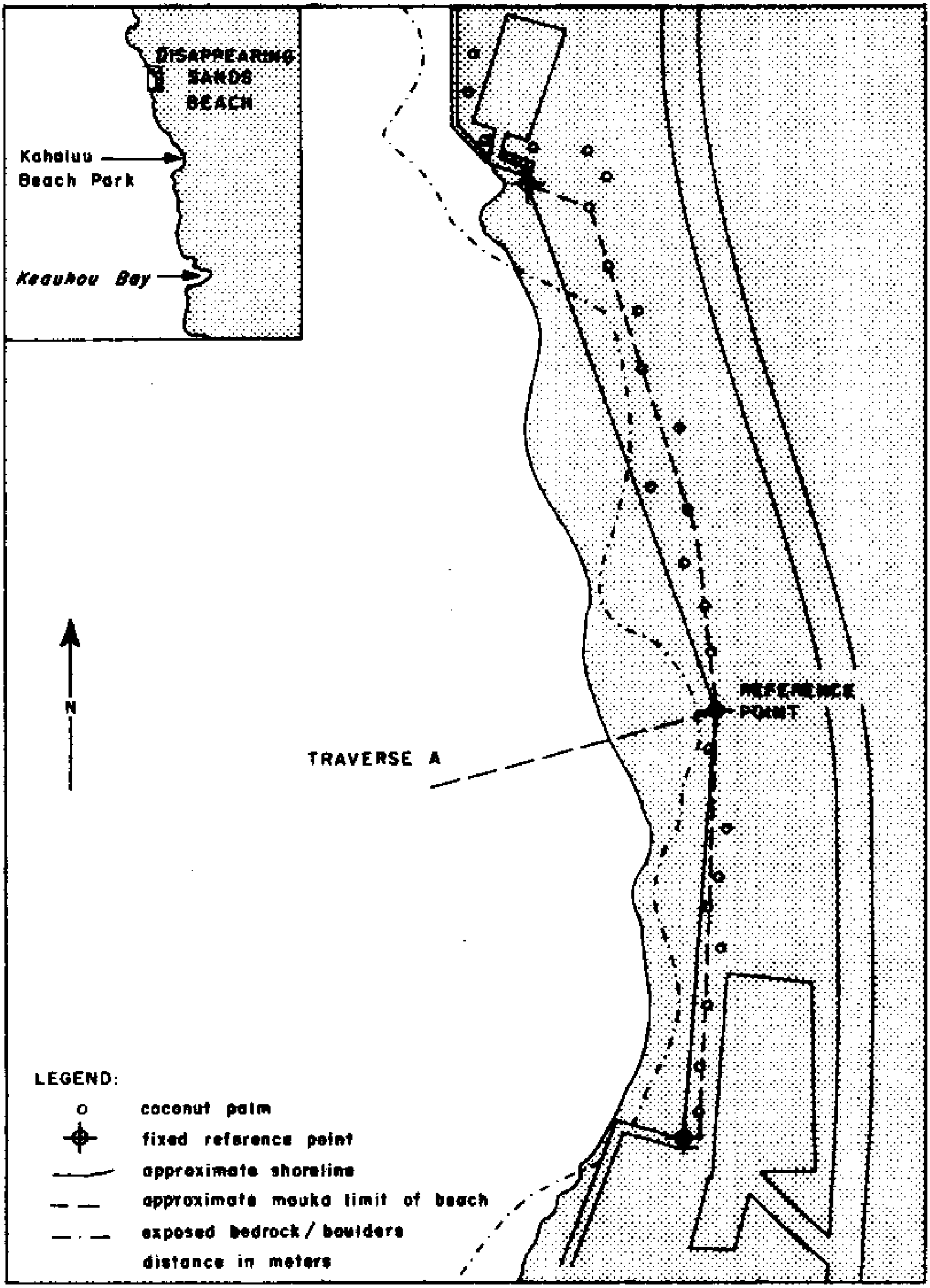


Figure 3. Disappearing Sands Beach

The latter study objectives were partially accomplished by using a series of reference stakes to monitor the size and depth of the submarine deposit. Sand levels were monitored periodically using the following technique: 20 rebar stakes 1.5 m each in length were secured at regular intervals along the perimeter of the deposit (Figure 4). Stakes were positioned in coral rock firmly fixed to the bottom and resistant to movement by waves and shifting sand (Plate 1).

A string of standard 210 cm length was extended from the top of each stake horizontally out over the sand. A groove was made on top of each stake after being secured to the bottom in order to standardize the angle of line extension. After the end of the line was tied to the top of the stake and extended over the deposit edge, the line was leveled with an attached line level. From the tip of the leveled line over the sand, another calibrated line with a brass plumb bob attached to one end was used to measure the vertical distance between the leveled line and the deposit surface (Figure 5 and Plate 1). The bubble indicator of the line level appeared to be insensitive to vertical fluctuations of ±4 cm when the end of the 210-cm line was moved up or down; thus, the ±4 cm value was estimated to be the precision of the vertical measurements.

In addition to the vertical measurements, horizontal measurements, "a" and "a", along the calibrated leveled line (Figure 5) were taken to identify any variations in distance between the immovable stake and the coral/sand interface, or deposit boundary.

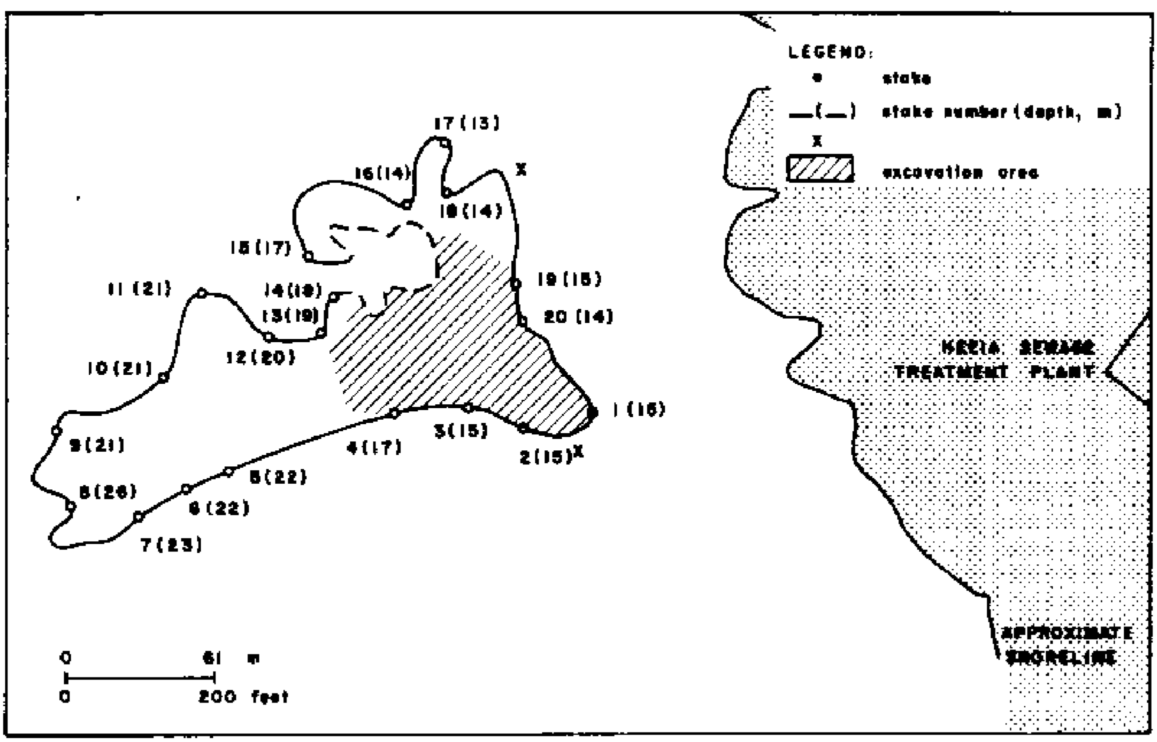


Figure 4. SSRS test deposit survey stake locations

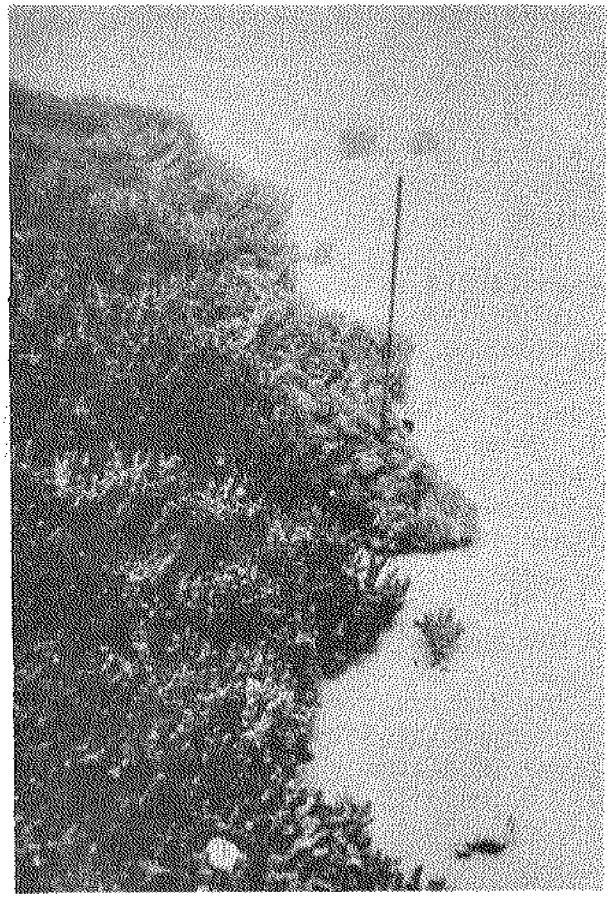


Plate 1. A secured rebar stake used in the estimation of bottom sediment transport in and out of the SSRS sand deposit is shown.

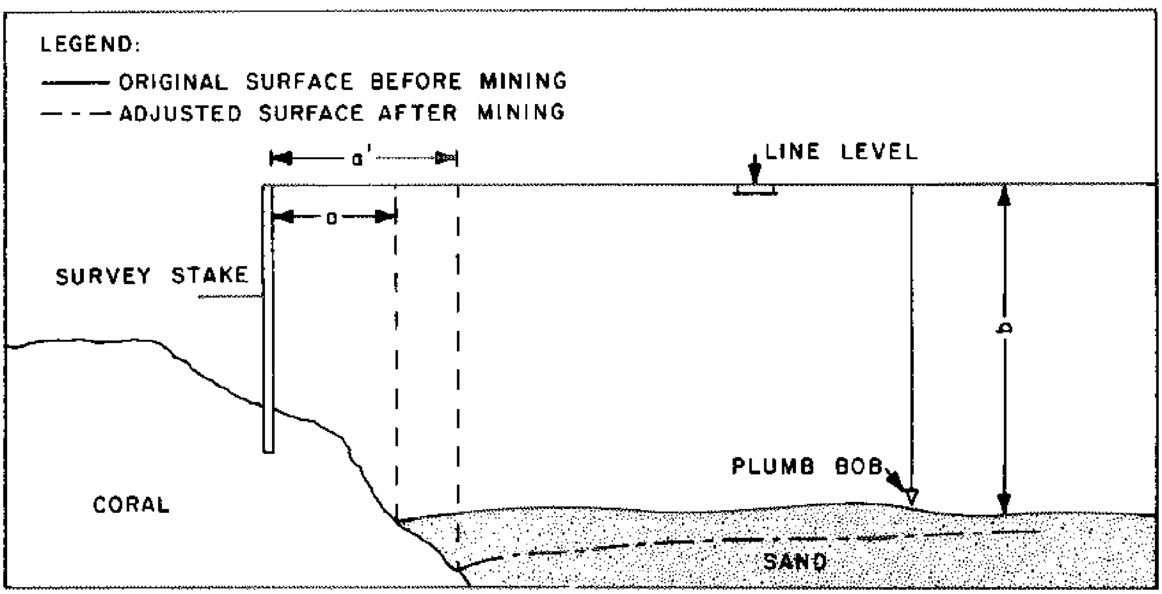


Figure 5. Sand level and distance measuring scheme

Sand level measurements were taken on September 10 and 21, 1974 and March 15, 1975. On those days, the full complement of 20 stakes were measured (see Table 2). In addition to the sand level measurements, wind and sea conditions, underwater visibility, and sand ripple formation were recorded.

Diver observations performed for the preparation of the EIS (NOAA, 1974) indicated that the SSRS deposit was completely isolated from adjacent beaches and sand deposits. A flourishing and elevated coral reef community surrounded the boundaries of the deposit and effectively confined the sand in a depression. Nevertheless the stake surveys were performed in order to document that bottom movement of sand across the boundary of the deposit was not expected and to alleviate public opposition to the project on the basis of possible impact to adjacent beaches.

The quantitative stake surveys were supplemented by qualitative diver observations during and after sand recovery. Divers inspected each crater or conglomerate excavation crater and recorded the condition of the walls and rim, reporting any evidence of sand migration from the immediate area surrounding each crater. If sand migration were evident, the distance from the existing crater rim to the outer boundary of migrating sand was measured and recorded.

Resuspended Sediments and Water Quality

Comprehensive data were collected on a variety of water quality parameters including resuspended sediments, turbidity, dissolved oxygen, nitrate- and nitrate-nitrogen, and pH. Most important was the monitoring of resuspended sediments.

It was suspected in the draft EIS that under certain circumstances sand recovery operations would disturb and resuspend some bottom sediments, possibly affecting corals and other marine life. Accurate information on the extent of sediment resuspension was provided by sediment trap experiments, diver observations, and turbidity measurements conducted before, during, and after sand recovery activities.

Sediment traps were placed at two stations at each end of the sand recovery deposit and at one station at the "control" site located approximately 0.5 km north of the recovery site (Figure 1). The control station was located along the northern boundary of another sand deposit to the north of the SSRS site. The "south" SSRS station was located at the shallow southeast corner of the sand deposit near the site of most of the sand recovery during the test; the "north" station was located near the northeast shallow corner of the same sand deposit (Figure 4).

The sediment traps consisted of one-quart glass "mason" jars strapped to metal stands; the metal stands functioned as stabilizers which inhibited the accidental toppling of the jars by waves, fish, and currents (Plate 2). Two jars (replicates) were placed at each SSRS station and three jars were placed at the "control" station.

TABLE 2. SAND STAKE DEPOSIT MEASUREMENTS BEFORE, DURING, AND AFTER SSRS TEST OPERATIONS AT KEAUHOU BAY

Stake Number	Measurement on 9/10 Dive	Measurement on 9/21 Dive	Δ_1	Measurement on 10/27 Dive	Δ_2	Measurement on 3/15 Dive	3	$\Sigma\Delta$
1	132	132	0	127	+ 5	142	-15	- 10
2	102	98	+ 4	104	- 6	114	-10	- 12
3	135	157	-22	221	-64	241	-29	-106
4	114	109	+ 5	114	- 5	142	-28	- 28
5	117	112	+ 5	---	---	140	-28	- 23
6	135	137	- 2	---	---	132	+ 5	+ 3
7	155	163	- 8	---	---	168	- 5	- 13
8	88	91	- 3	---	---	---	---	- 3
9	84	81	+ 3	---	---	86	- 5	- 2
10	76	---	---	---	---	91	-15	- 15
11	124	---	---	---	---	124	0	0
12	130	127	+ 3	---	---	155	-28	- 25
13	84	86	- 2	---	---	97	-11	- 13
14	97	99	- 2	---	---	114	-15	- 17
15	76	81	- 5	---	---	99	-18	- 23
16	152	150	+ 2	---	---	157	- 7	- 5
17	157	163	- 6	---	---	160	+ 3	- 3
18	135	132	+ 3	---	---	137	- 5	- 2
19	124	127	- 3	---	---	163	-36	- 39
20	137	141	- 4	135	+ 6	163	-28	- 26

Note: Stake numbers refer to those of Map 4. All depths expressed in centimeters; (-) values indicate a relative decrease in sand level between successive surveys while (+) values indicate relative increases in sand. The symbol "Δ" means the changes in depth between one survey (n) and the next (n + 1) and "ΣΔ" means the cumulative changes between the first and last surveys.

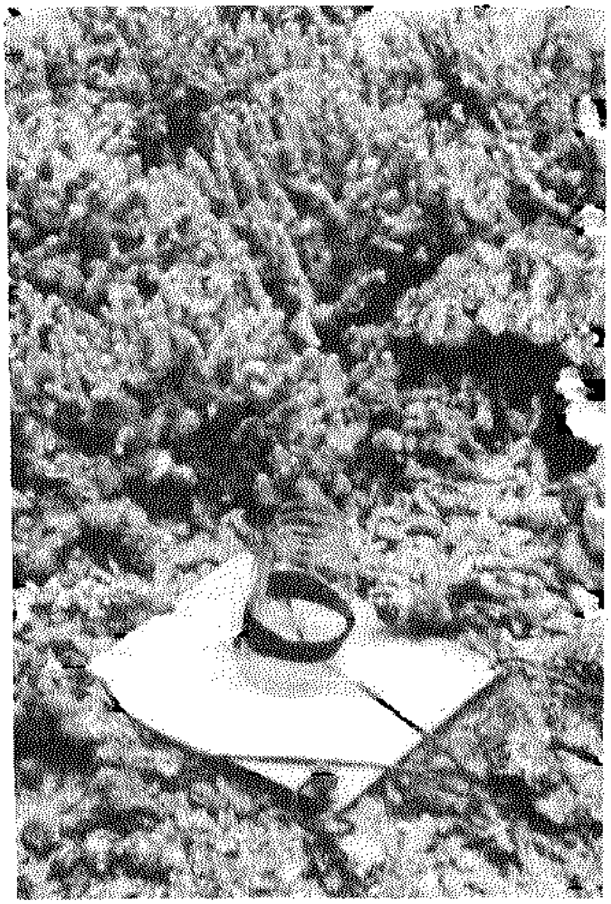


Plate 2. Sediment trap apparatus in position near a flourishing finger-coral community in August 1974 at the SSRS sand deposit site at Keauhou Bay

The sediment trap experiments were conducted simultaneously at all three stations over four separate time intervals between September and December 1974. The time intervals varied from 16 to 39 days (Table 3).

TABLE 3. SUMMARY DATA FOR SEDIMENT TRAP EXPERIMENTS CONDUCTED IN THE FALL OF 1974 AT KEAUHOU BAY

Time Interval	Dates	No. of Days	No. of Sand Mining Hours	Sand Recovery Activity
1	09/02-10/04	32	73	During mining
2	10/04-10/20	16	15	Down time
3	10/20-11/28	39	166	During mining
4	11/28-12/27	30	0	After mining

Time intervals 2 and 4 roughly coincided with times of little or no sand recovery activity while time intervals 1 and 3 coincided with moderate to heavy recovery activity (see Figure 6).

The use of sediment traps to estimate the level of resuspended sediments in the water relies upon the assumption that a constant proportion of the suspended sediment carried into the glass bottles will settle out and accumulate at the bottom of the jar. In order to detect measurable increases in the level of sediment resuspension attributed to sand recovery operations, it was necessary to compare the rates of sediment accumulation during recovery operations with "background" levels of accumulation measured at the control station and during time intervals when no sand recovery operations were conducted. These comparisons allowed an assessment of the method's utility and a quantitative and objective evaluation of the effect of sand recovery operations on the dynamics of sediment resuspension.

At the end of each time interval, the bottles were capped, collected by divers, and returned to the lab for analysis. The number of days on station and the field location of each bottle were recorded prior to analysis. Each sediment bottle was then opened and the contents emptied into calibrated settling funnels (Imhoff Cones). After a standard time interval of one hour, the volume of settled sediment was measured and recorded. This data, when divided by the number of days on station, provided resuspended sedimentation rates expressed as milliliters of sediment per day.

The sediment sample was then washed in fresh water and saved for size fraction, percentage of carbonate, and dry weight measurements.

Diver observations during sand recovery operations provided additional insight into the dynamics of sediment disturbance, transport, and turbidity generation. Underwater photographs (Plates 3 and 4) provide visual documentation on the extent and significance of sediment resuspension during SSRS probe and fluidizing pipe operation.

Turbidity (Jackson turbidity units or JTU), dissolved oxygen (parts per million or ppm), pH, nitrate- and nitrate-nitrogen (ppm), and phosphate (ppm) measurements were also acquired from water samples analyzed with a Hach model DR-EL portable Water Engineer's Laboratory. Water quality measurements utilizing more accurate instrumentation were not possible due to limitations of funds and loaned equipment. The water samples were collected at selected depths and locations by a diver using a 6-inch long and 3-inch diameter plastic (PVC) pipe with screw caps at each end. Prior to sample collection, the pipe was flushed thoroughly at each location in order to obtain accurate uncontaminated water samples. Water quality readings were then taken on the deck of a nearby ship, boat, or platform using the Hach instrument. The water quality data were collected on two occasions during sand recovery operations at both the test and control sites.

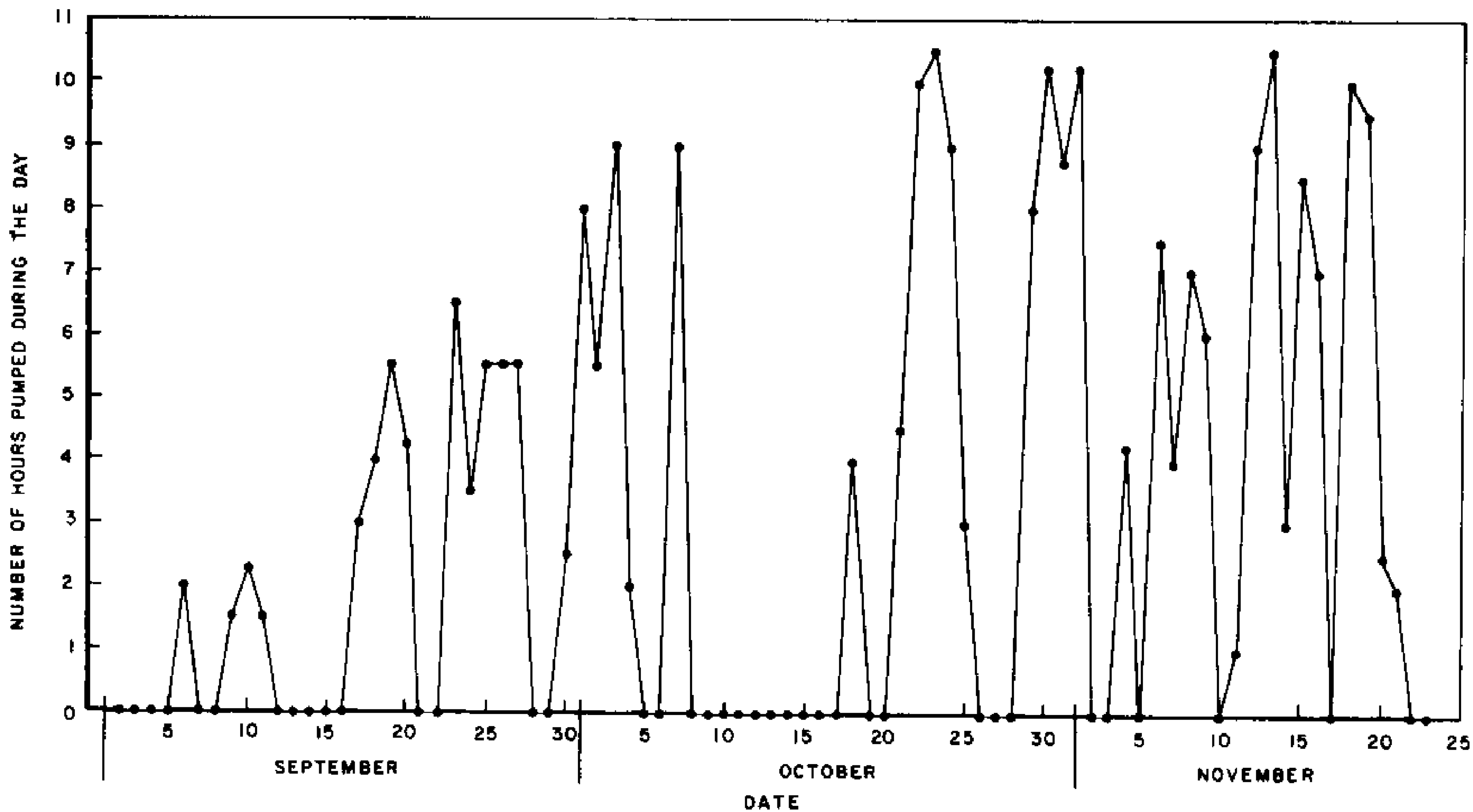


Figure 6. Time log of sand pumping activity during September through November 1974 at Keauhou Bay, Hawaii

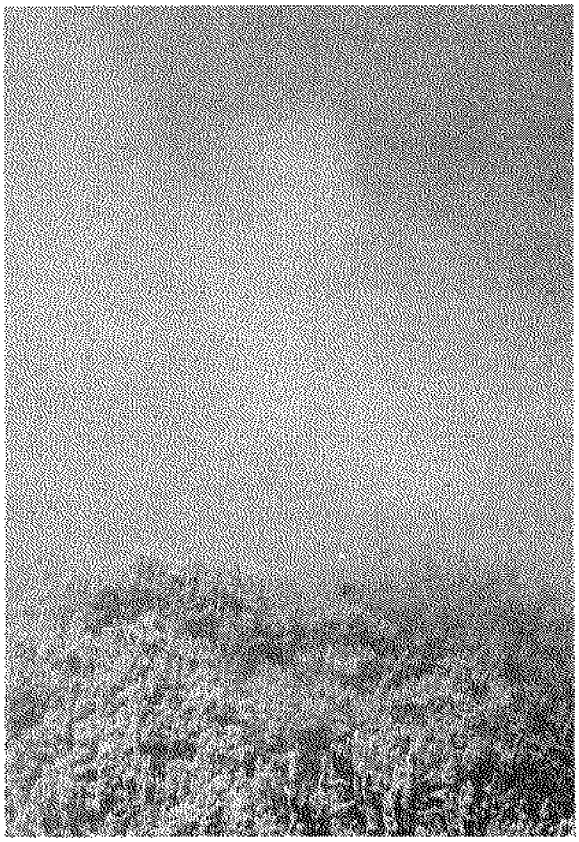
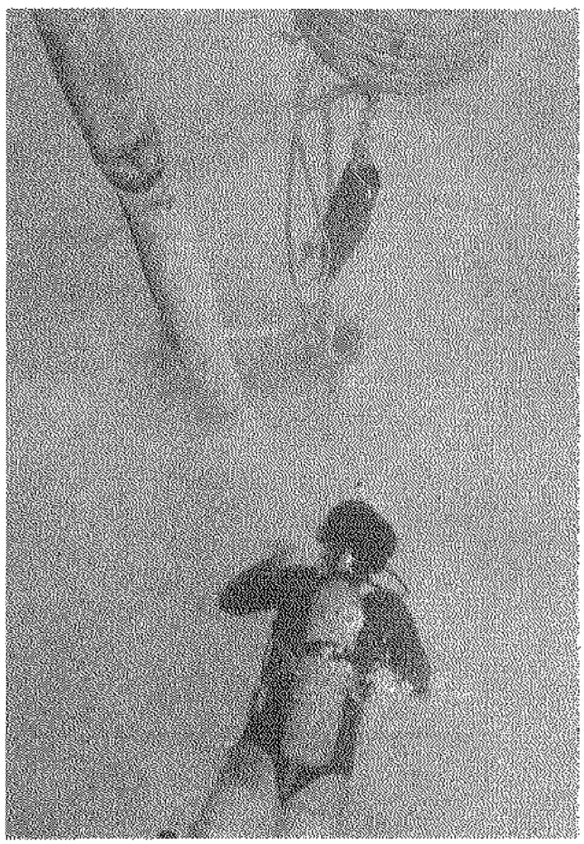


Plate 3. Sediment-laden water migrating from the vicinity of sand recovery operations towards a flourishing coral community nearby

Plate 4. The extent of the vertical transport of resuspended sediments during a typical operation of the sand recovery probe is shown. Photograph is taken looking down from the ocean surface towards the probe.



Corals and Echinoderms

Studies on the abundance, distribution, and response of corals and echinoderms consisted of qualitative diver observations and quantitative sampling surveys along permanent line transects. In addition, underwater photographs of important phenomena and reef features were taken at the recovery and control sites.

Qualitative diver surveys were conducted at both sites in July, October, and December which correspond to before, during, and after test operations. Extensive observations on the general geological and biological features of the sand recovery site were conducted earlier and reported in the EIS (R. Bowers in NOAA, 1974). In addition, checklists of coral and echinoderm species were prepared and the dominant or common forms noted and mapped.

The "control" site was chosen because its general biological, physical, and geological features were similar to those at the sand recovery site. For both sites transect lines were established on flourishing fingercoral and massive coral communities (*Porites compressa* and *Porites lobata*, respectively) near the boundaries of extensive sand deposits. A view of a section of the control reef site is shown in Plate 5.

Two permanent 50-m long transects were established at both the sand recovery and control sites near the location of the respective sediment traps in July 1974. The two SSRS site transects, located along the southern and eastern faces of the southeast corner of the sand deposit, were designated the southern (offshore) and the eastern (inshore) transects, respectively and were located very near the sites of the earlier transect surveys (Figure 4) conducted for the EIS. The depths of the permanent transects ranged from 14 to 20 m deep. The transects were positioned near sites planned for sand recovery operations and, during some instances, recovery operations occurred within 10 m of the southern transect line. The transects were established by placing two 50-m long polypropylene ropes along each transect. The lines were stretched straight along the fingercoral communities, usually within 1 to 3 m of the sand deposit boundary, and then fastened or tied to the reef to prevent their movement (Plate 6). The lines were marked at 1-m intervals using small lead weights. All transect lines were left in position for the 5-month duration of the study (August through December 1974).

Two transect lines were similarly established at the control site at depths between 13 and 22 m. Metal stakes were also established at 5-m intervals along the deeper control transect in order to determine the degree of movement of the polypropylene line attributed to surge, currents, and fishes.

Species number and percentage of coverage of live corals and the densities of sea urchins were estimated using a quadrat technique. The quadrat consisted of a square meter frame subdivided by wires into a grid of 100 squares of equal area. Coral and sea urchin abundance was estimated at 5-m intervals along the transect lines using the quadrat which was centered over each appropriate lead marker by a diver. A total of 11

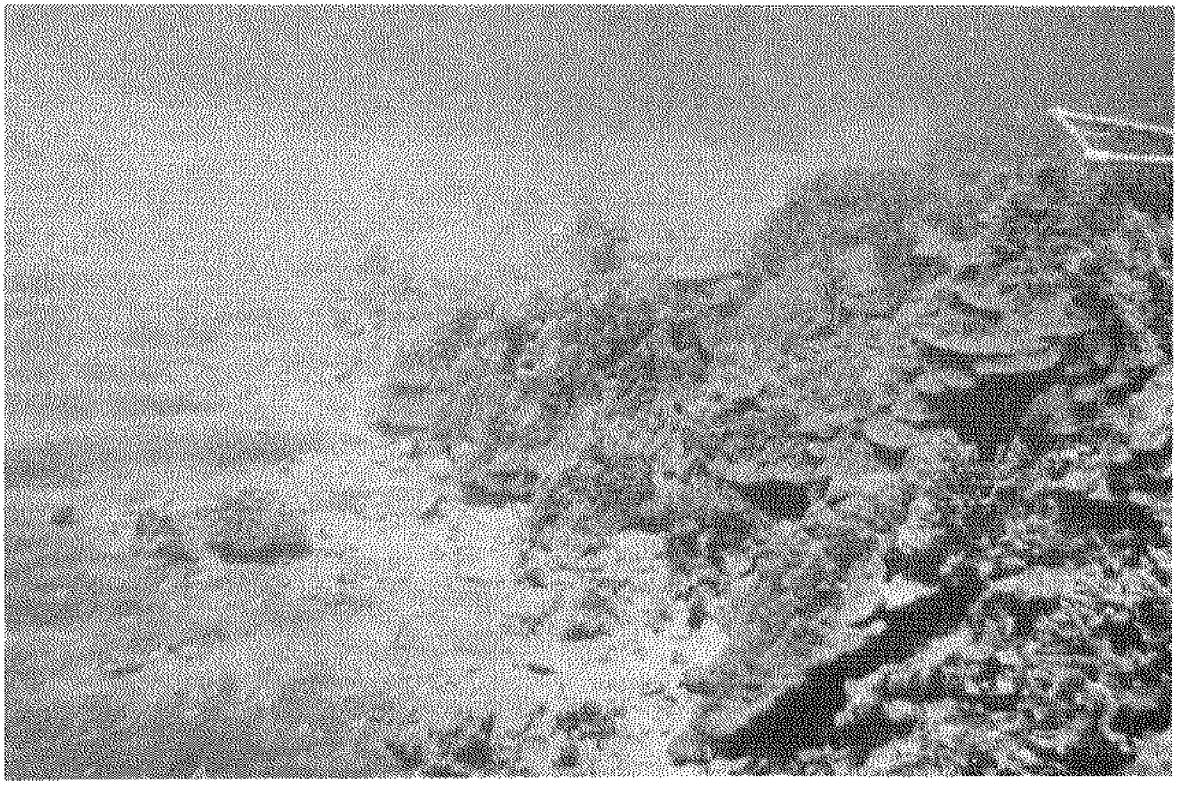


Plate 5. Boundary between sand deposit and coral reef community at the control site. Note the square meter quadrat frame to the right of the reef fringe.

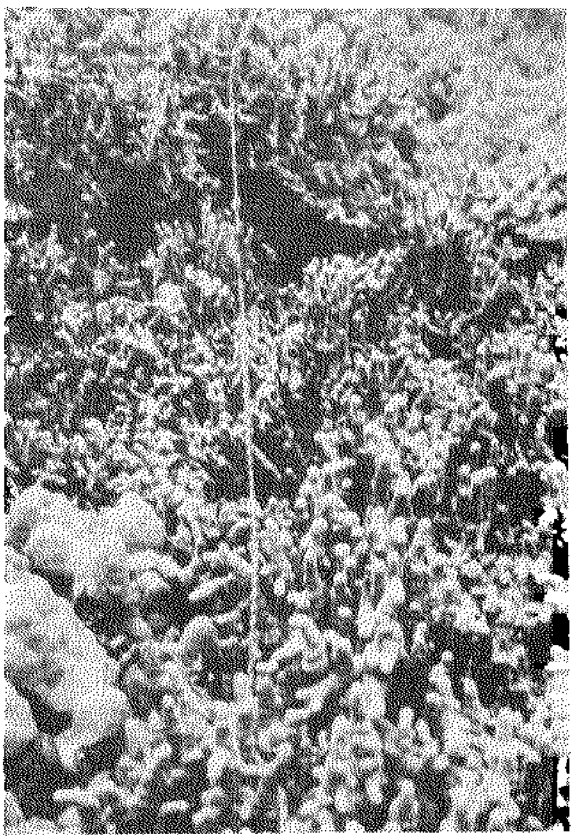


Plate 6. A representative section of the flourishing finger-coral communities located near the sand deposit at the SSRS test site at Keauhou Bay. The rope in the picture is a portion of the permanent east-inshore transect line.

quadrats were used to survey each 50-m transect line. At each location, the diver would record the dominant species of coral or bottom type occurring under each square of the quadrat frame and the number of each species of sea urchin occurring within the frame. Data recorded on underwater writing slates were later converted into percentage of coverage estimates for the corals and density estimates for the sea urchins.

These quadrat surveys were conducted twice before and twice after sand recovery operations at both the recovery and control sites. An extra set of surveys was also conducted during sand recovery operations along a 20-m section of the southern transect because it was accidentally moved by personnel of the SSRS team, thus rendering the original baseline data along this section useless. An extra set of sea urchin surveys was also conducted during sand recovery operations at the test site.

Two sets of quadrat surveys were performed along each transect line during each stage of the study in order to acquire information on the precision and accuracy of the technique. Without this information, it would not have been possible to determine whether variations in the abundance of coral or echinoderms (comparing before and after surveys) would have been caused by precision errors or by aspects of sand recovery activities. It is for this reason that the data on coral abundance also includes standard deviations from the mean values.

Mollusks

The purpose of these surveys was to acquire estimates of the numbers of living mollusks inhabiting the sand to be excavated. Two approaches were utilized in acquiring the population estimates; one focused on habitat surveys (transects and quadrat studies) at the deposit prior to sand recovery while the other focused on sampling of the discharge slurry for mollusks and shell fragments during the pumping of sand to shore.

Habitat surveys

Three types of surveys were conducted at the deposit site. The first involved a series of six 1-meter square quadrats randomly placed on the sand deposit and corresponded to the procedures used for the earlier EIS surveys (Bowers in NOAA, 1974). All mollusks at the surface within the quadrats were collected, identified, and counted, and data were recorded by divers using underwater slates. The sand was then sifted to a depth of approximately 30 cm with a 0.6-cm dip net to uncover mollusks. Data on these mollusks were similarly tabulated and recorded.

In the second type of survey at the deposit, five transect lines of 50-m length each were established at widely separated areas of the sand pocket. Divers counted and recorded all mollusks crawling on the surface within 5 m of each side of the line, thus covering approximately 500 m^2 of the sand per transect. No sifting or other concentrated search was conducted.

In the third type of deposit survey, mollusks were collected and identified by fanning 20 random spots of standard area throughout the sand pockets. All surveys were conducted during daylight hours because of the inaccessibility of the site and increased risks associated with night diving.

Sand slurry counts

The cryptic and nocturnal habits recognized for many sand dwelling mollusks justified acquiring population estimates utilizing additional techniques. The low densities of mollusks reported at the deposit during the earlier surveys for the EIS were reaffirmed by the latter studies and prompted the need to obtain additional information on mollusks.

The slurry discharge was sampled for mollusks by placing a wire screen with a mesh size of 1-cm in the discharge water during pumping in order to sort the larger shells from the smaller sand particles. During three one-hour-long periods, samples were mesh filtered from the discharge slurry on separate days when pumping activity was "typical." After collection, the shells and fragments were examined, sorted, identified, classified as recently alive or dead, and counted. The density of shells was estimated by relating the number of shells to the sand volume. The latter was estimated from pumping time, the rate of slurry volume pumped, and the average fractional value of sand in the slurry water. The technique suffered one major limitation, that of selective sampling of whole shells large enough to be retained by the wire mesh but small enough to pass through the crusher apparatus. Thus, in order to make the sampling more "representative," identifiable shell fragments were also collected from the mesh. The slurry sampling was supplemented by random collections of shells observed on the sand deposit accumulating in the deposition basin. In retrospect, the value of the unconventional slurry sampling procedure, which was unknown during the time of the surveys, could have been increased utilizing screens with a variety of mesh sizes in order to sample a greater range of shell sizes.

Benthic Algae

Prior to the SSRS test it was suspected that the rate of slurry discharge into the deposition and settling basins might exceed the rate at which the water would percolate through the ground and walls of the basins, resulting in overflow and surface drainage of slurry water back into the ocean, possibly affecting tidal and subtidal organisms. To assess the impact of this possible occurrence, two areas were surveyed before and after sand recovery operations. One site, designated the "basin" site, was located at a point along the shoreline close to the settling basin. The other site, designated the "control" site, was located along the shoreline 200 m north of the deposition basin near where the intake pipe crossed the shoreline. The control site surveys were conducted because benthic algal populations were expected to undergo seasonal variations and there would be a need to differentiate the changes attributed to seasonality from those attributed to possible SSRS impacts. The algal communities at the control site were sufficiently removed from the basins to be unaffected by possible surface discharge of slurry.

Quadrat surveys at both the basin and control sites were conducted near the shoreline at water depths between 0 and 3 m below high tide level (Plate 7). The algal communities within these bands were similar in their exposure to wave action, composition, tidal range, and zonation. Within these bands were three zones of algal growth, each dominated by different algae, although at times the zonation pattern became indistinct. Furthest and highest from the ocean was an elevated splash zone consisting of closely cropped growths of the red alga *Ahnfeltia concinna*; an intermediate and highly diverse zone was composed of up to 12 species of algae; and a third, lower supra-surge zone was dominated by the encrusting red coralline alga *Porolithon onkoides* and the brown alga *Sargassum* sp. Quadrat surveys included sampling of all three zones at both sites.

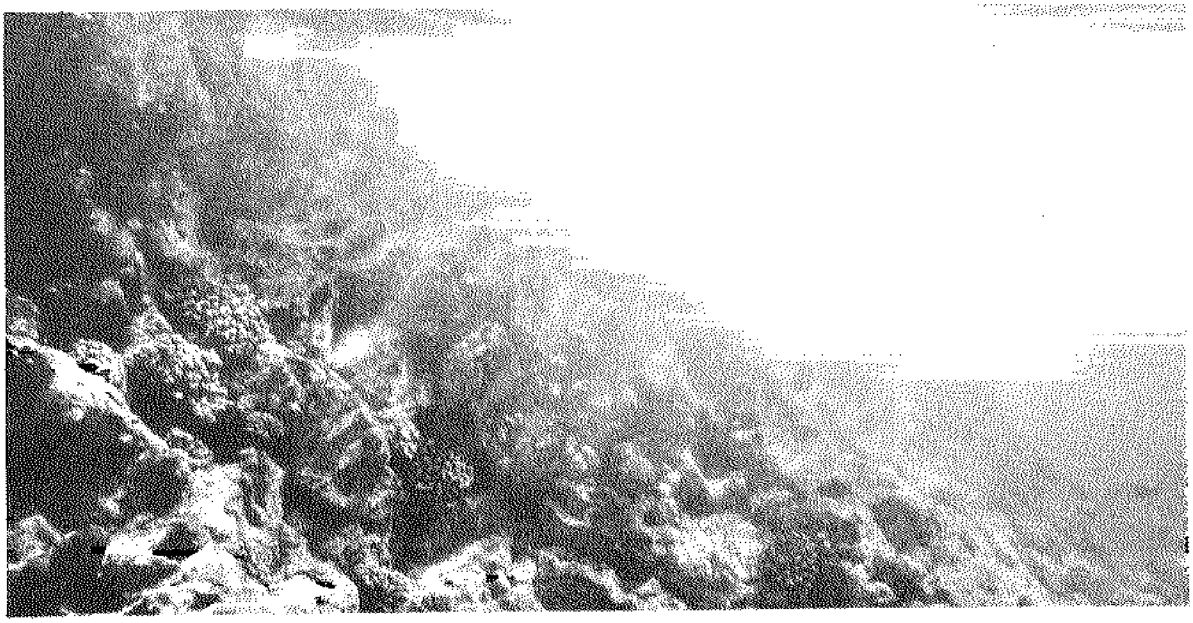


Plate 7. Upper submerged shoreline showing algal and coral communities offshore from the settling pond

A meter square quadrat with 121 points of intersection was used to estimate the species composition and relative abundance of algae within the 3 m wide band close to the settling basin and control sites (Plate 8). The species of algae or type of substratum (e.g., rock), lying directly under each intersection point of the quadrat was recorded by a diver on a plastic slate and later transcribed to data sheets.

The first series of surveys were performed on August 31, 1974, shortly before commencement of sand recovery operations. Starting points at both sites were permanently marked by driving a metal spike into the rock substratum. From these starting points a line marked off at 5-m intervals was laid following the contour of the shoreline.

At the settling basin site, the quadrat was placed at the starting point (0 meter) and at distances of 5 and 10 m from the starting point.

Plate 8. A diver estimating the abundance and composition of the algal community using a one meter square quadrat

At the control site the quadrat was placed at a point 15 m from the stake. At these positions data were collected by noting what lay under the intersection points.

On November 30, 1974, after the sand mining operation ended, data were collected at both the settling pond and inlet pipe sites. However, wave action prohibited the collection of data from the 10-m position.

The quadrat sampling method, normally used to estimate substrate coverage in deeper waters subject to less surge, proved cumbersome and was subject to error when used in the surge and supra-surge zones. At the control site, wave action made it impossible to place and anchor the quadrat at positions other than the 15-m point. Error was also incurred due to movement of the quadrat while collecting data at all positions; this error was not quantified.

The quadrat surveys were supplemented by occasional observations along the boundaries of the settling basins in order to document overflow and discharge of slurry, if any, back into the ocean and to pinpoint the sites of impact, so that they could be examined more closely.

Fishes

Field surveys of fish populations consisted of transect censuses and general diver observations of fish behavior. The transect surveys were conducted along the same 50-m lines established for the coral quadrat surveys at both the SSRS and control sites. Both transect lines at the SSRS site and the inshore transect line at the control site were censused for fishes in August, October, and December 1974, representing surveys before, during, and after SSRS operations.

The fish censusing technique corresponded to a variation of the method developed by Brock (1954). Precautions were taken not to disturb the fish or swim within the transect areas before and during fish censuses. The numbers and species of fishes observed along each transect line were recorded on underwater slates. The diver recorded and enumerated only those fishes observed within 3 m on either side of the transect line. Only those fishes readily observable were recorded. Upon completion of the fish transects at each site, the diver swam throughout the general area and recorded fish species not seen along the transect line. Fishes observed in this manner were recorded as species only, without enumeration. Identical methods were used at each transect site for each series of surveys.

RESULTS

Crater Formation and Degeneration

The process of excavating sand via the SSRS resulted in the formation of conical depressions or craters (Plate 9) with the recovery probe situated in the apex position (Plate 10). These craters, formed from a single recovery probe location, were characterized by uniform sloping walls and a nearly symmetrical conical shape. Due to variations in sand particle size and composition and their effects on hydraulic properties, some minor slope variations were observed in the lower regions of each crater (Figure 7).

Utilization of a fluidizing pipe to excavate sand increased recovery efficiency at each probe location (Plate 11) and modified the shape of the sand depressions. Water streams issuing from the pipe perforations eroded limited sections of the crater wall and fluidized the sand, carrying it to the crater apex where recovery via hydraulic suction took place. An originally symmetrical crater would undergo various transformations, including diameter extension and decrease in wall slope, through use of the fluidizing pipe. In one instance the fluidizing pipe generated depressions which connected and subsequently incorporated several isolated craters into an irregularly shaped conglomerate crater.

The pumping of sand from each crater caused the formation of a sand migration zone of up to 3 m in width around the perimeter of the crater. Increasing in size with elapsed time, the zone progressively widened to a maximum of 15 m. The sand dynamics during excavation in a typical crater is shown in Figure 7.

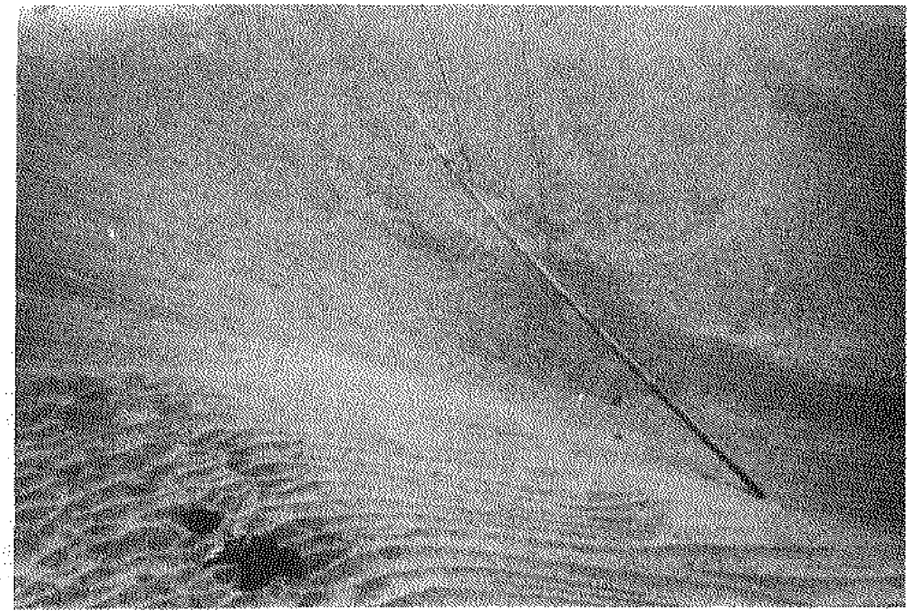


Plate 9. The upper edge and wall of a sand crater at Keauhou Bay created during the recovery of sand using the SSRS. In the background is the sand fluidizing pipe.

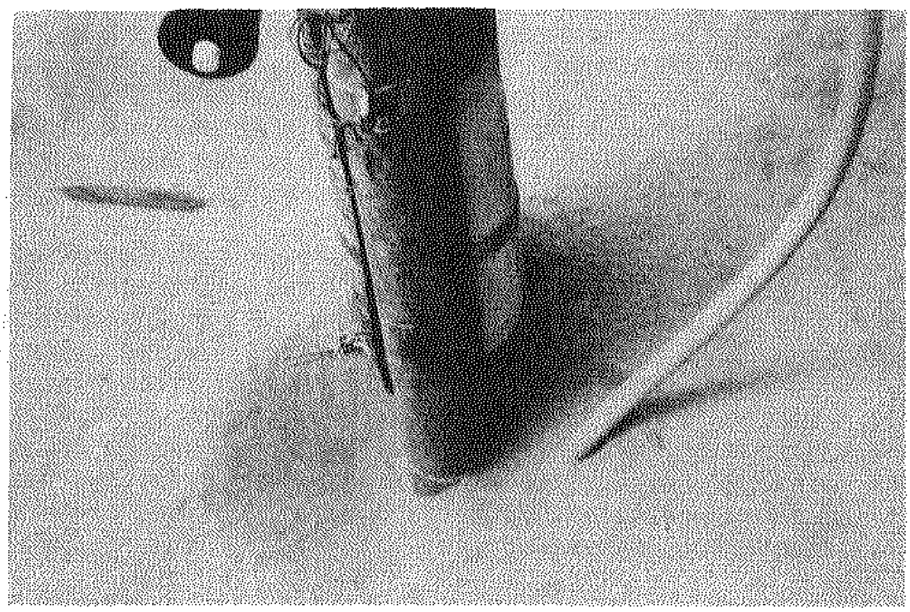


Plate 10. The sand recovery probe buried in the apex position of a crater excavated by sand recovery operations. The probe was not in operation at the time the photo was taken.

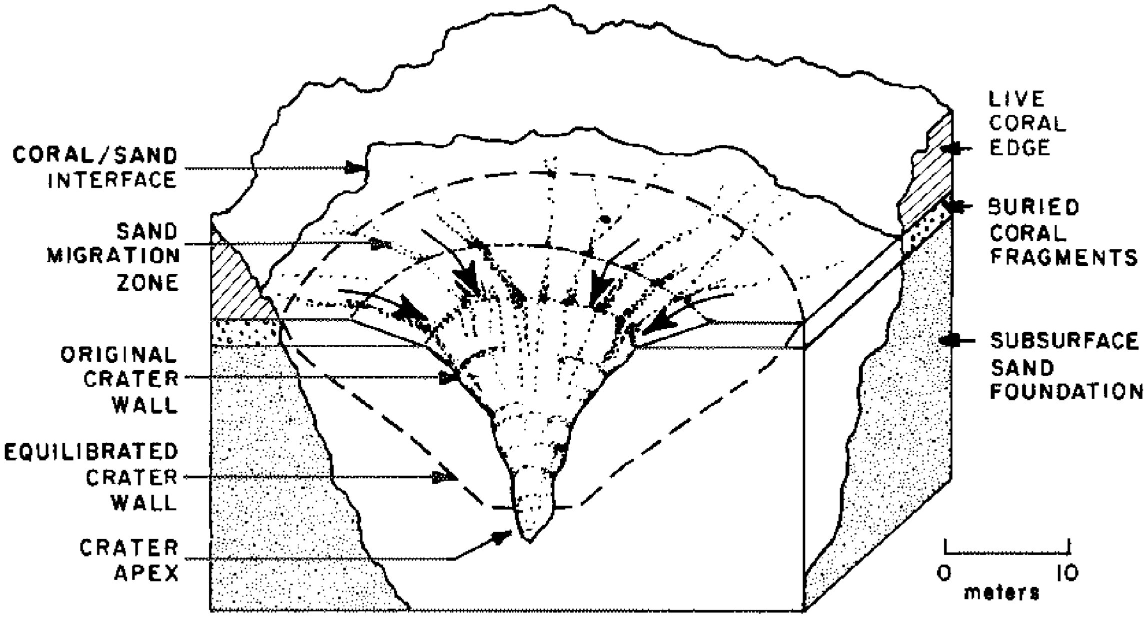


Figure 7. Diagrammatic representation of an excavation crater and sand migration zone during recovery operations

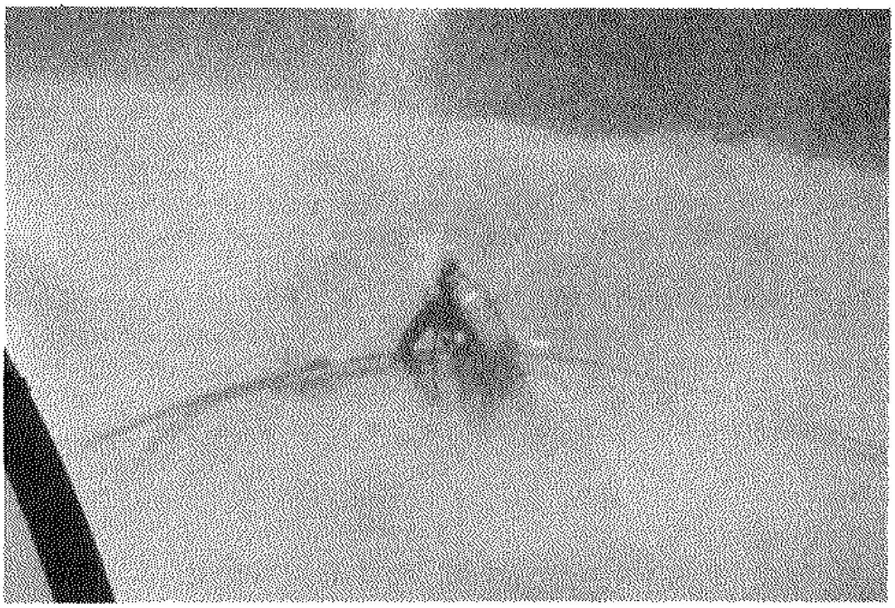


Plate 11. Diver moving the PVC fluidizing pipe to another location at the SSRS site at Keauhou Bay

A gentle sloping of the sand surface into the craters coupled with the variation in sand color between freshly uncovered, grayish or poorly oxidized sand and the lighter-shaded, well-oxidized surface material served as a significant indication of the migration zone. Another sign of freshly uncovered sand was the presence of small, well-defined ripples or rills in the migration zone surrounding each crater rim. The original sand surface adjacent to this area did not display this pattern, but was distinguished by irregular indentations and subtle contours assumed to characterize relatively undisturbed sand deposits.

Post SSRS degeneration of newly formed crater walls was expressed as changes of crater slope and diameter. With further passage of time, the underlying degeneration pattern observed for all nine craters included an increase in diameter, a decrease in wall slope, and a decrease in crater apex depth.

By the September 21 observational dive, the probe had been relocated to the second recovery position for two days, allowing the first crater to adjust for the same length of time. The wall of the original crater appeared uniform in degree of slope except for an increase in steepness at the apex where material of a greater compactness was presumed to exist. By the March 15 dive, the entire southeastern end of the shallower portion of the deposit was transformed into a large conglomerate depression of what was previously the location of several well-defined excavation craters.

The general pattern of overall softening of crater rim and wall slope with further passage of time was observed in all successive craters. The maximum distance from which sand migrated towards a crater rim was approximately 15 m, as observed on the March 15 dive. It should be noted that the distance itself was dependent upon rim location and crater diameter, both of which changed with passage of time.

Observed during the September 10 and September 21 dives was a 15 to 25 cm layer of semi-fluidized, fine-grained sand covering the crater walls. This segment of somewhat "elastic" sand proved uniform in thickness and homogeneous in consistency. Upon penetration of the entire band, a foundation of coarser, more compact sand was encountered underneath.

The upper band of "elastic" sand was assumed to represent the finer-sized remnants of what once comprised the moving layer of fully fluidized and resuspended sediment previously generated during actual recovery operations. Termination of the suction action in the crater apex allowed the fluidized sediment layer to settle out and form the observed bottom layer.

Stake Surveys of Sand Deposit

Monitoring changes in the depth of the sand deposit at various locations and times using the stakes as reference points revealed that the SSRS operations caused only localized deepening and no lateral shifting of the deposit. The results of the stake measurement studies (Table 3) indicated that all areas of the deposit deepened with time, but that the most pronounced changes occurred at the stake sites closest to the excavation craters where a maximum depth increase of 106 cm was reported, while the deposit at the other stake sites showed depth increases of only 39 cm or less. The depth increases along sectors of the deposit away from the SSRS operations and craters were probably caused by natural transport and fluctuation of sand into deeper craters by currents and waves. The deepest portion of the deposit terminated as a sand channel appearing to descend to great depths, and it is likely that sand was transported from the deposit downslope through the channel.

These results were also supported by diver observations which indicated that sand migration towards the craters was localized and most conspicuous in the southeast corner of the deposit where the craters were concentrated.

Depletion of sand at the coral reef-sand deposit interface exposed previously buried reef rock which could be distinguished from the other reef rock by the absence of the characteristic algal film and by color differences. Much of the reef rock was unconsolidated, and coral rubble and fragments fell into the deposit and migrated towards the craters, sometimes clogging the suction device during pumping. The loss migration of coral fragments towards the SSRS apparatus also undermined the edge of the coral community causing the collapse of some of the fingercoral colonies (*Porites* spp.).

Monitoring changes in the horizontal distance from the edge of the deposit to the stakes at various locations and times revealed that the SSRS operation did not appreciably change the position and area of the deposit (Table 4). Measurements at only 4 of the 20 stakes indicated a reduction or contraction of the surface area of the deposit while the remaining stake measurements revealed no changes at all. As expected, the greatest reductions occurred at the stake locations nearest the SSRS operations and craters, but none of the changes exceeded 89 cm. As with the depth changes, the horizontal distance changes were attributed to the removal of the sand by SSRS operations near the boundary of the deposit resulting in the exposure of reef rock and the corresponding "shift" in the coral reef-sand deposit boundary (Figure 7). It is important to mention that the sand deposit itself was surrounded by an elevated coral reef and this arrangement would hinder lateral shifting of the deposit sand.

Beach Profile Studies

Single profiles taken on separate dates at Disappearing Sands Beach are shown on Figure 8. The mean lower low water (MLLW) datum provided by the National Ocean Survey Tide Tables (1974, 1975) was used as a base of estimation. A definite increase in the horizontal length of the backshore or berm with the row of coconut palms as reference points occurred (Figure 8). This seaward increase in beach volume concealed boulders previously exposed in the foreshore and swash zones of the July 24 profile. The overall volume of the beach increased during the mining operations.

TABLE 4. HORIZONTAL MEASUREMENTS FROM THE STAKES TO THE BOUNDARY OF THE SAND DEPOSIT BEFORE AND AFTER SSRS OPERATIONS

Stake number	Measurement on 9/10 Dive (cm)	Measurement on 3/15 Dive (cm)	Net distance change (comparing first and last surveys) (cm)
1	61	61	0
2	94	183	-89
3	30	43	-13
4	36	36	0
5	38	38	0
6	25	25	0
7	160	160	0
8	-	-	-
9	41	41	0
10	28	28	0
11	91	135	-44
12	152	152	0
13	38	38	0
14	18	18	0
15	15	15	0
16	51	51	0
17	38	38	0
19	50	50	0
20	30	99	-69

Note: A (-) value indicates contraction of the deposit or shift of the boundary towards the center of the deposit. No (+) values were reported during the study.

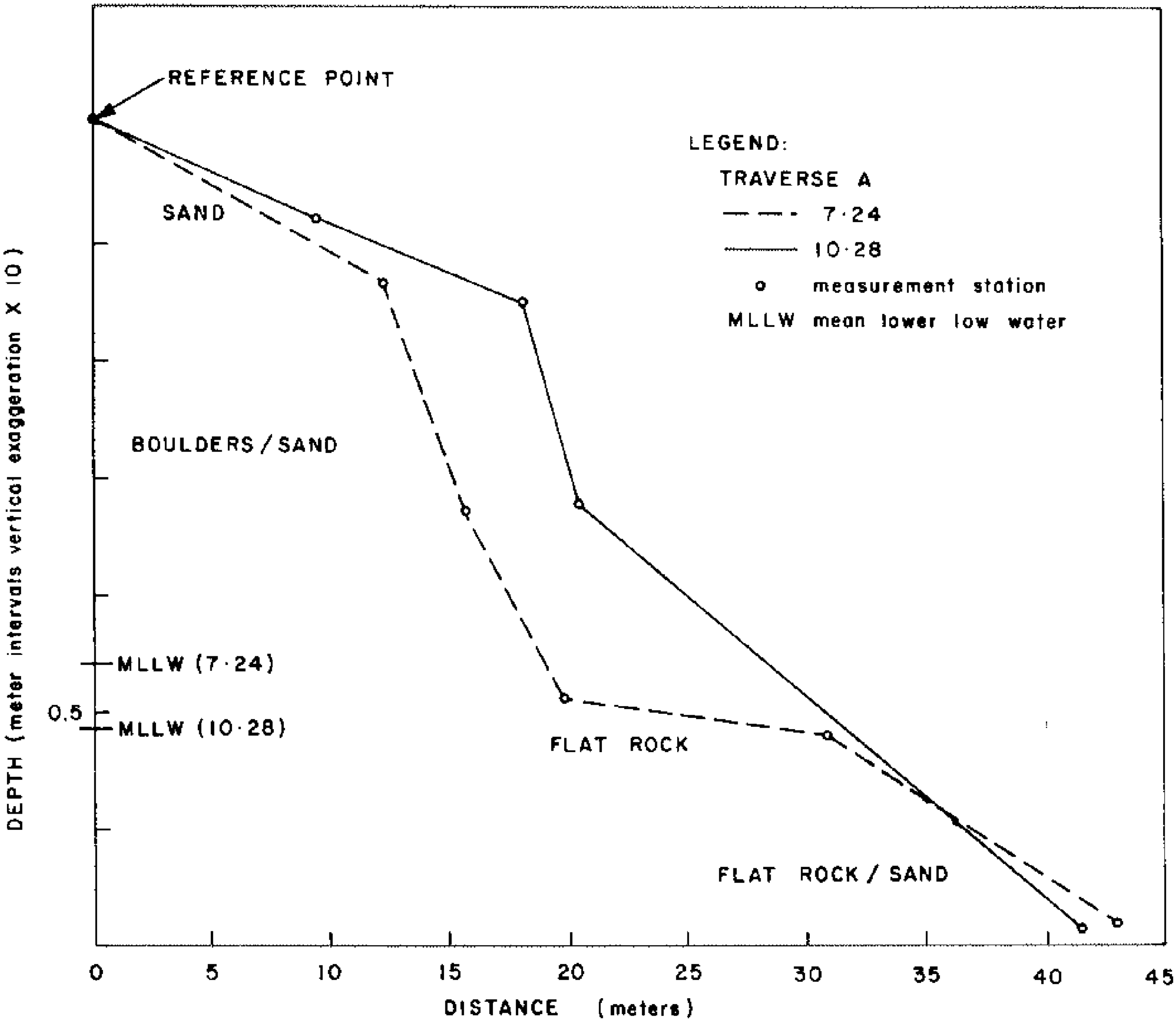


Figure 8. Beach profiles of traverse A at Disappearing Sands Beach taken before and after sand mining operations

Profiles of the three Kahaluu Beach Park traverses are depicted in Figures 9 and 10. Profile C of the northermost traverse on the beach revealed no significant erosion (Figure 10). Morphological changes at the traverse were limited to relocation of runnels and ridges in the foreshore/backshore; estimated beach volume remained constant. Profile A for Kahaluu Beach Park was the only profile to reveal an estimated decrease in beach volume. The two profiles for traverse A were identical except for a 2.75 m shortening of the backshore area which was observed on the October 28 visit.

Not indicated on Figure 2 of Kahaluu Beach Park is a small intermittent groin running from the shoreline at the southern park boundary to approximately 75 m offshore of traverse C. This groin may have influenced beach dynamics during the study.

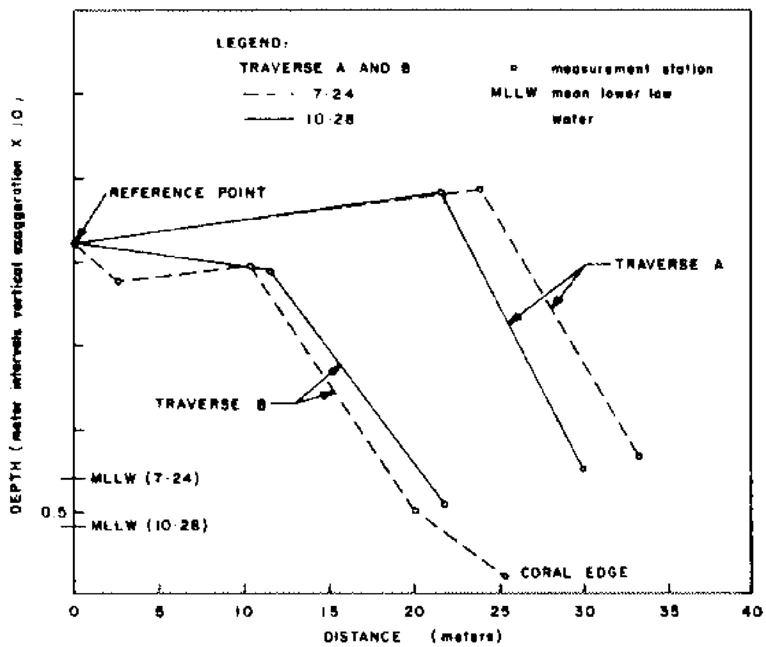


Figure 9. Beach profiles of traverses A and B at Kahaluu Beach Park taken before and after sand mining operations

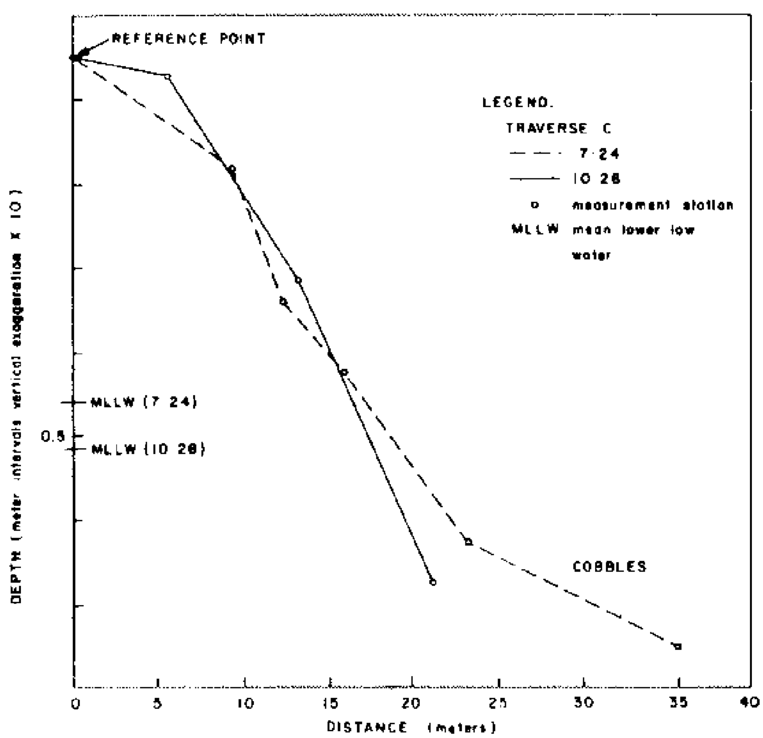


Figure 10. Beach profiles of traverse C at Kahaluu Beach Park taken before and after sand mining operations

These surveys revealed that changes to the beach volumes or configurations could not be correlated in time with mining activity at the test site. Furthermore, most of the observed changes were accretional rather than erosional, indicating that beach changes were not attributed to the excavation of sand at the offshore test site.

At the Keauhou Bay site, no appreciable submarine migration of sand was observed between the onshore beaches, which were at a minimum of 1.25 km from the test site, and the offshore deposit. The long distances between the beaches and the test deposit site suggest interrelated sand transport to be unlikely. This contention was further supported by diving observations which revealed no physical connection between the test deposit and the nearest beaches. In fact, the test deposit site was surrounded by massive and flourishing coral formations whose physical presence virtually eliminated the possibility of large-scale sand transport between the deposit and the beaches.

Resuspended Sediments

In most instances the jetting-in procedure caused only a limited amount of sediment to be resuspended; most that remained suspended after a few minutes appeared to be sediment particles of extremely small size (mud or clay-sized). These observations were supported by sediment observations in the craters which revealed that fine sediments were the last to settle out, forming a distinct layer several centimeters thick. Additional sediment was also placed in suspension when the crater expanded in size due to sand removal. This caused the collapse or slumping of sediment towards the central depression of the crater where the suction probe was located.

Operation of the fluidizing pipe also generated plumes of sediment composed of small-sized particles. The fluidizing pipe also created small moving plumes of sediment or "turbidity currents," but these were usually confined to the crater depression in "channels" created by the transport of sand along the pipe down the crater walls.

Negligible amounts of sediments were also suspended by the feeding activities of goatfish (weke) which congregated at the recovery site during operations; these fish were apparently feeding on polychaete worms exposed during the collapse and removal of sand from the deposit.

Negligible quantities of sediments were also rafted on the ascending air bubbles produced by scuba divers working within the crater during recovery operations. This phenomenon resulted in a small amount of fine sediment being carried upward above the suction probe of the recovery apparatus. Divers also stirred up bottom sediments with their swim fins.

The combined effect of all these sediment-generating mechanisms produced a turbid plume of water which on all but one occasion remained confined to the immediate vicinity of the crater (Plate 12). Although the amount of turbidity (and resuspended sediment) increased as recovery operations during any one day progressed, the size of the excavated crater also increased proportionately to accommodate most of the generated sediment. In all cases, the sediment-laden turbidity plume remained confined below the upper edges of the crater walls. At the end of a day's recovery operations, the plume remained visible within the crater for several hours but usually dissipated completely by the following morning.

Plate 12. Sediment plume generated during operation of SSRS probe is shown.

Horizontal underwater visibility estimates recorded at various times throughout the SSRS study indicated that general water visibility was not affected by the operations except in the immediate vicinity of the crater being excavated. The lack of strong surge currents and tidal currents at the sand recovery site resulted in only limited transport of turbid water beyond the craters.

On one occasion, a plume of fine sediment was transported south over a section of the flourishing fingercoral communities beyond the sand deposit boundary located nearby (Plate 3). Observations during and after the transport of turbid water revealed the plume had no visible or measurable effect on coral or other marine life. The sediment did not settle out on the coral because of the small size of the suspended particles. The plume was completely dissipated by the morning of the next day. The corals exposed to the turbid plume were monitored the next day and again during the next visit to the site one month later; no visible short or long-term effects were detected.

It appears that turbidity attributed to sediment resuspension during recovery operations resulted in two to threefold increases over ambient levels. Turbidity measurements using the Hach instrument (Tables 5 and 6) indicated that the maximum readings of 150 JTU were confined to within 1 m of the suction probe during operation. The values dropped quickly to 10 JTU at 15 to 30 m from the probe on the downcurrent side. The ambient or background levels of turbidity ranged from 0 to 10 JTU with most of the values falling within the 3 to 5 JTU range. Measurable day-to-day variations in turbidity were also affected by wave and tidal conditions during the time of measurement.

TABLE 5. WATER QUALITY ANALYSES DATA: SSRS FIELD TEST--KEAUHOU BAY, HAWAII

Date	Location	Depth	O_2 (ppm)	NO_3/NO_2 (ppm)	pH	PO_4 (ppm)	Turbidity (JTU)
Oct. 3	test site	Surface	10	19	8.6	0.4	10
Oct. 3	test site	25 ft	11	16	8.6	0.05	10
Oct. 3	test site	55 ft	9	14	8.6	0.2	5 ?
Oct. 3	control site	Surface	11	12	8.6	0.10	10
Oct. 3	control site	25 ft	11	11	8.6	0.05	0
Oct. 3	control site	50 ft	10	14	8.7	0.05	5
Nov. 18	test site	Surface	10	15	7.0	0.15	8
Nov. 18	test site	30 ft	11	15	6.95	0.20	5 ?
Nov. 18	test site	65 ft	10	14	7.1	0.10	10
Nov. 19	control site	Surface	10	16	7.1	0.4	5

Note: Measurements taken along a vertical axis immediately above suction probe at test site and above sand deposit nearest the transects at the control site.

TABLE 6. WATER QUALITY ANALYSES DATA AT SSRS FIELD TEST SITE: TURBIDITY READINGS

Sample Location	Turbidity (JTU)
At suction probe	150
50 ft downcurrent (S)	10
100 ft downcurrent (S)	10
200 ft downcurrent (S)	3
50 ft upcurrent (N)	3
300 ft upcurrent (N)	3
Surface	5

Note: Turbidity readings taken horizontally 10 ft above bottom on November 15, 1974 at 65 ft depth

The sediment trap experiments which represent long-term studies of sediment resuspension failed to provide any measurable or significant differences between recovery site and control site values and between recovery-time and down-time values (Tables 7 and 8). Comparison of the sediment volume rates, sediment weight rates, grain size, mud fraction, or percentage of carbonate data likewise did not uncover any trends, patterns, or differences in these values which could be solely attributed to mining activities. It is interesting to recall that a layer of very fine sediment was reported to have settled out within one crater after termination of sand recovery operations. The lack of this sediment layer within the sediment traps located within 30 to 100 m from the suction probe indicates that only limited quantities of fine sediments were transported and settled beyond the craters and supports the observations that the most turbid water generated by recovery operations remained confined to the excavation sites.

TABLE 7. SUMMARY OF SIZE FRACTION ANALYSES ON RESUSPENDED SEDIMENT SAMPLES FROM SEDIMENT TRAPS

Location	Time Interval	Gravel	Mean Phi Size	Percentage of Mud (Size)
Mining Site-East	1	-	2.21	5.18
	2	-	2.78±0.02	14.0±0.3
	3	-	2.52±0	8.8±0.4
	4	-	1.69	0.73
Mining Site-South	1	+	2.72±0.01	19.1±3.6
	2	-	2.50±0.05	9.6±0.3
	3	-	2.67±0.06	9.9±2.1
	4	-	2.75	10.9
Control Site	1	-	2.27±0.06	16.7±2.5
	2	-	2.72±0.03	18.3±5.3
	3	+	2.54±0.09	14.9±3.1
	4	-	2.57±0.02	12.1±1.2

+ = present, - = absent

TABLE 8. SUMMARY DATA ON SEDIMENTATION RATES IN TRAPS

Time Interval	Sediment Volume (ml)	Sediment Weight (gm)	Sediment Rate ($ml/day/cm^2$)	Sediment Rate ($gm/day/cm^2$)	Percentage of Carbonate (resuspended sediment)	Percentage of Carbonate (bottom sediment)
Mining Site-North						
1	17.5	12.5	0.6	0.4	83	83
2	15.8±1.1	6.8±0.5	1.0	0.5	91±3	
3	130.0	86.6±12.1	3.3	2.2	87±1	
4	625.0	498.5	21.6	16.6	84	
Mining Site-South						
1	13.0±2.0	5.6±1.1	0.4	0.2	76±6	94
2	19.4±0.1	8.7±0.3	1.2	0.6	88±1	
3	44.0±7	31.0±5.0	1.1	0.8	83±2	
4	200.0	153.0±6	6.9	5.1	96±1	
Control Site						
1	11.9±1.5	3.1±0.3	0.4	0.09	85±1	58
2	9.4±0.4	2.4±0.1	0.6	0.16	84±4	
3	14.8±4.2	5.6±1.5	0.4	0.14	91±6	
4	29.0±2.0	15.9±1.8	1.0	0.53	98±1	

The sediment trap experiments did show that wave and current variations can result in considerable temporal fluctuations in the quantities of resuspended material transported over and deposited in the traps. The largest accumulation rate of 16.6 $gm/day/cm^2$ was reported at the recovery site during a time interval when no mining activity occurred but when heavy waves from a storm were generated. Conversely, the smallest values were reported during an interval of frequent sand recovery operations at the south station (the station closest to the operations). Thus, there was no logical correlation of sediment accumulation in the traps with mining activity.

Water Quality Studies

The water quality analyses data provided in Tables 5 and 6 reveal that changes in the concentration of dissolved oxygen, nutrients, and pH do not correlate with the presence or absence of sand recovery operations. The highest concentrations of nutrients occurred in surface waters--those most removed from the vicinity of recovery operations. Thus, the hypothesis that bottom sediment disturbance and excavation could cause a liberation of nutrients was not supported by the data. The near constancy in the pH and dissolved oxygen values also suggests little interaction or effect by sand recovery operations (Table 5). The abnormally low pH values reported for all recovery and control site measurements taken during the second series are likely the result of machine malfunction, analytical errors, cooler water temperatures, or some combination of these.

Coral and Echinoderm Surveys

Quantitative transect surveys

The quadrat surveys along the transects indicated that live coral covers 80 percent or more of the substratum at both the sand recovery and control sites (Table 9). Furthermore, eight or more species of corals were reported within the quadrats along each transect, and *Porites compressa* and *Porites lobata* accounted for over 90 percent of the live corals (Table 10). Thus the surveys confirm the results of the earlier surveys performed for the EIS, that the SSRS site is surrounded by flourishing coral communities (Plate 13).

Using total live coral coverage estimates (Table 9), comparison of replicate transect surveys conducted one after the other along the transect lines indicated the accuracy of the quadrat technique to be between 1 and 2 percent. However, there was more variation when comparing the coverage of the individual species, indicating the method is less accurate (5 to 10 percent error) at this level (Table 10). This greater degree of error at the individual species level could be attributed to mistaken or inconsistent identification of some of the corals, the overlooking of some concealed or small corals during one of the two surveys, and the movement of the transect line over short distances causing sampling errors.

TABLE 9. TOTAL PERCENTAGE OF LIVE CORAL COVERAGE WITHIN INDIVIDUAL QUADRATS AT BOTH CONTROL AND MINING SITES BEFORE AND AFTER SAND MINING OPERATIONS

Quadrat	Control Station		Sand Mining Station	
	before	after	before	after
1	97.5±0.4	98	100.0±0	92.5±4.5
2	99.0±0.8	100	71.0±0.8	70.5±1.2
3	97.5±0.4	100	72.5±0.4	78.5±2.9
4	99.5±0.4	100	84.0±0	93.5±1.2
5	96.5±0.4	99	63.5±2.0	71.0±4.5
6	98.5±1.2	98	85.5±0.4	91.0±1.6
7	98.0±0.8	100	69.5±1.2	74.5±2.0
8	97.0±2.4	92	83.0±1.6	85.0±0
9	96.0±0	98	88.5±2.0	88.0±0
10	98.5±0.4	100	78.5±1.2	85.5±0.4
11	47.0±1.6	46	43.5±0.4	42.5±0.4
12	56.0±2.4	49	94	91.5±1.2
13	98.5±0.4	100	56	57.0±1.6
14	95.0±1.6	98	70	66.5±2.0
15	99.5±0.4	100	78	78.5±0.4
16	99.0±0.8	N.D.	77	77.0±0
17	15.5±0.4	23	82	82.0±0
18	18.5±0.4	N.D.	85	83.5±1.2
19	74.5±2.9	N.D.	82	84.0±1.6
20	96.0±2.4	N.D.	70	71.5±1.2
21	95.5±0.4	97	74	73.5±0.4
22	95.5±0.4	98	85	91.5±5.3
Mean	84.9±1.0*	85.9	78.2±1.0*	78.6±1.6*

Note: The numbers following the "±" designation are standard deviations from the mean which were computed only for quadrats where more than one survey were conducted. An asterik indicates the mean standard deviation. "N.D." designates data were not obtained or lost because of accidental movement of transect line.

TABLE 10. AVERAGE PERCENTAGE OF LIVE COVERAGE BY INDIVIDUAL SPECIES OF CORALS, CORALLINE ALGAE, AND OTHER BOTTOM TYPES FOR BOTH THE CONTROL AND MINING SITE TRANSECTS BEFORE AND AFTER SAND MINING OPERATIONS

Species	Control Station before	Control Station after	Sand Recovery Stations before	Sand Recovery Stations after
Deep Transect (quadrats 1-11)			South Offshore Transect	
Porites lobata	38.2±2.0	41.9	9.6±0.4	15.0±0.4
Porites compressa	51.2±0.5	49.1	68.0±0.3	61.6±2.0
Pocillopora meandrina	0.3±0	0.3	0.4±0.1	0.4±0.04
Palythoa sp.	0.1±0	0.1	0	0
Pavona varians	0	0.1	0.4±0.04	0.3±0
Montipora verrucosa	0	0.1	0.2±0.04	0.4±0.1
Anthelia (=Sarcothelia) edmondsoni	2.1±0	1.6	0.3±0	0.4±0.2
Montipora patula	-	-	0.4±0.1	0.2±0.04
Coralline algae	0.1±0.04	0.5	1.1±0.1	0.4±0.04
sand	2.8±1.7	0.6	4.6±0.7	9.6±0.8
rubble	5.3±0.2	5.6	14.8±1.2	11.9±0.5
Shallow Transect (quadrats 12-22)			East Inshore Transect	
Porites lobata	40.6±0.8	N.D.	22.2±0.3	21.8±0.4
Porites compressa	33.2±0.9	N.D.	50.4±0.4	52.0±0.4
Pocillopora meandrina	0.4±0.04	N.D.	0.2±0.04	0.2±0.1
Palythoa sp.	0.2±0.04	N.D.	0	0
Anthelia (=Sarcothelia) edmondsoni	1.8±0.4	N.D.	0	0.2±0.2
Montipora verrucosa	0.5±0.1	N.D.	0.9±0.2	0.8±0.2
Coralline algae	0.8±0.6	N.D.	0	0.5±0
sand	2.2±0.9	N.D.	9.7±0.5	8.6±0.7
rubble	20.5±1.7	N.D.	15.0±0.4	15.2±0.1
Cyphastrea ocellina	0	0	0	0.05±0.04
Montipora patula	0	0	0	0.2±0.04

Note: Numbers following the "±" designation are standard deviations from the mean which were computed only for transects where more than one survey were conducted. "N.D." designates data were not obtained or were lost because of accidental movement or disturbance of the transect line.

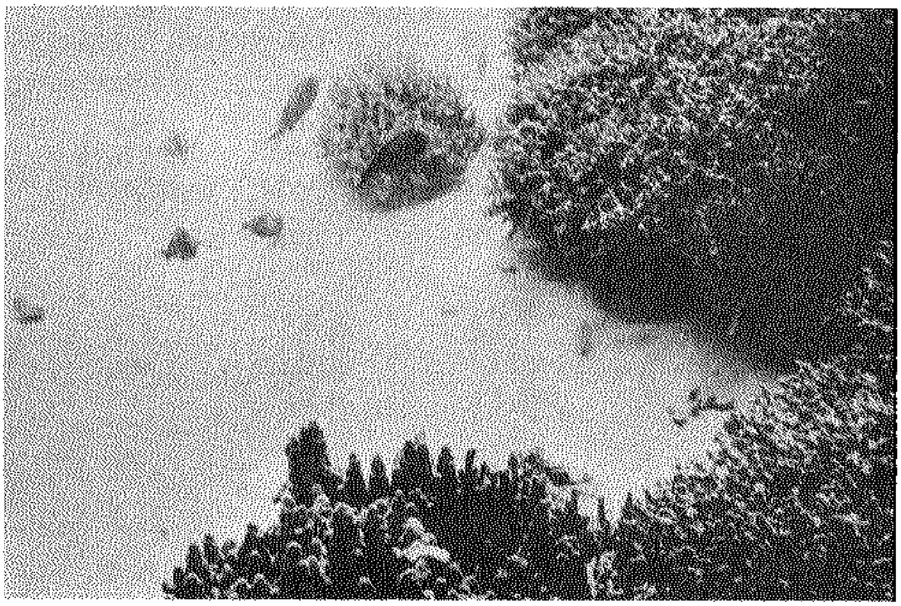


Plate 13. A typical section of the boundary between the coral community and sand deposit at the SSRS test site prior to mining operations

No significant change in the total coverage of living corals at the sand recovery transects was reported. Variations within replicate surveys were greater than or comparable with variations between the means of the before and after surveys. Comparing replicate and before and after transects showed that the variation in abundance of individual coral species was similar. Nevertheless, the total coverage of all live coral species showed a slight increase, and there was no consistent trend of either a decrease or increase of certain species.

The analysis of the replicate and the before and after surveys conducted at the control station yielded similar results. The variations between replicate surveys were of a magnitude comparable with that between the before and after surveys. The coverage of individual species again was more variable, but no consistent pattern nor a net decline or increase in coverage was reported. The amounts and patterns of variations in live coral abundance were very similar at both sand recovery and control transects. Any effects attributed to recovery operations were too small to be detected by the surveys.

Analysis of the replicate transect survey results for the sea urchins indicated widely fluctuating densities, even over short time periods. In comparison with sessile or attached organisms such as corals, sea urchins are capable of rapid and active movement and migration over the reefs. The data provided in Table 11 show, for example, that the average density of sea urchin species may change two to threefold over a two-week period and that the comparison of before and after surveys at the same quadrat locations are rendered meaningless due to the fluctuations. In fact, some species were common during one survey but completely absent during latter surveys.

TABLE 11. SEA URCHIN DENSITIES REPORTED AT BOTH CONTROL AND MINING SITES BEFORE, DURING, AND AFTER MINING OPERATIONS

Control Site Transects	Before 8/27/74 (number/m^2)	During 10/20/74 (number/m^2)	After 12/27/74 (number/m^2)
Deep			
Heterocentrotus mammillatus	1.4	N.D.	1.1
Tripneustes gratilla	0.1	N.D.	0
Echinothrix diadema	0.1	N.D.	0
Echinometra mathaei	p	N.D.	0
Echinothrix calamaris	0.1	N.D.	0
Shallow			
Echinothrix diadema	0.1	0	0.1
Echinometra mathaei	p	p	0
Echinothrix calamaris	0	0.3	0
Heterocentrotus mammillatus	1.6	1.5	1.8
Tripneustes gratilla	0.5	0.4	0.9

Mining Site Transects	Before 8/26/74 (number/m^2)	During 10/20/74 (number/m^2)	During 10/5/74 (number/m^2)	After 12/27/74 (number/m^2)
East Inshore				
Heterocentrotus mammillatus	4.1	2.8	3.4	2.0
Tripneustes gratilla	3.8	6.3	2.4	1.0
Echinothrix diadema	0	0	0	0
Echinothris calamaris	0.3	0.2	0	0
Echinometra mathaei	p	p	p	p
Chondeocideris gigantea	0.1	0	0	0
Pseudoboletia indiana	0	0.2	0	0
South Deep				
Tripneustes gratilla	1.7	2.5	2.7	2.7
Echinothrix calamaris	0	0.2	0.1	0
Echinothrix diadema	0	0	0	p
Echinometra mathaei	p	p	p	0
Heterocentrotus mammillatus	3.5	1.0	3.7	2.9

Note: "p" = present but not counted. "N.D." designates data were not obtained or were lost due to accidental movement or disturbance of the transect line.

Qualitative diver observations

The reconnaissance swims conducted at the sand recovery site proved valuable in providing additional evidence on the impact of SSRS operations on the geology and biology at the sand deposit.

Both diver observations and photographs (Plates 13 and 14) supported the hypothesis in the EIS (NOAA, 1974) that removal of sand along the coral boundary is capable of weakening the fragile framework of the reef and will cause fragmentation of live and dead fingercoral colonies. Observations conducted in November and December 1974 and March 1975 clearly indicate a trend of some structural damage to both live and dead coral. After the excavation of crater-like depressions in the sand deposit by recovery operations near the coral reef boundary at the southeastern corner of the deposit, the following events took place: (1) the craters began to "fill in" as a result of the migration of sand from adjacent areas; (2) the migration of sand from the coral reef boundary depressed the sand level; (3) the active crumbling and fragmenting of fingercoral undermined by the transport of sand (Plate 15); and, (4) in some cases, the active migration of some of the coral fragments down the slope in the craters.

Plate 14. Edge of sand deposit in late December 1974 showing undermining and migration of coral fragments

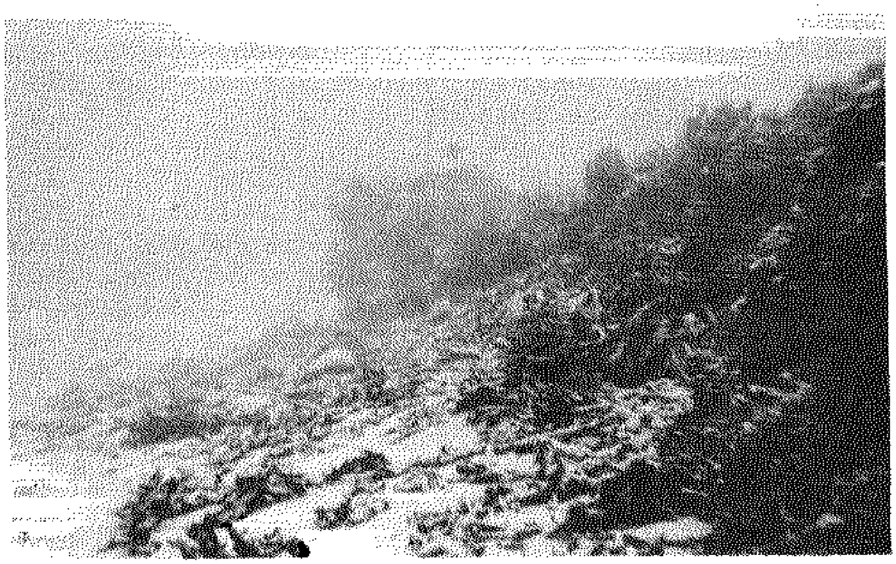


Plate 15. The zone of exposed and migrating coral fragments caused by the transport and removal of sand away from the coral reef-sand deposit boundary of the deposit by mining operations. This area showed the greatest amount of reef undermining.

These phenomena became more and more conspicuous within one to four months after termination of sand recovery operations and as the sand migration zones expanded in size away from the craters and towards the coral reef-sand deposit boundary. It is certain that given the manner in which coral appears to grow out over the sand and becomes supported by the sand (Plate 13), more damage to the framework of the reef near the interface would have occurred had more sand removal been conducted near the fingercoral reefs. The migration of coral fragments into the craters caused the suction probe to clog during operation. Subsequently, excavation of sand did not occur too close to the coral reef interface during the latter half of the recovery operations for both engineering and environmental reasons.

Diver observations also revealed that the greatest adverse impact to coral reefs was caused by the setting and dragging of platform or ship anchors (Plate 16) and by the swath and whiplash of steel cables used to moor the platform, buoys, and the ship (Plate 17). Some of the damage by anchors and cables which was particularly destructive to fragile fingercoral was unnecessary. For example, the attachment of both the ship and pumping platform to the same anchor (Plate 16) caused the anchor to drag back and forth along a section of the reef creating larger piles of broken coral. Nevertheless, it was necessary to anchor the larger structures to hard reef substrata; otherwise the anchors would drag over the sand causing movement of the ship or platform and disruption of sand excavation activities.

Diver examination did indicate that many of the broken fragments were still alive; some of these may survive and regenerate.

Plate 16. Structural damage to fragile living fingercoral communities caused by the dragging of the pumping platform and ship's anchor

Plate 17. Damage to fingercoral communities caused by the movement and swath of anchoring cables

The concrete block assembly used for the anchoring of the deep end of the metal pipe used for the transfer of offshore sand from the recovery site to the settling pond did not appear to cause much damage to the coral reef (Plate 18). The bottom near the shoreline is more rugged, less dominated by live coral, and more dominated by live filamentous and coralline algae. Furthermore, the concrete anchor appeared to be stable and did not show signs of movement. Thus, damage appeared to be limited to algae and corals (especially *Pocillopora meandrina*) which were covered or crushed by the concrete block assembly during initial placement.

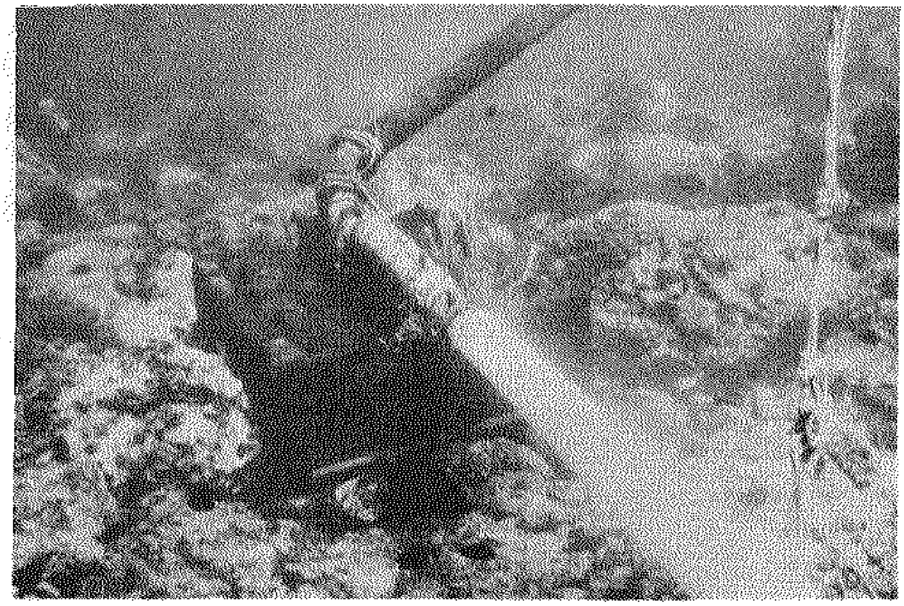


Plate 18. The concrete block assembly used to anchor the deep end of the metal pipe used for transfer of sand slurry from the recovery site to the settling basin. The block is resting on a coral reef community at a depth of about 5 m.

Diving observations conducted after termination of sand recovery operations also indicated that the sand craters or depressions may have acted as traps for sea urchins migrating across the surface of the sand deposit. On one occasion, a group of several sea urchins were aggregated at the bottom of one of the pits and were attempting to exit the crater with little success (Plates 19 and 20). The sea urchins (especially *Tripneustes*) were moving horizontally around the side of the crater rather than vertically up the wall of the crater. This peculiar behavioral pattern may have prevented the successful escape of many of the urchins. Many of the urchins were subsequently buried under slumping sediment since the craters were actively "filling in" during this time. The skeletons of several newly killed urchins were uncovered in the depressions.

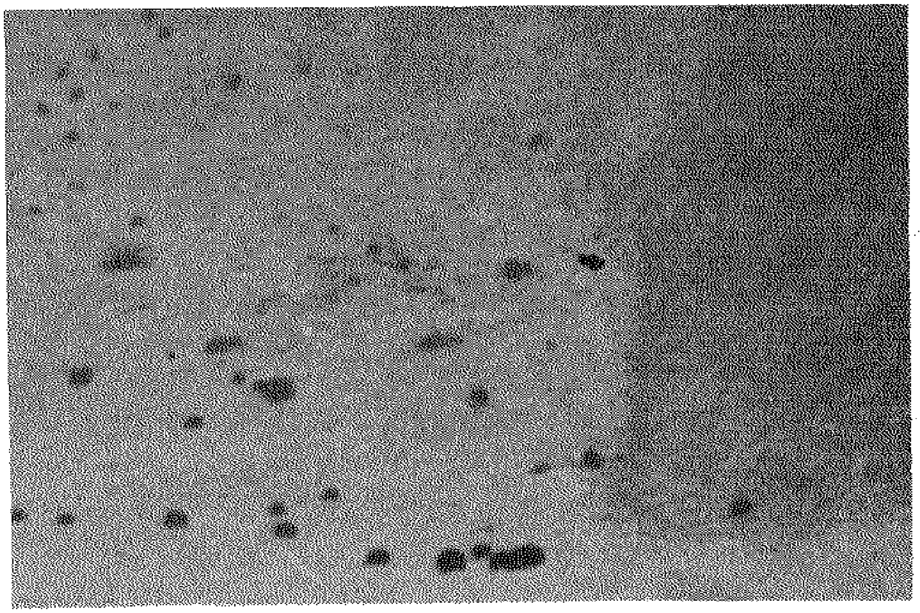


Plate 19. Sand crater excavated by SSRS showing trapped sea urchins

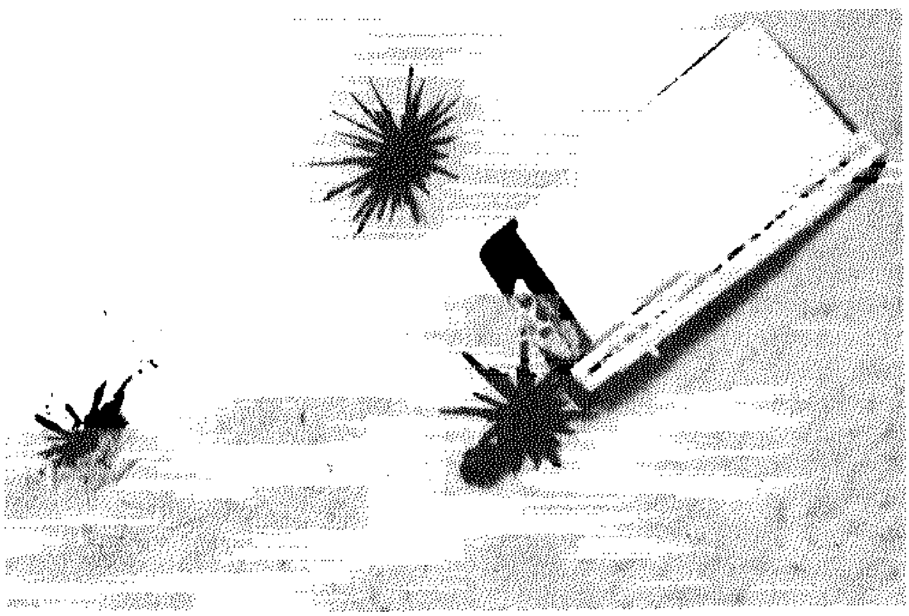


Plate 20. Close-up of trapped sea urchins in excavated sand crater. The clipboard is present for scale.

Mollusks

The quadrat surveys identified a total of 12 species and 184 individual specimens of mollusks prior to sand recovery operations in the deposit (Table 12). The random sifting method detected more numbers and varieties of mollusks than the surface quadrat techniques, supporting the hypothesis that many of the mollusks show only limited surface activity and are generally cryptic. The low numbers and varieties of mollusks reported may also be attributed to the nocturnal habit of many species. Night diving observations confirmed that many mollusks were active at night.

TABLE 12. MOLLUSCAN SPECIES OBSERVED IN THE SAND DEPOSIT PRIOR TO SSRS OPERATIONS

Species	No. of Specimens		
	Survey 1 (1 meter quadrats)	Survey 2 (50 meter quadrats)	Survey 3 (random sifting)
Cerithium pharos Hinds	-	10	-
Conus quercinus Solander	-	-	2
Hastula pencillata Hinds	-	-	43
Mitra peasei Dohrn	-	-	2
Nassarius splendidulus Dunker	-	-	2
Natica sagittata	1	-	-
Terebra affinis Gray	-	6	17
Terebra areolata Link	-	2	4
Terebra crenulata Linnaeus	-	5	-
Terebra maculata Linnaeus	3	11	3
Terebra nitida Hinds	-	-	52
Terebra propinqua (*T. collumellaris*)	21	-	-

In contrast, the wire mesh filtering of the sand slurry within the deposition basin during three sampling periods was able to recover 1,200 intact shells and major fragments belonging to 34 genera and 78 species of mollusks (Table 13). A representative assortment of shells and fragments collected from the wire mesh is shown in Plate 21. Of these, approximately 19 species (24 percent) were epifaunal mollusks which are not characteristic of sand habitats; their presence in the slurry could have been the result of current and wave transport of shells downslope into the deposit from the surrounding reef habitats or unintentional migration of the animals across the deposit and their subsequent burial. Several of the epifaunal mollusks, particularly *Cypraea* spp., were active on the coral reef during the night dive and may have approached the boundaries of the sand deposit. Thus it is likely that the source of the epifaunal species in the deposit was the coral reef habitat.

TABLE 13. LIST OF INDIVIDUAL MOLLUSCAN SPECIES RETRIEVED FROM SLURRY AT KEAUHOU BAY, HAWAII

Species	Number*
[*Acar hawaiensis* D.B.R.]†	11
[*Arca ventricosa*]§	1
Atys cornuta Pilsbry	4
Casmaria erinaceus Linnaeus	18
[*Cellana sandwichensis* Pease]	2
Charonia tritonis Linnaeus	1
Chlamys cookei D.B.R.§	33
Conus litoglyphus Hwass#	3
Conus leopardus Roding#	6
Conus obscurus Sowerby	6
Conus pertusus Hwass	1
Conus pulicarius Hwass#	26
Conus quercinus Solander#	31
Conus striatus Linnaeus#	2
Conus suturatus Reeve#	14
Conus textile Linnaeus	1
Conus vitulinus Hwass	1
[*Cypraea fimbriata* Gmelin]	6
[*Cypraea granulata* Pease]	3
[*Cypraea helvola* Linnaeus]	13
[*Cypraea isabella* Linnaeus]	12
[*Cypraea talpa* Linnaeus]	1
[*Cypraea teres* Gmelin]	1
[*Cymatium nicrobaricum* Roding]	7
[*Distorsio anus* Linnaeus]	1
Gemmula monilifera Pease#	17
Hastula lanceata Linnaeus#	22
Hastula lauta Pease#	44
Hastula pencillata Hinds#	80
Hastula strigilata Linnaeus#	18
Hydatina amplustre Linnaues	1
Imbricaria olivaeformis Swainson	2
[*Latirus nodus* Martin#]	3
[*Mitra aurora* Dohrn]	2
[*Mitra cucumerina* Lamark#]	25
Mitra mitra Linnaeus	6
Mitra peasei Dohrn#	84
Moduius t	4
Nassarius papillosus Linnaeus	1
Nassarius splendidulus Dunker#	25
Nodipecten langfordi D.B.R.§	2
Phillipia hybrida Linnaeus	2

*The number of species are the total of three separate collections, each two to three hours in duration.
†Species given in brackets are epifaunal types not characteristic of sand deposit habitats.
§Single values
#At least one live specimen was found.

TABLE 13. LIST OF INDIVIDUAL MOLLUSCAN SPECIES RETRIEVED FROM SLURRY AT KEAUHOU BAY, HAWAII (continued)

Species	Number*
Polynices pyriformis Recluz	5
Pyramidella terebellum Muller	6
Pyramidella sulcata Adams	3
[*Spondylus sparsispinosus*]§	28
Strombus dentatus Linnaeus	4
Strombus helii Kiener	6
Strombus maculatus Sowerby	1
Tellina crassiplicata Sowerby §	52
Tellina dispar §	60
Terebra achates Weaver#	14
Terebra affinis Gray#	288
Terebra albula Menke#	22
Terebra areolata Link#	35
Terebra babylonis Lamarck#	41
Terebra columellaris Hinds	9
Terebra crenulata Linnaeus#	4
Terebra dimidiata Linnaeus	2
Terebra funiculata Hinds#	17
Terebra guttata Roding	4
Terebra maculata Linnaeus#	74
Terebra nitida Hinds#	16
Terebra pertusa Born#	17
Terebra thannumi Pilsbry	1
Terebra undulata Gray	1
Terebra species#	11
[*Tonna perdix* Linnaeus]	2
Trachycardium hawaiensis D.B.R. §	6
[*Trochus intextus* Keiner]	64
Turbonilla varicosa Adams	6
[*Turbo intercostalis* Menke]	8
Vexillum affinis#	7
Vesillum interstriatum Sowerby	1
Vexillum modestum	5
Vexillum pacificum#	14
Vexillum unifasciatum Wood	1
Xenuroturris cerithiformis Powell	3

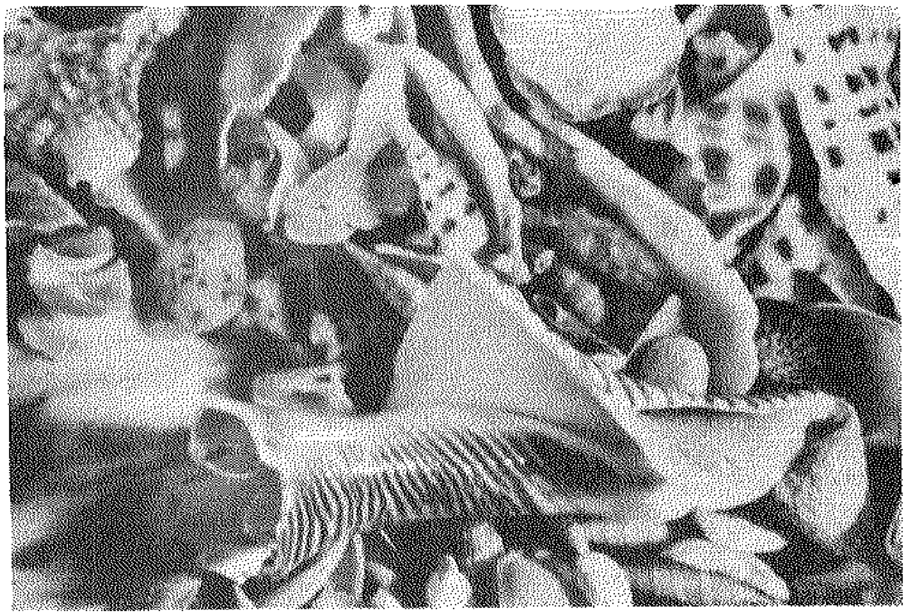


Plate 21. Typical assortment of shells and shell fragments retrieved from sand slurry during sand mining at Keauhou Bay, Hawaii, September-November 1974

Shells and shell fragments could be found in the slurry at almost any time during the sand recovery operation; obviously these shells, collected only during three one-hour periods, represent only a tiny fraction of the total shells excavated over the two months of mining. It was not possible to speculate on the depth at which the shells were collected.

Despite the high number of shells collected by the sand slurry filtering technique, only a small portion of the shells (2 to 4 percent) contained recently living animals. For example, all of the cowry shells (*Cypraea* spp.) retrieved were empty, dull, and had obviously fallen from the reef habitat into the sand deposit. A great majority of the cone shells were empty, devoid of periostracum, and polished, although a small percentage did contain living animals and an intact periostracum showing that the abrasiveness of the slurry had not made the others appear artificially old. Those species of which at least one living specimen was observed are given in Table 13. The majority of live specimens belonged to genera highly characteristic of sand environments, particularly *Conus*, *Hastula*, *Mitra*, *Terebra*, and *Vexillum*. Live specimens from only two epifaunal species were recovered.

Despite the low percentage of live specimens recovered, a conservative estimate of several thousand living mollusks was excavated during the SSRS test, based upon the number of live mollusks taken each hour multiplied by the number of hours of pumping activity. Nevertheless the sand from which these mollusks were recovered represents only a small fraction of the total sand deposit at the site; and it is unlikely that the mollusks in the non-excavated fraction nor the total mollusk population in the deposit were significantly affected by the SSRS operations.

Fishes

Table 14 lists the fish species and the numbers of each species observed along the transect lines for each of the three study periods. Also included are the species observed while swimming throughout both the project and control sites. Table 15 lists the total number of fishes and fish species observed for each study period.

The data presented in Table 15 show that the number of fishes observed at the eastern transect of the SSRS site decreased 32 percent while the number of fishes observed at the southern SSRS site transect increased 21 percent between August and December 1974 (the before and after SSRS surveys, respectively). The number of fishes observed at the control site transect decreased 5 percent between August and October 1974, but only 2 percent between August and December 1974. When the results of the eastern and southern transects are combined to produce an average figure (Table 15), there is a 6 percent decrease between August and October 1974 and a 0.5 percent increase between August and December 1974.

The number of observed fish species varied considerably and did not appear to follow any pattern. For example, between August and October 1974, the number of species observed at the eastern transect of the SSRS site decreased 19 percent while the southern transect showed a 19 percent increase. For the same time period, the control transect site showed a decrease of 10 percent. Overall species counts for the SSRS site showed an increase of 27 percent and the control site showed a 2 percent decrease.

Between August and December 1974, the number of species observed decreased 14 percent at the eastern transect of the SSRS site and 15 percent at the control site transect. At the southern transect of the SSRS site there was no change. When the numbers for the eastern and southern transects are averaged, there is a 9 percent decrease. Overall species counts between August and December 1974 showed an increase of 9 percent at the SSRS site and an increase of 11 percent at the control site.

Two fish species, the goatfish or weke (*Mulloidichthys samoensis*) and the surgeonfish (*Acanthurus olivaceus*), were commonly observed feeding on worms (*Arenicola* sp. and others) on the surface of the sand deposit. Table 12 shows that there was a steady decrease in numbers of these fishes observed at the eastern transect of the SSRS site (goatfish--94 percent; surgeonfish--85 percent). These same two fish species showed increases at the southern site during the recovery activities (goatfish--58 percent; surgeonfish--31 percent. Following completion of the sand recovery activities, the numbers of the two species of fishes at the southern transect site decreased to what they were prior to SSRS operations. The numbers of these fishes remained low at the eastern transect site, however.

It is interesting to note that while the sand suction probe was in actual operation, many large individuals of *Mulloidichthys samoensis* (weke) would actively feed on the organisms which became exposed as the sand tumbled down into the cone created by the SSRS probe and the fluidizing pipe (Plates 22 and 23). Although smaller weke were seen near the edge of the sand cone, they never attempted to feed in this manner. In fact, no other carnivorous reef fishes were observed to feed in this way.

TABLE 14. FISH SPECIES AND NUMBERS OBSERVED AT EACH TRANSECT SITE FOR EACH MONITORING PERIOD DURING 1974

Species	Inshore Site Transect			South Site Transect			Overall Observation Site			Control Transect			Overall Control Observations		
	Aug	Oct	Dec	Aug	Oct	Dec	Aug	Oct	Dec	Aug	Oct	Dec	Aug	Oct	Dec
ACANTHURIDAE															
Acanthurus achilles	4			4			X*	X	X	3	1	7	X	X	X
Acanthurus dussumieri							X	X	X						
Acanthurus glaucopareius								X							
Acanthurus leucopareius								X						X	
Acanthurus nigrofuscus	9	1		3	11	9	X	X	X	12	26		X	X	X
Acanthurus olivaceous	33	22	5	40	58	35	X	X	X	6	8	12	X	X	X
Acanthurus sandvicensis									X				X		X
Ctenochaetus hawaiiensis	2	2	1	8	5	9	X	X	X	5	1		X	X	
Ctenochaetus strigosus	99	104	99	148	150	203	X	X	X	97	103	100	X	X	X
Naso hexacanthus										1			X	X	X
Naso literatus	1				1	1	X	X	X	9	8		X	X	
Naso unicornis									X			3		X	X
Zebrasoma flavescens	39	32	24	77	54	41	X	X	X	61	62	55	X	X	X
Zebrasoma veliferum															X
CHAETODONTIDAE															
Chaetodon auriga	1				1	2	X	X	X						
Chaetodon corallicola	1	2		1	2	6	X	X	X						
Chaetodon lineolatus								X							
Chaetodon lunula	1			1			X	X					X	X	X
Chaetodon multicinctus	17	6	9	27	2	27	X	X	X	41	35	49	X	X	X
Chaetodon ornatissimus	6			7			X			2	7		X	X	X
Chaetodon quadrimaculatus															X
Chaetodon trifasciatus		1	2		8	12		X	X			9			X
Chaetodon unimaculatus	2	1					X	X							
Centropyge potteri	9	6	10	15	13	12	X	X	X	22	25	20	X	X	X
Forcipiger flavissimus	14	9	7	7	7	5	X	X	X	11	6	9	X	X	X
Holocanthus arcuatus		1						X							
LABRIDAE															
Anampses cuvieri	2		1			6	X	X	X	1			X		
Bodianus bilunulatus			4			2			X			3			X
Cheilinus rhodochrous	10	5	3	14	14	4	X	X	X	12	8		X	X	
Coris gaimardi	5		1	3	3	5	X	X	X	1		2	X		X
Gomphosus varius	1		1			1	X		X	2	1	2	X	X	X
Halichoeres ornatissimus			2			2			X	6	7	9	X	X	X
Inistius pavoninus								X							
Labroides phthirophagus	1	1			2		X	X	X		1	1	X	X	X
Pseudocheilinus evanidus	2	6		8	8		X	X			1			X	
Pseudocheilinus octotaenia	6	4	1	11	8		X	X	X	7		8	X	X	X
Pseudocheilinus tetrataenia		1			1			X							
Stethojulis albovittata				3	2			X		3	1		X	X	
Stethojulis axillaris			4	4	3	2	X	X	X	10	1	5	X	X	X
Thalassoma ballieui				1										X	
Thalassoma duperreyi	23	17	15	24	42	33	X	X	X	35	35	41	X	X	X
POMACENTRIDAE															
Abudefduf abdominalis															X
Abudefduf imparipennis								X			35			X	X
Chromis leucurus	61	38	81	81	125	212	X	X	X	43	47	73	X	X	X

*For overall observations an "X" indicates a particular species was observed.

TABLE 14. FISH SPECIES AND NUMBERS OBSERVED AT EACH TRANSECT SITE FOR EACH MONITORING PERIOD DURING 1974 (continued)

Species	Inshore Site Transect			South Site Transect			Overall Observation Site			Control Transect			Overall Control Observations		
	Aug	Oct	Dec	Aug	Oct	Dec	Aug	Oct	Dec	Aug	Oct	Dec	Aug	Oct	Dec
Chromis verater									X				X		X
Dascyllus albisella					1			X							
Plectroglyphidodon johnstonianus	16	14	8	12	9	2	X	X	X	15	22	15	X	X	X
Pomacentrus jenkinsi									X	10					
SCARIDAE															
Calotomus spinidens	2						X								
Scarus perspicillatus				1						4			X		
Scarus rubroviolaceus						1		X	X	1	2	4	X	X	X
Scarus sordidus			2	1	1				X	4	3		X	X	X
Scarus taeniurus	1						X								
Gray Scaridae (unidentified)					4	4		X	X		14	7		X	X
MULLIDAE															
Mulloidichthys auriflamma			1				X	X	X	5			X	X	
Mulloidichthys samoensis	35	21	2	17	40	20	X	X	X	7		1	X		X
Parupeneus bifasciatus	13	2	2	11	15	11	X	X	X			7	X		X
Parupeneus chryserydros	1	1	1	2			X	X	X		1	1		X	X
Parupeneus multifasciatus	8			3			X			18	5		X	X	
Parupeneus pleurostigma					4	1	X	X	X						
CIRRHITIDAE															
Cirrhitops fasciatus													X		X
Paracirrhites arcatus							X	X		8	5	8	X	X	X
Paracirrhites forsteri	1	2			1		X	X							
BALISTIDAE															
Melichthys buniva								X	X				X	X	X
Melichthys vidua											1		X	X	X
Sufflamen bursa	2		1		22	3	X	X	X	6	2	2	X	X	X
MONACANTHIDAE															
Amanses sandwichiensis			1		1			X	X	1		1	X		X
Pervagor spilosoma		3		1				X							
BLENNIIDAE															
Cirripectus variolosus											1			X	
Exallias brevis	2	1	1		1	2	X	X	X	1	2	1	X	X	X
TETRAODONTIDAE															
Arothron hispidus															X
Arothron meleagris		1						X	X			1		X	X
CANTHIGASTERIDAE															
Canthigaster jactator												1			X
Canthigaster rivulatus							X								
HOLOCENTRIDAE															
Holocentrus sammara										5	5		X	X	
Holocentrus spinifer										3		3	X	X	X
Myripristis argyromus			1				X	X	X	5	10	3	X	X	X
LUTJANIDAE															
Aprion virescens					1			X							X
Lutjanus vaigiensis								X							
AULOSTOMIDAE															
Aulostomus chinensis	1	5		2	2		X	X		1	3		X	X	X

TABLE 14. FISH SPECIES AND NUMBERS OBSERVED AT EACH TRANSECT SITE FOR EACH MONITORING PERIOD DURING 1974 (continued)

Species	Inshore Site Transect			South Site Transect			Overall Observation Site			Control Transect			Overall Control Observations		
	Aug	Oct	Dec	Aug	Oct	Dec	Aug	Oct	Dec	Aug	Oct	Dec	Aug	Oct	Dec
CHANIDAE															
Chanos chanos															x
PRIACANTHIDAE															
Priacanthus cruentatus														x	
CARANGIDAE															
Caranx melampygus													x		
Decapterus pinnulatus					1			x						x	
OSTRACIONTIDAE															
Ostracion meleagris			1						x			1			x
APOGONIDAE															
Apogon menesemus			1						x						
SPARIDAE															
Monotaxis grandoculis								x		7	1		x	x	x
KYPHOSIDAE															
Kyphosus cinerascens								x							
FISTULARIIDAE															
Fistularia petimba															x
ZANCLIDAE															
Zanclus canescens	1	3	1		1	6	x	x	x	3	1	6	x	x	x
MURAENIDAE															
Gymnothorax flavimarginatus								x		1			x		
Gymnothorax meleagris															x
Total Number of Fish	432	312	293	537	604	679				495	472	486			
Total Number of Species	36	29	31	30	37	30	43	59	47	41	37	35	50	49	56

TABLE 15. TOTAL NUMBERS OF FISH SPECIES AND INDIVIDUALS (INDIVIDUAL NUMBERS IN PARENTHESES) OBSERVED DURING THE FIVE-MONTH DURATION OF THE KEAUHOU BAY SAND DREDGE STUDY

Station	Date		
	August	October	December
Dredge Site--Eastern Transect	36(432)	29(312)	31(293)
Dredge Site--Southern Transect	30(537)	37(604)	30(679)
Dredge Site--Overall Species Count	43	59	47
Control Site Transect	41(495)	37(472)	35(486)
Control Site--Overall Species Count	50	49	56
Dredge Site--Average of Eastern and Southern Transects	33(484)	33(458)	30(486)

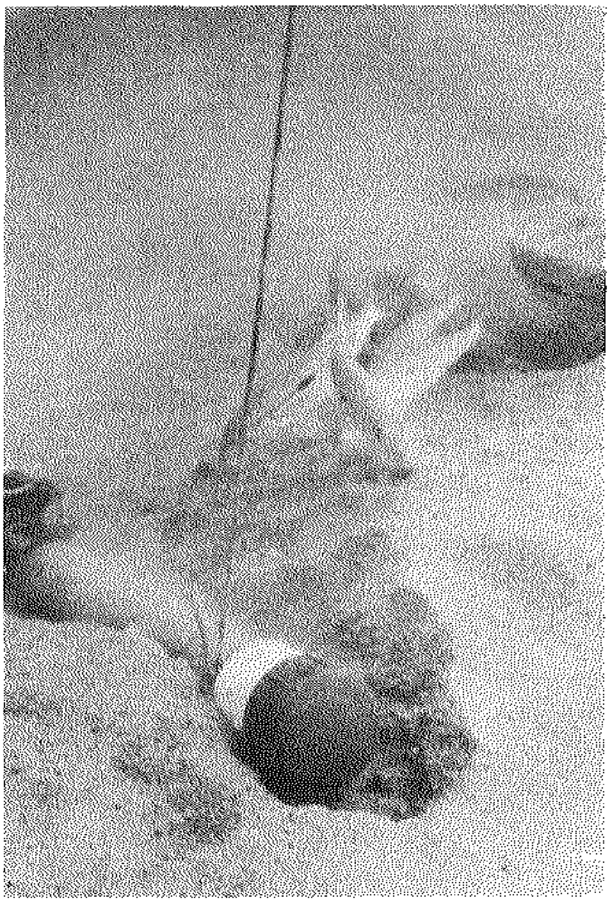


Plate 22. Goatfish (*Mulloidichthys samoensis*) feeding on organisms uncovered during operation of the SSRS probe, approximately 2 minutes after moving the fluidizing pipe to this location

Plate 23. Goatfish (*Mulloidichthys samoensis*) feeding on organisms uncovered during operation of the SSRS probe, approximately 5 minutes after moving the fluidizing pipe to this location

Herbivorous fishes including the surgeonfish (*Acanthurus olivaceus*) were seen feeding on filamentous algae which had recently colonized on pipes and other equipment used for the SSRS operations (Plate 24).

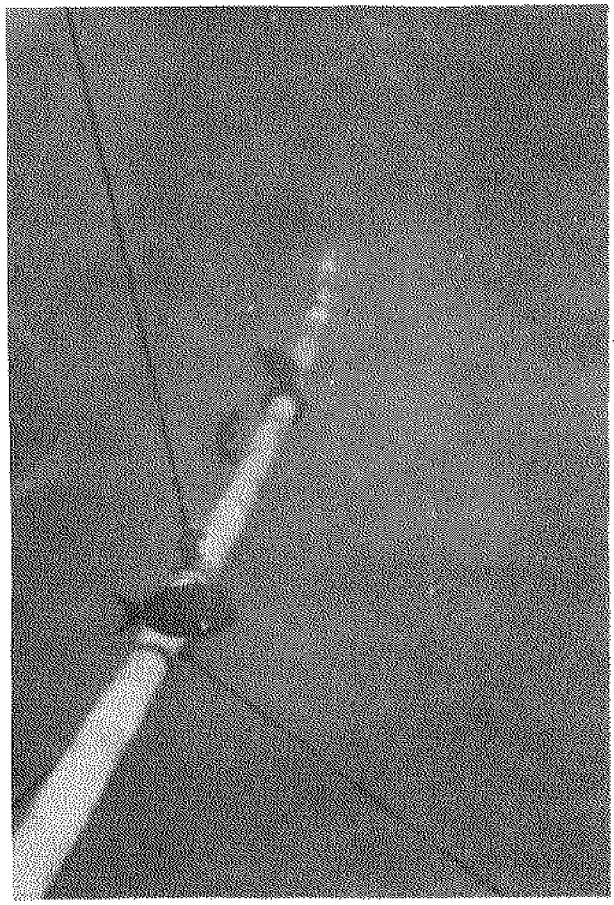


Plate 24. Surgeonfish feeding on algae which have colonized the PVC pipes used to transport the sand onshore

Observations on the fish populations near the SSRS site before, during, and after the sand recovery operations suggest that sand removal has a limited adverse effect on fish populations. The variations in the number of fishes and fish species observed throughout the study do not appear to follow any pattern at the transect sites.

However, the population of goatfish attracted to the immediate site of the recovery operations appeared to steadily increase throughout the two-month test period. Some of the divers and workmen even claim that the amount of food resource exposed by the SSRS and consumed by the fish resulted in noticeable fish size increases. These claims, of course, cannot be substantiated.

Benthic Algae

Inspection of the deposition and settling basins during and after SSRS operations indicated that sand slurry caused no impact to littoral and subtidal benthic communities. On only one occasion did the deposition basin fill up enough to cause a small amount of overflow into the settling basin. There was no surface overflow and discharge of slurry back to the shoreline from either basin. The porous basaltic rock comprising the basins apparently allowed enough percolation of slurry water into the ground to offset the amount of slurry pumped into the basin from the offshore barge. Additional observations along the shoreline near the basins indicated that subsurface seepage of basin water back into the ocean could not be detected from water turbidity differences. Apparently the percolation of slurry water through the basalt rock effectively filtered out all detectable sand and solid particles from the water prior to its re-entry into the ocean.

Because of the lack of surface discharge of slurry back into the sea, there was no need for the benthic algal quadrat surveys along the shoreline. Nevertheless the surveys were performed but not without problems. Heavy wave action hampered the studies and portions of the November 30 surveys could not be carried out. The results of the quadrat surveys are presented in Tables 14 and 15. The surveys also included estimates on the abundance of bare rock and sponges (Phylum Porifera).

Twelve genera and "unspecified" encrusting algae were represented on August 31 at the 0-m position at the settling pond site. On November 30, 9 of the 12 genera were present along with *Hemitrema* sp., which was not noted on August 31. However, the three genera not present on November 30 represented only 3.3 percent of the coverage on August 31 (Table 16).

Four genera and "unspecified" encrusting algae were represented on August 31 at the 5-m position at the settling basin site. "Unspecified" encrusting algae and three out of the four genera were again represented on November 30. The genus *Sargassum* sp. which made up only 0.8 percent of the August 31 survey, was not noted on November 30 (Table 17). Contrarily, a species of *Ceramium* not noted on August 31 was present on November 30.

At the control site, five genera and "unspecified" encrusting algae were present on August 31. In November, four of the five genera were again recorded. *Turbinaria ornata* and "unspecified" encrusting algae, which made up 0.8 percent and 1.6 percent, respectively of the total coverage on August 31, were not present within the quadrat on November 30 (Table 17).

The presence/absence data show that the majority of the genera present before the commencement of sand deposition in the settling pond were also present after the mining operation ended when the settling pond was partially filled up with sand. The genera not present under any of the intersection points at the time of the "after" surveys represented only 3.3 percent of the coverage of the "before" surveys. These data results from the settling basin site are similar to those obtained from the control site where two genera present at the "before" surveys were not present at the time of the "after" surveys. These two algae, *Turbinaria ornata* and an "unspecified" encrusting algae, made up only 2.4 percent of the coverage during the "before" surveys at the inlet pipe site on August 31.

TABLE 16. ALGAL SPECIES COMPOSITION AT THE SETTLING BASIN AND CONTROL QUADRAT SURVEY STATIONS

Species	Settling Basin Site						Control Site	
	0-m		5-m		10-m		15-m	
	Before	After	Before	After	Before	After*	Before	After
Padina sp.	X	X	X	X				
Chnoospora pacifica							X	X
Ectocarpus sp.	X							
Sargassum sp.	X	X	X				X	X
Turbinaria ornata							X	
Dictyota sp.	X	X						
Cladophora sp.	X	X			X		X	X
Valonia sp.	X	X			X			
Ahnfeltia concinna	X	-						
Gelidiella sp.	X	X						
Jania sp.	X	X	X	X				
Galaxura sp.	X	X	X	X				
Pterocladia sp.	X							
Ceramium sp.				X	X			
Hemitrema sp.		X						
Porolithon onkoides	X	X					X	X
Unspecified	X	X	X	X	X		X	
Sponge	X							
Rock	X	X	X	X	X			X

Note: An "X" indicates the presence of an alga during a survey, and a "-" indicates absence. "Before" indicates surveys conducted on August 31, 1974 before SSRS operations and "after" indicates surveys conducted on November 30, 1974 after completion of SSRS operations. An asterisk (*) indicates the survey was not performed because of heavy wave action. The category "unspecified" includes a mixture of encrusting algae species other than *Porolithon onkoides*.

TABLE 17. PERCENTAGE OF COVERAGE OF ALGAE WITHIN THE QUADRATS AT BOTH THE SETTLING BASIN AND CONTROL SITES

Species	Settling Pond Site						Control Site	
	0-m		5-m		10-m		15-m	
	Before	After	Before	After	Before	After*	Before	After
Padina sp.	18	14	14	30.6				
Chnoospora pacifica							0.8	4.1
Ectocarpus sp.	1.7							
Sargassum sp.	5.8	10	0.8				19	3.3
Turbinaria ornata							0.8	
Dictyota sp.	1.7	7.4						
Cladophora sp.	4.1	8.3			1.7		2.5	29.8
Valonia sp.	5	5.8			0.8			
Ahnfeltia concinna	0.8							
Gelidiella sp.	11.6	8.3						
Jania sp.	5	14	16.5	33	38.8			
Galaxura sp.	7.4	9.1	1.7	2.6				
Pterocladia sp.	0.8							
Ceramium sp.				26.4	0.8			
Hemitrema sp.		0.8						
Porolithon onkoides	6.6	8.3					75.2	27.3
Unspecified	9.9	10.7	21.5	1.7	54.5		1.6	
Sponge	0.8							
Rock	20.7	3.3	45.5	5.8	3.3			35

Note: "Before" indicates surveys performed on August 31, 1974 before SSRS operations and "after" indicates surveys performed on November 30, 1974 after completion of the SSRS test. An asterisk (*) indicates that survey was not performed because of heavy wave action.

Three generalizations can be made to summarize the results of the algal composition studies: (1) the majority of genera present before the SSRS operations were also present afterwards; (2) only less common genera present at one survey were absent from the other; and (3) similar patterns or shifts in algal composition occurred at both the control and settling basin sites. Because it is known that surface discharge of slurry did not occur and could not have affected any of these findings, it is concluded that normal seasonal fluctuations of benthic algae and sampling error were responsible for the reported changes in composition from one survey to the other. The fact that changes occurred at both the control and settling basin sites indicates the causative factors were not restricted to just the site near the SSRS operations.

Data on the percentage of coverage of the algal genera based on quadrat surveys at both sites and times are provided in Table 17. Certain algae at both sites showed considerable fluctuation in coverage between the before and after surveys. For example, the coverage of bare rock and the alga *Gelidiella* decreased while the algae *Jania*, *Sargassum*, *Dictyota*, *Cladophora*, *Padina*, and *Ceramium* increased substantially at the settling basin site. At the control site fluctuations in algal coverage also occurred, including increases in *Chnoospora*, *Cladophora*, and bare rock and decreases in *Sargassum*.

The same magnitude of fluctuations occurred at both the settling basin and control sites, supporting the contention that seasonal fluctuations, sampling errors, and heavy wave action were responsible for the variations.

DISCUSSION

Summary of Impacts

Various studies on turbidity confirmed that the amount generated by the SSRS was small and confined to the location of the crater being excavated. On only one occasion did a turbid water plume migrate beyond the boundaries of the crater to the coral reef communities nearby. However, the particles were so small that they did not appear to settle on the corals which displayed no adverse responses based on subsequent observations. The turbidity was caused by the resuspension of fine sediments during the slumping and cascading of sediments down the walls of the crater during suction head and fluidizing pipe operation. At times the momentum of sediment laden currents rushing down the walls of the crater and impinging upon the bottom would result in the formation of a plume column directly over the crater. Additional sediment may have been placed in suspension by divers swimming along the bottom and dispersal may have been promoted by the rafting of turbid water on ascending air bubbles from SCUBA divers. The opacity of the plumes was never enough to prevent partial visibility through the plumes. It is concluded that SSRS generated turbidity did not pose a significant adverse effect to the reef environment.

The volume of slurry water piped to the deposition basin was never sufficient to result in an overflow to the settling basin and ocean. The porosity of the basaltic rock which formed the walls and floor of the basins facilitated rapid percolation and effective filtration of water from the sand. These observations were supported by the shoreline algal sutdies which suggested no consistent nor significant effect of the slurry water on the abundance and diversity of littoral benthic algal populations. Slurry water was never detected discharging into the ocean from the shoreline.

Despite the fact that the water quality measurements lacked the precision and reliability desired, the results indicated that SSRS operations did not generate noticeable amounts of nutrients. The consumption of oxygen as indicated by measurements of dissolved oxygen concentration did not fluctuate noticeably during and after SSRS operations. Thus it appears that nutrient generation and oxygen consumption was not affected by removal of sand from the deposit.

Beach profile surveys indicated that the beaches either accreted sand or did not change their volume after testing of the SSRS. Furthermore, the nearest beaches were located at least a mile from the deposit and reconnaissance swims indicated that the beaches and the deposit were separated by vast expanses of flourishing coral communities over which the transport of sand could not have occurred without leaving noticeable effects. It is concluded that the SSRS test did not affect the beaches.

The stake surveys at the deposit also indicated that sand did not migrate in or out of the deposit during the SSRS test. The elevated coral reef surrounding the deposit effectively isolated the test deposit from other sand deposits.

The excavation of the craters and their subsequent readjustment after the field test caused some erosion of sand from the coral reef-sand deposit interface, resulting in the collapse and migration of reef fragments into the deposit. The level of the sand dropped 1 m along one section of the coral reef-sand deposit boundary. It is not known whether the exposed coral rock will eventually be colonized by marine organisms because the environmental studies were terminated before sufficient time for colonization was possible. However, the reef platform is predominantly composed of fragile dead fingercoral (*Porites compressa*) fragments which are not stable substrates for colonization by corals. The slumping and collapse of coral due to undermining did not result in significant damage to the coral communities. However, the fragments which migrated down into the craters occasionally hampered the operation of the SSRS. As a result, there is both engineering and economic justification to avoid future sand excavations near reefs.

Results of the transect studies indicated no changes in the abundance and composition of coral communities attributed to test operations within the time period of the survey. However, the setting, dragging, and hoisting of anchors and the whiplash of mooring cables caused significant but localized damage to the coral communities. Also some corals were buried under the concrete clump used to anchor the steel delivery pipe at the shoreline. The damage caused by the anchor and cable was the most significant adverse effect to the reef communities attributed to the SSRS test. Most of the coral damage at Keauhou Bay, however, will probably be only temporary since corals have the capacity to repair and regenerate themselves.

The results of fish surveys and observations indicated the possible migration of reef fish populations towards the test site and the definite attraction of schools of goatfish to the immediate vicinity of the mining activity. Schools of the goatfish (weke; *Mulloidichthys samoensis*) were reported feeding on the lug worm *Arenicola* and other worms as they became exposed during sand excavation. The average size of the fishes increased noticeably during the two-month test period and, after termination of the test, the fish schools lingered in the vicinity of the craters for at least several weeks.

Surveys of sand dwelling mollusks at the sand deposit were hampered by logistic problems and inaccessibility of the site for night diving. In situ surveys were inadequate in assessing the magnitude and diversity of mollusk populations. However, the nature of the recovery procedure allowed for an unconventional method for sampling of the mollusks recovered from the deposit; over 1,200 shells belong to 34 genera and 78 species were collected in a matter of several hours by screening the sand slurry discharge of the SSRS. Although most of the shells were dead and 24 percent of the species collected were epifaunal types uncharacteristic of sand habitats, the magnitude of the remainder indicated that a very large, complex, and diverse community of mollusks inhabit the sand deposit. The destruction of the sand dwelling mollusks probably represented the most severe unavoidable impact attributed to the SSRS test at Keauhou Bay.

The quadrat surveys of echinoderms in the coral thickets indicated considerable fluctuations in sea urchin population densities, but these could not be correlated with any natural or SSRS test factor. However, many sea urchins were observed at the bottom of the craters after completion of the test. They may have migrated across the deposit and fell or got trapped in the craters and were buried and killed in the bottom sediments. It is not known whether the sea urchins remained in the craters because of behavioral reasons or because of their inability to climb up the soft and steep walls of the craters. This impact could have a long-term effect on local sea urchin populations, at least until the craters fill in.

Evaluation of the Accuracy of the EIS

The EIS serves as a valuable document for protecting environmental resources because it allows public disclosure of the scope of various proposed project developments and/or an estimate of their probable impact prior to implementation. In this capacity, the EIS must be reasonably accurate in its predictions to serve as an effective planning tool and decisionmaking document. Environmental monitoring surveys of projects allow for an evaluation of the accuracy of EIS's and a refinement of their predictive capability for future endeavors.

The EIS prepared for the SSRS test (NOAA, 1974) was moderately accurate in predicting environmental impacts, but several impacts were underestimated or overlooked. The EIS correctly predicted that turbidity generation and undermining of coral rock from the SSRS test would not result in significant environmental impact. Furthermore, as confirmed by monitoring surveys, it correctly predicted that nearby beaches would not be affected. It also predicted that anchoring operations would damage coral reefs, but, based upon its observed severity and significance, the impact was not emphasized sufficiently. It was the supposition in the EIS that fish populations would avoid the vicinity of the SSRS test; however, the opposite was true. The magnitude of the error was neither significant nor adverse. The large collection of mollusks recovered from the sand slurry discharge pipe indicated that the EIS grossly underestimated the size and diversity of mollusks inhabiting the deposit. This discrepancy emphasizes the need to perform more comprehensive and appropriate surveys prior to future operations. In addition, the EIS underestimated the destruction of the sand dwelling mollusks, probably the most severe impact caused by the SSRS test. An area where environmental impact was overlooked was the trapping and smothering of sea urchins in the sand craters.

It is important to emphasize that most of the adverse impacts attributed to the SSRS operation can be avoided using common sense precautions and advanced planning. Damage to corals from cables and anchors can be prevented by anchoring only in the sand, mining sand at deposits removed from coral formations, utilizing alternate mooring methods, and mooring only one vessel or barge to each anchor. Damage to sand dwelling mollusks and sea urchins can be avoided by surveying candidate sites prior to sand recovery using survey techniques designed to assess quantitatively the abundance and diversity of soft bottom infauna. The sites supporting the least developed mollusk and sea urchin populations, based on the survey results, should then be selected for sand mining. This precaution would eliminate unavoidable adverse impact to mollusks and other organisms.

The use of conventional transect methods to sample mollusk populations in deeper water has not been widely applied in Hawaii. Because of the cryptic and nocturnal habits of many infaunal mollusks, the performance of diver surveys in deep water is severely constrained by bottom time limitations, the hazards of night and deep-water diving, and the time requirements for in situ sampling of infaunal mollusks. In fact, few, if any quantitative macromollusk surveys in marine waters below depths of 15 m have been performed in Hawaii except when using grab samplers operated from surface vessels. The grab sampling technique can also suffer limitations if the mollusks show low densities or burrow deep into the sand (Environmental Consultants, Inc., 1973a, 1973b).

Thus it may be necessary to explore other techniques for in situ sampling of mollusk populations. Although lacking scientific tradition and experience, a modification of the sand slurry sampling method employed for the Keauhou Bay SSRS test could continue to serve as an effective interim tool for assessing impacted mollusk populations, especially if slurry sampling occurred over longer time intervals and utilized screens having a variety of aperture sizes. This procedure, of course, is limited in its use because it can only be employed after commencement of recovery operations. Hence the slurry method will only serve as a check for other types of surveys conducted prior to sand removal for the purpose of site evaluation and selection.

Other impacts which were not significant at the Keauhou Bay test site could be significant at other sites, if proper precautions are not taken. These impacts include:

1. Accidental breaks in the pipeline, resulting in sedimentation and possible damage to marine life along the pipeline corridor.

2. The emergency use of backflushing to clear clogged lines, also causing the temporary discharge of turbid water and sediment.

3. The unsuitability of sites as deposition basins which could lead to the selection of basins where surface overflow discharge could damage marine life.

4. The potential erosion of beach sand reservoirs, if sand deposits selected for sand recovery are located near marine communities and if surface discharge of slurry water back into the ocean becomes substantial.

The first potential impact can be reduced significantly by posting watches during sand mining operations and periodically inspecting pipes and equipment. The need to use backflushing of lines during a contingency can be reduced considerably by design improvements to crushers and other equipment and careful site selection of sand deposits where large shell, coral, and other fragments are uncommon. The last two potential impacts can be prevented by selecting sites where suitable deposition basins can be established and where sandy beaches and their offshore reserves are not connected to the deposits to be mined. This can be best accomplished by conducting advanced diving and beach surveys near prospective sites.

CONCLUSIONS AND RECOMMENDATIONS

The SSRS has been shown to be an effective sand mining technique which minimizes the generation of turbidity and resuspended sediments--impacts which are caused by other dredging methods and which result in significant adverse effects to marine life. By utilization of advanced planning, surveys, design improvements, and other precautions, the SSRS holds promise as a sand mining technique compatible with the concept of environmental preservation and protection.

The field environmental monitoring studies at Keauhou Bay have demonstrated that the environmental impacts predicted beforehand can be substantially different in type and emphasis from those observed during mining operations. Environmental monitoring programs can provide valuable insight on potential environmental effects for proposed projects and can help to improve the accuracy of future EIS's and the objectivity of planning tools. In this manner, the resource manager will be able to make more rational decisions on the use of natural resources.

Experience gained from the Keauhou Bay study indicates that monitoring studies are probably more valuable if a combination of both qualitative observations and quantitative surveys is considered. In the case of the Keauhou Bay study, both types of approaches yielded valuable information and insight. In addition, the concept of using control stations, replicate sampling, and time-series monitoring studies will render environmental surveillance studies more informative and interpretive.

Future environmental surveys of offshore sand mining projects should be divided into three phases. The first should focus on evaluation and selection of alternative sites for sand mining and insure that sites of recovery activity are positioned away from coral reefs, beach reservoir systems, and important or large populations of sand dwelling mollusks and echinoderms. Second phase studies should be conducted during recovery operations to document short-term impacts to fishes and other marine life including sand dwelling mollusks, water quality, and sediment dynamics. Third phase studies should be conducted after termination of mining and adjustment of the sand and biological resources and should focus on the long-term impacts and responses.

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