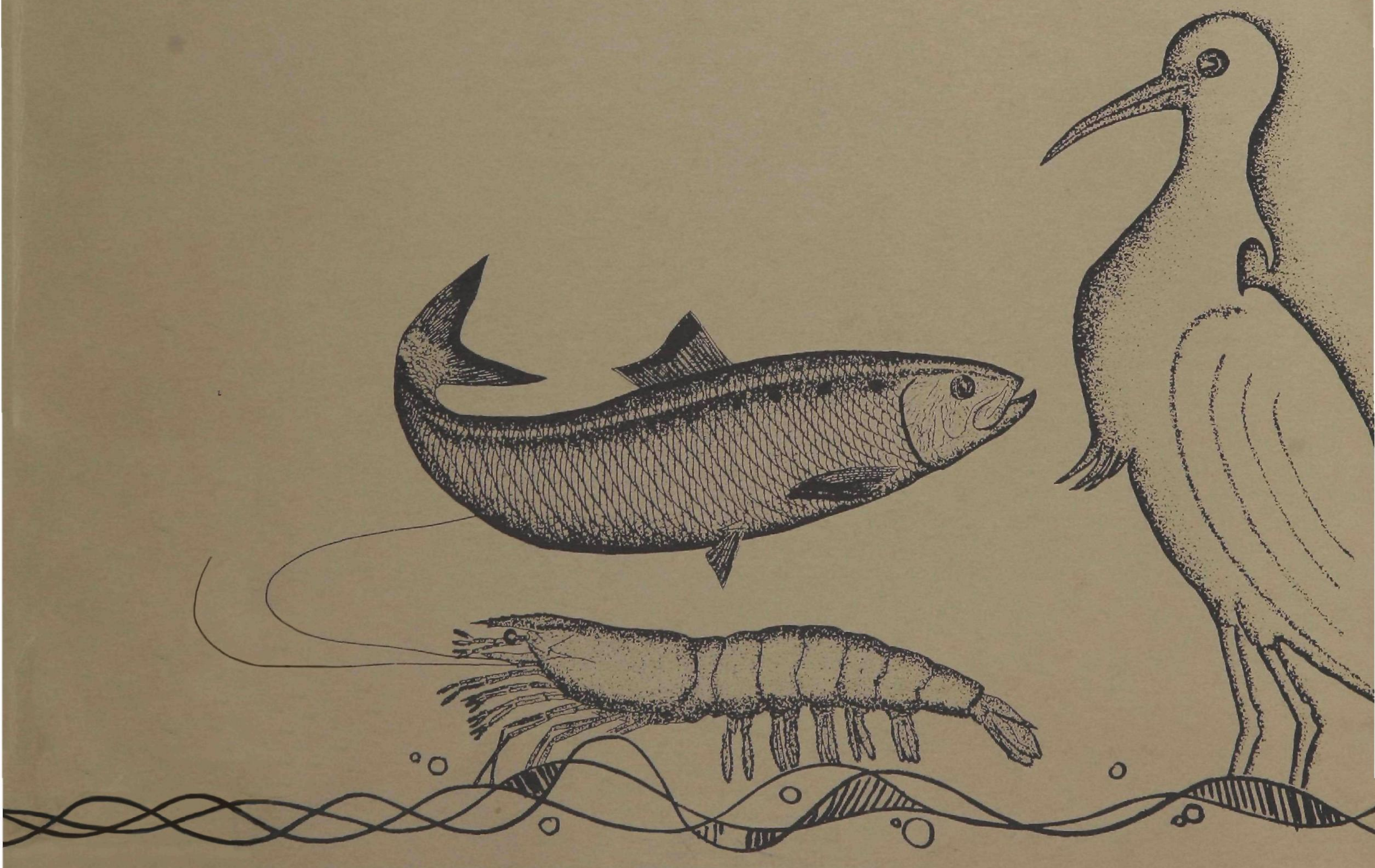
WATER POLLUTION CONTROL RESEARCH SERIES • 18050 DAI 02/70

BIOLOGICAL EFFECTS OF EFFLUENT FROM A DESALINATION PLANT AT KEY WEST, FLORIDA



U.S. DEPARTMENT OF THE INTERIOR • FEDERAL WATER QUALITY ADMINISTRATION

WATER POLLUTION CONTROL RESEARCH SERIES

On Cover:

Snowy egret	*Leucophoyx thula*
American shad	*Alosa sapidissima*
Brown shrimp	*Penaeus aztecus*
American oyster	*Crassostrea virginica*

Drawings By:

Alston Badger
Bears Bluff Field Station
National Marine Water Quality Laboratory

BIOLOGICAL EFFECTS OF EFFLUENT FROM A DESALINATION PLANT AT KEY WEST, FLORIDA

by

W.D. Clarke, J.W. Joy
and R.J. Rosenthal

Westinghouse Ocean Research Laboratory
San Diego, California

for the

FEDERAL WATER QUALITY ADMINISTRATION

DEPARTMENT OF THE INTERIOR

Project #18050 DAI
Contract #14-12-470
February 1970

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $1

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 REASONS FOR STUDY

The Key West study was undertaken to determine the impact of the discharge from a large desalting plant on the surrounding environment. There is little information on the effects of elevated temperatures and high salinity on tropical organisms and so the geographical location of the desalting plant was an important factor for proposing the study. The current population growth and economic development in the low latitudes of the world will create a greater demand for desalting plants to meet the fresh water requirements of growing communities, particularly in the more arid regions. This projected development is creating a greater need to gather more information on the environmental and biological effects of discharges from existing desalting plants. The Key West desalting plant affords a good site for modeling studies and controlled experiments which can be carried out in the follow-up studies to the present one.

1.2 LOCATION AND ENVIRONMENT

Key West lies at the western end of a long chain of low-lying islands and keys that extend southwestward from the tip of Florida (Figure 1). These islands are called the Florida Keys and lie just outside the tropical zone. For heuristic purposes, they can be considered a tropical environment. The northern edge of the Gulf Stream bathes these islands and coral patch reefs are quite extensive throughout the area. The flora and fauna of the keys are made up of typically warm-water tropical forms but the total numbers of species are somewhat impoverished when compared with regions to the south. Part of this impoverishment is probably related to the local climate. During the winter months, the area is somewhat atypical for a tropical area being subject to extremely low air temperatures (51°F. or 10.5°C.). These low temperatures occur when the cold continental air mass moves south off the mainland. The shallow inshore waters are drastically chilled at these times and this is reflected in the biota. Species of fish and invertebrates found in the Greater Antilles and Caribbean are absent from or occur only seasonally in the shallow-water habitats around the Florida Keys.

1.3 BACKGROUND AND PURPOSE

The Key West desalting plant is the largest one currently operating in the United States (2.62 MG/D, 9.92 million liters/day). Westinghouse, having an interest in environmental problems, believed that a study of the environmental effects of the effluent would be a valuable investigation. The study was originally proposed to FWPCA as an exploratory investigation to determine the magnitude of the impact of the desalting plant effluent on the surrounding environment. The main purpose of the study was to establish the approximate extent of the effluent plume by physical measurements and to see if the effluent was producing any changes in the local

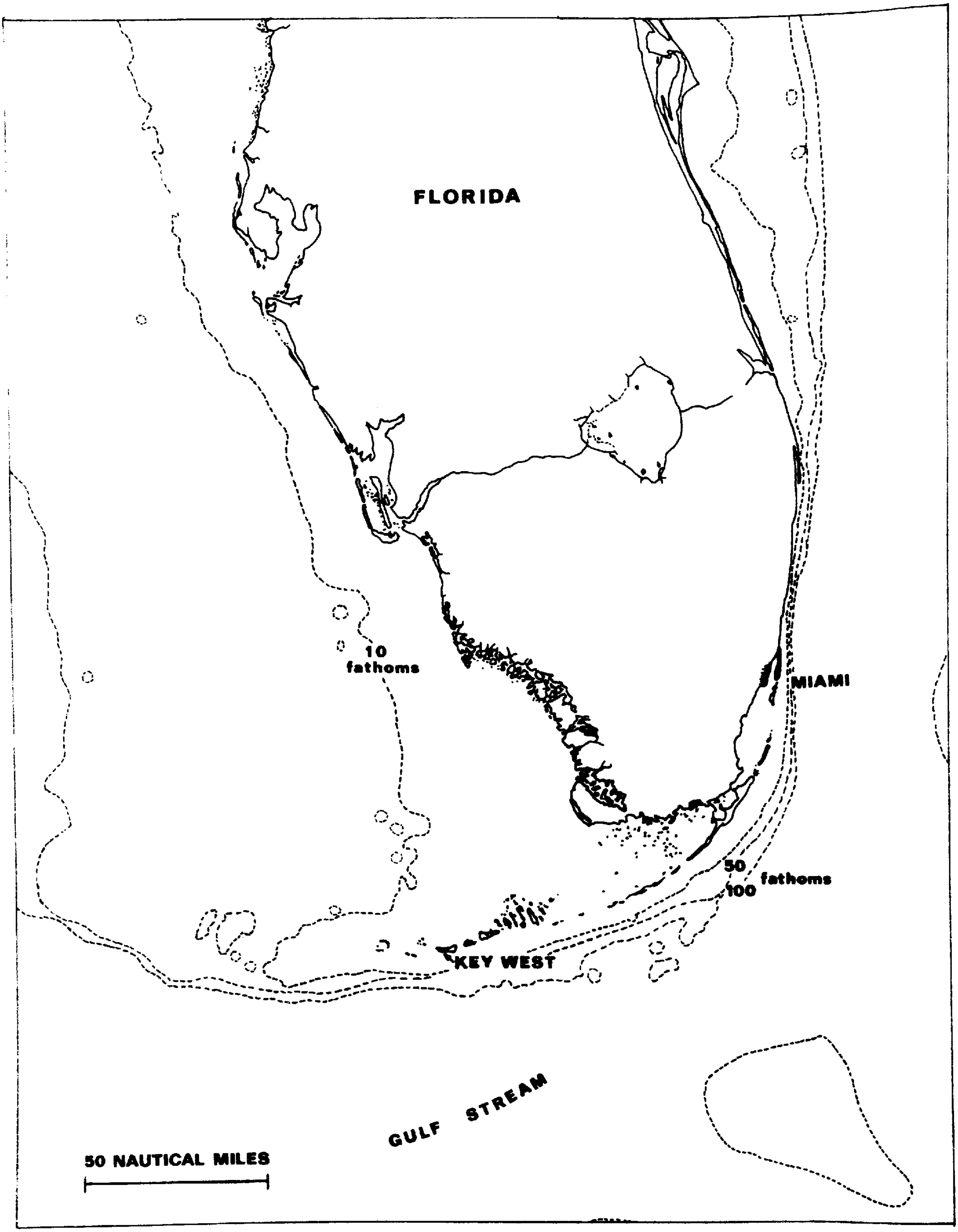


Figure 1. Location of Key West.

biological communities. It was desirous to ascertain whether or not the discharge was deleterious, had minimal effect on the surrounding environment, or might even have a beneficial effect. The work carried out under the present study was also intended to lay the ground work for a follow-on study to look in greater detail at the environmental and biological implications of a heated, hypersaline discharge.

2. DESCRIPTION OF STUDY AREA

2.1 GEOGRAPHICAL LOCATION

The Key West desalting plant is located on Stock Island, the first major island to the east of Key West (Figure 2). The plant is built on the eastern jetty of the entrance channel to Safe Harbor, a man-made harbor on the south side of Stock Island (Figures 3, 4 and 5). The study area during this project was confined to the harbor proper, the entrance channel, approach channel, and the shallow flats to the east and west of the harbor out to a distance of about one-half kilometer from the harbor entrance.

2.2 GEOGRAPHY AND GEOLOGY

The near shore area off Stock Island is typical of that found throughout much of the Florida Keys. It is primarily a shallow-water shelf, representing a submerged platform of Pleistocene limestone on which the present day islands stand. The only deep areas on this shelf are man-made channels and harbors. The major features of Safe Harbor are all man-made. The main axis of the harbor,entrance channel and approach channel runs in a north-south direction. The harbor and channels were dredged originally to a depth of 9 meters (m), but the approach channel in places has filled with sediment to nearly one-half its original depth, thus there is a sill between the deep basin of the harbor proper and waters of equivalent depth off shore. The head of the harbor is expanded on its eastern and western sides into a series of anchorages and marinas. Most of these extensions communicate with the main harbor through unrestricted openings. The marina at the very head of the harbor is an exception in that its basin is cut off from the main harbor by a shallow sill only 2.7 m deep.

The entrance channel because of its manner of construction is deeper by about 1.5 m along the edges near the jetties than it is in the middle. The walls of the channel consist of nearly vertical limestone rock exposures and steeply sloping deposits of coarse sands and fine gravels that are, in many instances, at the angle of repose. The channel is carpeted with very fine sands and soft muds. The fine sands are limited to the edges of the channel bottom. The approach channel is similar in form, having the same distribution of rock outcroppings and sediments. The main differences are; thicker accumulation of fine mud sediments on the bottom of this channel and the lack of jetties along its edges.

Right at the entrance to Safe Harbor, there is a large basin of deep water which shoals gradually to the east and deepens to entrance channel depths on its west side. The bottom of this basin is covered with fine mud sediments. The walls of the basin are similar to those of the channels and were formed by dredging.

The shallow flats on either side of the harbor and channels are carpeted with fine sand sediments. Exposures of the underlying limestone platform

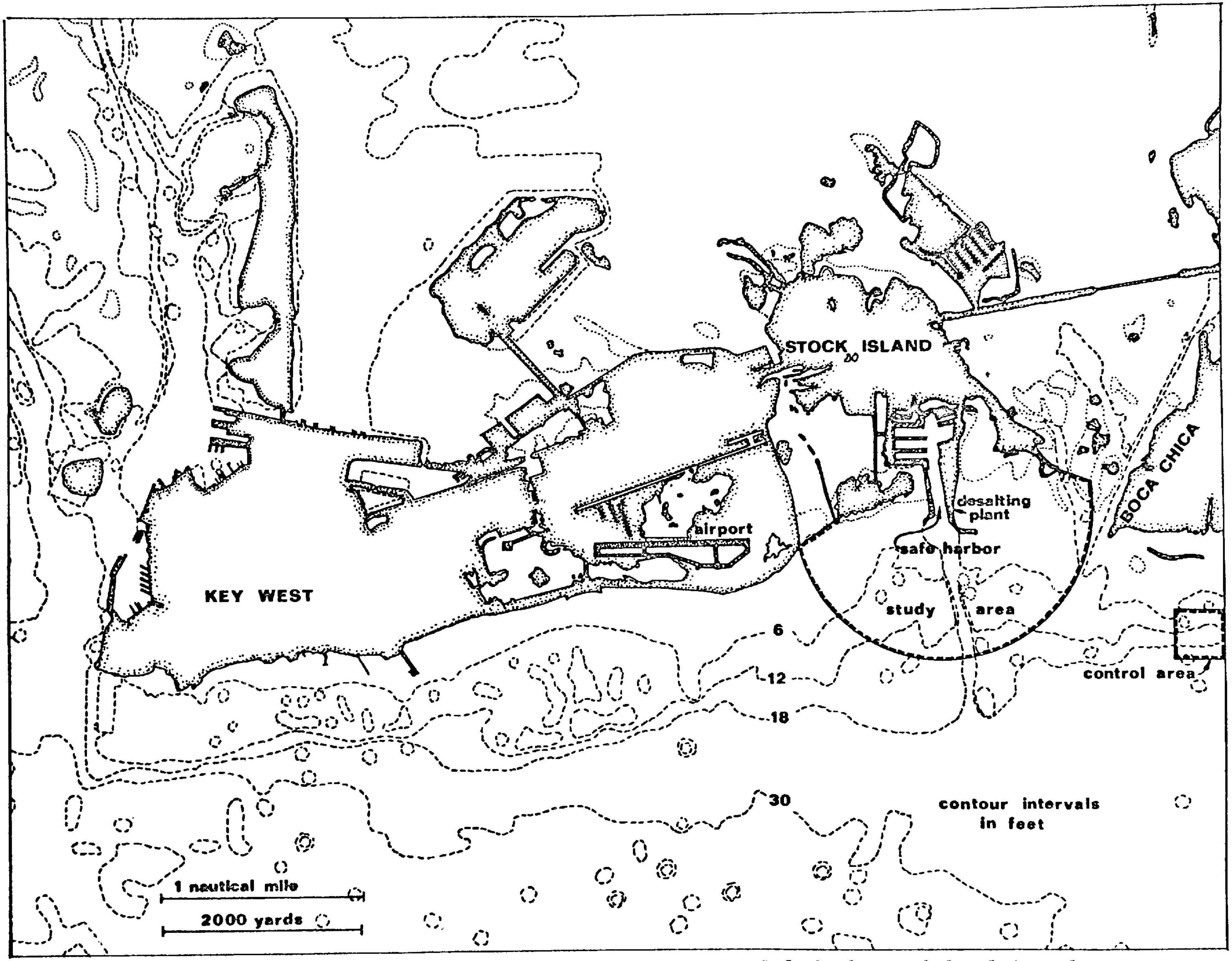


Figure 2. Locations of Key West, Stock Island, Safe Harbor and desalting plant.

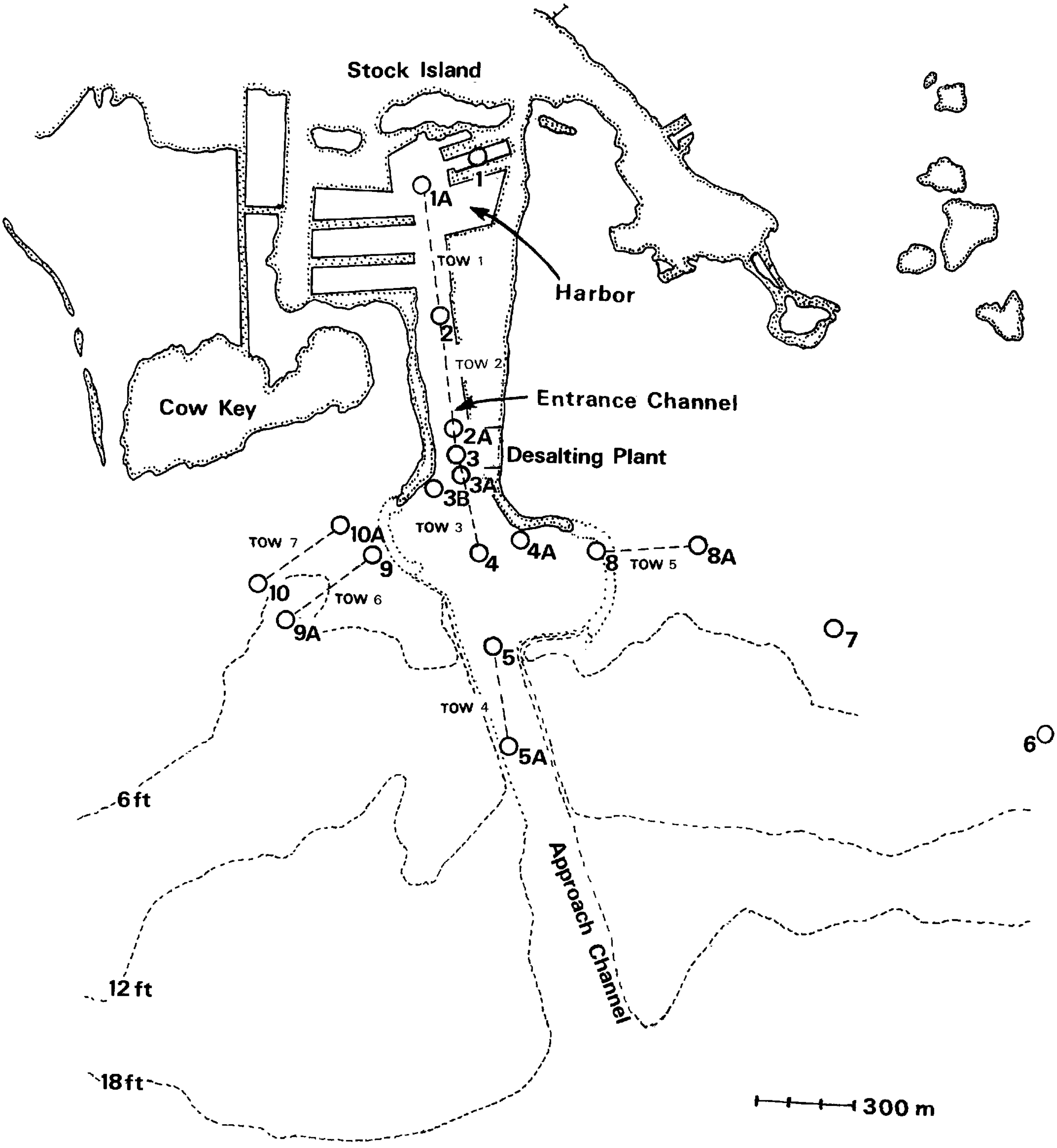


Figure 3. General bottom topography and surface features in the vicinity of Safe Harbor, including locations of stations used during the study.

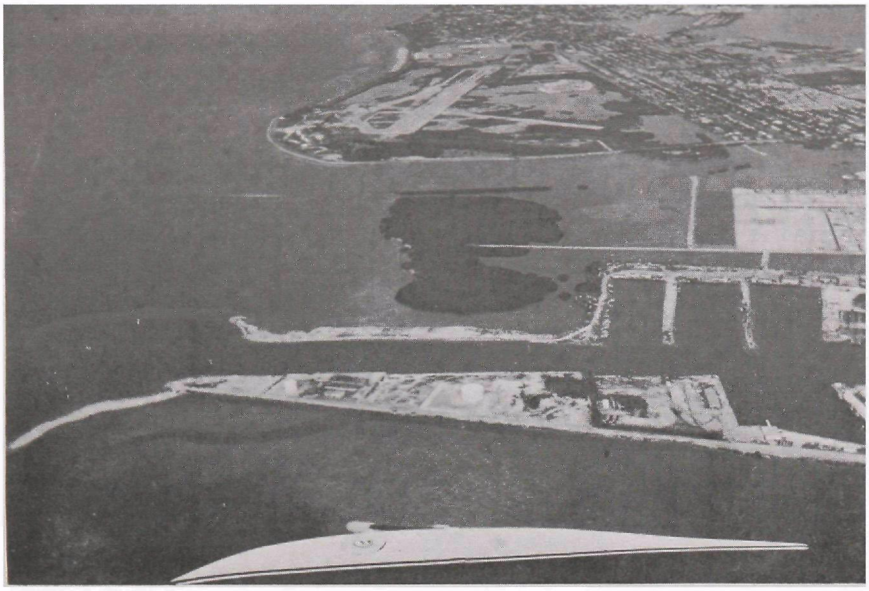


Figure 4. Aerial view, looking west, of Safe Harbor and desalting plant (left foreground) and Key West (background).

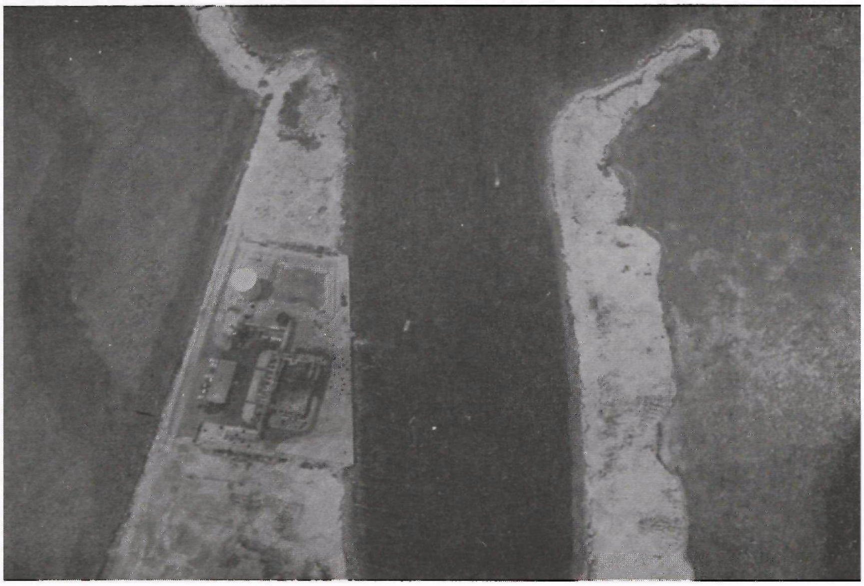


Figure 5. Aerial view of entrance to Safe Harbor and desalting plant (left).

occur on parts of the shallow flats. Large areas of the sand are consolidated by extensive beds of marine grasses and algae. The rock outcroppings on deeper portions of the island shelf are covered in places with coral patch reefs and isolated coral heads.

There is no permanent fresh water drainage in the Stock Island area and runoff is limited to periods of heavy rainfall. In restricted bodies of water such as the marina at the head of Safe Harbor or the very shallow waters near the island, runoff rain water can greatly lower the salinity of the sea water.

3. PLANT CHARACTERISTICS

An oil-fueled boiler supplies heat for the plant's fifty flash-distillation units. These units make up the major part of the physical plant (Figures 6 and 7). Electrically powered pumps draw salt water from three deep wells into the plant and circulate the fresh water and brine produced by the flash-distillation units through the plant as well as the cooling water required for plant operation. The source water for distillation comes from 180-foot-deep wells (55 m) drilled down through the jetty at Safe Harbor. At peak operation the three wells can supply 6,600 gallons (25,000 liters) per minute. Characteristics of the source water are given in Table 1. The limestone walls of the wells provide a natural filter which prevents intake clogging problems common to the alternative of drawing the salt water supply directly from the ocean.

Table 1

CHARACTERISTICS OF SOURCE WELL WATER

Temperature	25.6°C(78.0°F)	Throughout year
Salinity	40°/₀₀ average	Range 39°/₀₀ to 42°/₀₀
Calcium Carbonate	197 ppm	
Hydrogen Sulphide	6 ppm	

The well water is preheated to 100°F (38°C) and treated with sufficient sulfuric acid to convert the CO_3^- ion to CO_2 gas. Increasing the acidity of the well water also drives off the unwanted H_2S gas in solution in the well water. Caustic soda is then added to neutralize the excess acid and to bring the pH of the well water to a suitable level to reduce scaling problems in the flash-distillation units. An anti-foaming agent POLYGLYCOL 15-200 (see Appendix A), is also added to the water prior to its entering the flash-distillation units. The treated well water is then heated to 250°F (121°C) and enters the first flash-distillation unit. It passes through a total of fifty units, fresh water is produced at each stage and the heated brine loses 3°F (1.6°C) per unit. A final temperature of 100°F (38°C) is attained in the last unit. The cooling is accomplished by circulating the 78°F (25.6°C) untreated well water through the units. A schematic of the desalting plant is given in Figure 8. Piping used in the flash-distillation units is a cupro-nickel alloy similar to monel; it is approximately 70% Ni and 30% Cu.

At peak operation, production is 1,800 gallons (6,800 liters) of fresh water per minute resulting in 3,600 gallons (13,600 liters) of briny "blow-down" water per minute with a salinity of about 60°/₀₀. The blow-down water is mixed with the cooling water in an open sump (Figure 9) before discharge into the entrance channel of Safe Harbor. Cooling water discharges into the

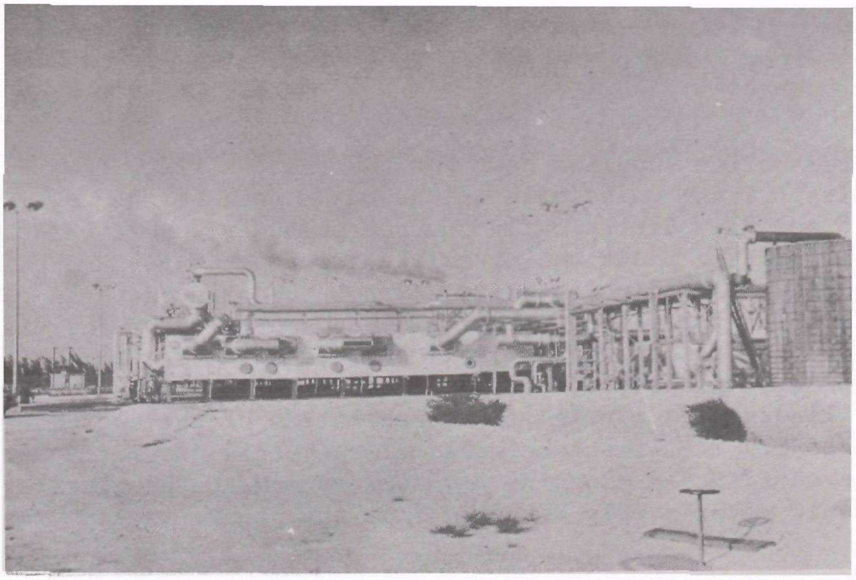


Figure 6. General view of desalting plant, showing flash-distillation units that produce fresh water.

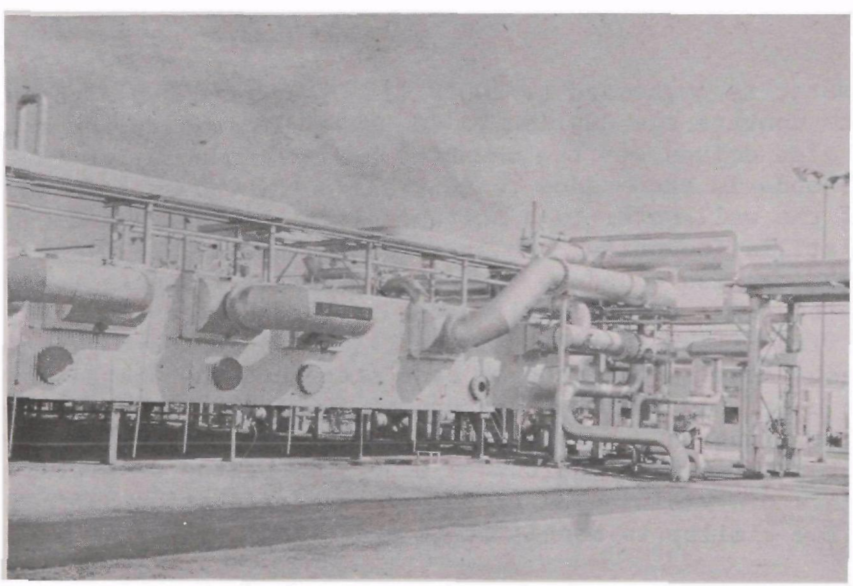


Figure 7. View of flash-distillation units.

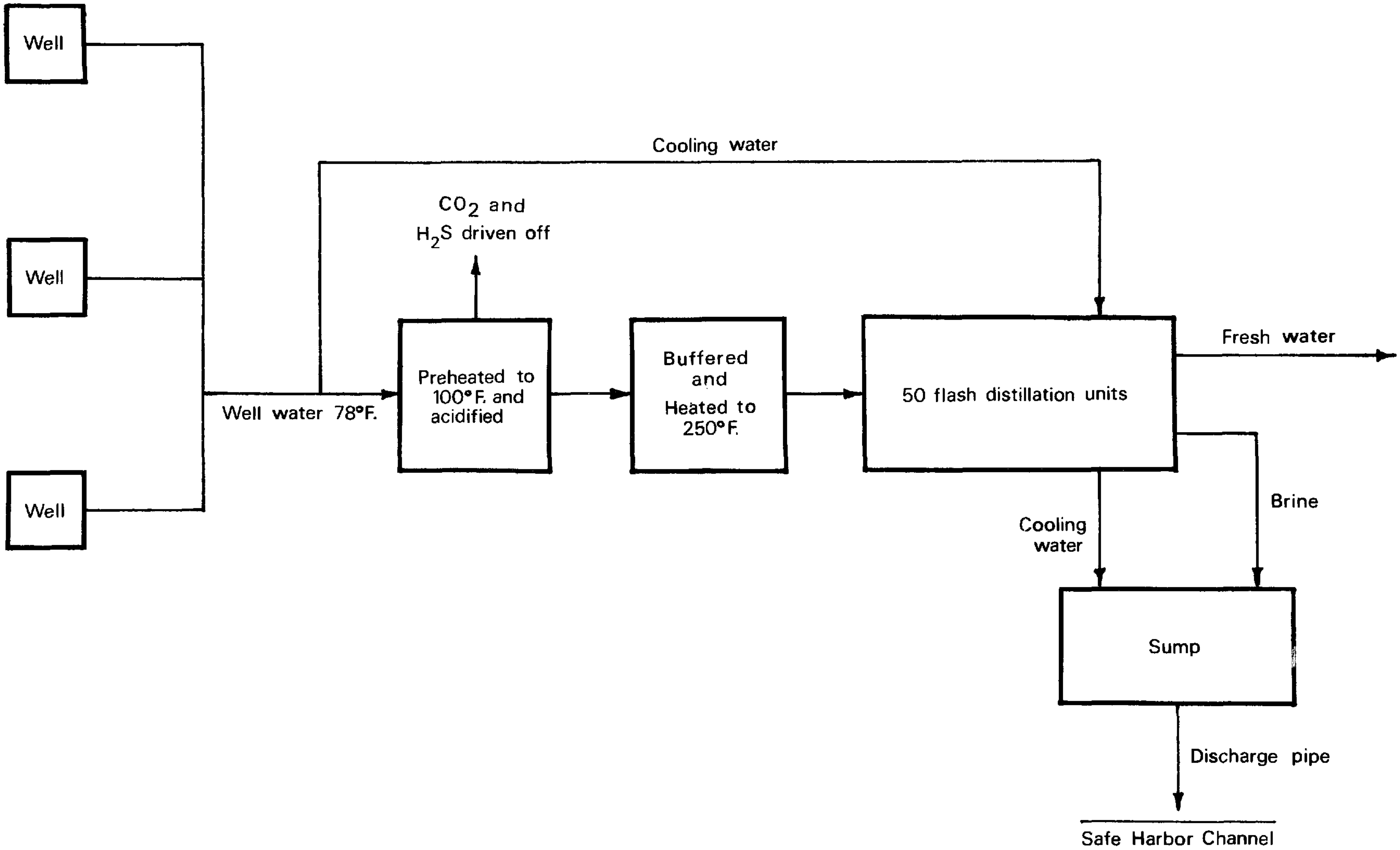


Figure 8. Schematic of desalting plant.

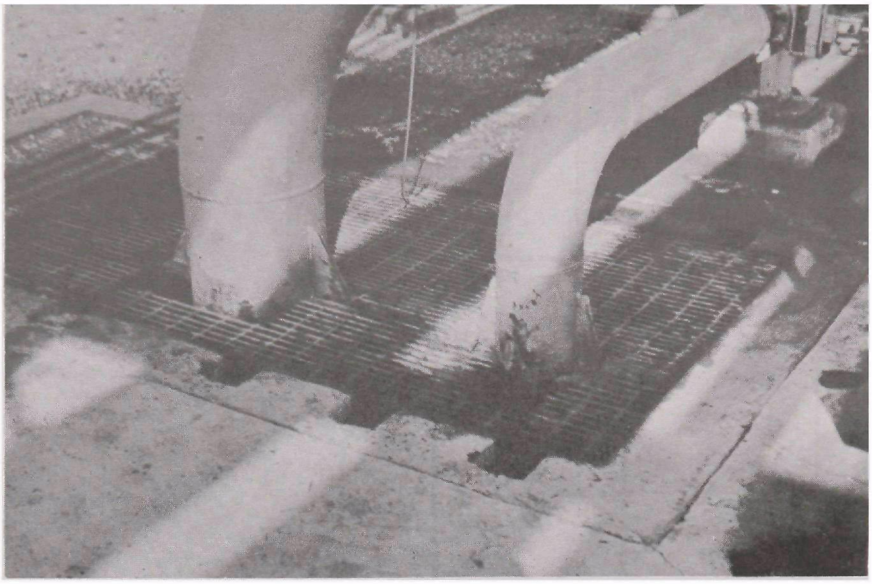


Figure 9. Open sump that receives blow-down water (left) and cooling water (right) discharges.

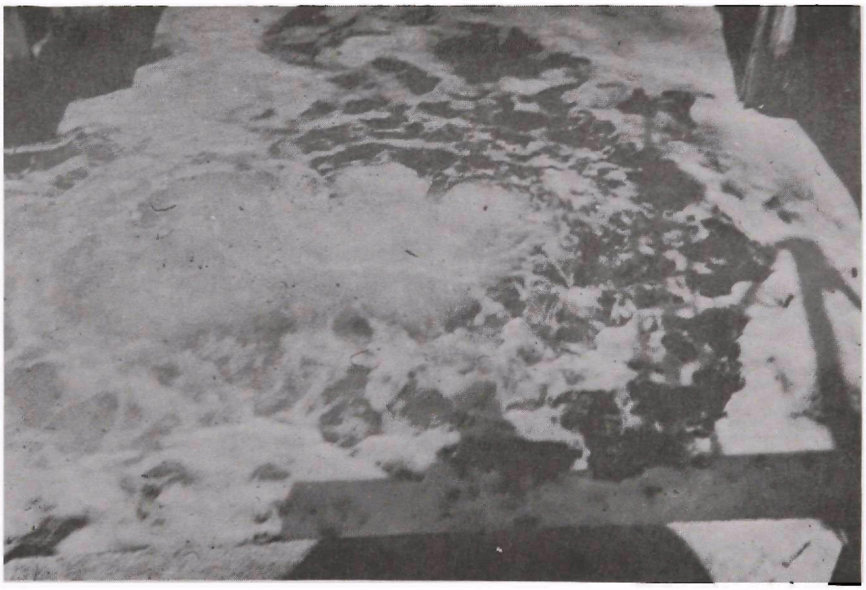


Figure 10. Effluent discharging from subsurface pipe into Safe Harbor's entrance channel.

sump at a rate of 1,200 gallons (4,500 liters) per minute along with the blow-down water which discharges into the sump at a rate of 3,600 gallons (13,600 liters) per minute. Thus, at peak operation, the total discharge from the 61 centimeter (cm) diameter pipe that drains the sump is 4,800 gallons (18,200 liters) per minute into the entrance channel of Safe Harbor (Figure 10). The effluent consists of a mixture of one part coolant water to three parts of blow-down. Both components have a maximum temperature of about 98°F (37°C) when they enter the sump. The coolant water, however, has a salinity of about 40‰ in contrast to approximately 60‰ for the blow-down water.

The characteristics of the effluent vary with time since they are dependent on the level of fresh water production at which the desalting plant is operating. The reason for this is that the amount of well water being desalted varies depending on how much fresh water is being produced, while the cooling water cycle runs at a constant rate and volume. Thus the amount of effluent and its salinity become less as fresh water production drops.

The demand for fresh water from the desalting plant depends on the status of the water supply at Key West. The fresh water product of the desalting plant supplements the water supply piped from the mainland. The plant, in general, has operated below full capacity during most of the study period. The average output per day in 1968 was 1.8 million gallons (6.8 million liters) or 70% of peak production. During this period the plant operated 90% of the time. The average rate of effluent discharge was about 3,700 gallons (14,000 liters) per minute with a salinity of about 55% during 1968. Figures to date for 1969 look as though fresh water production by the plant will be slightly higher.

A unique feature of the Key West desalting plant is that it draws its salt water from deep wells. The water level in these wells follows the tidal fluctuations quite closely. The vertical excursion of the water level in the wells differs from the tidal excursion by not more than 5 to 10% and its phase lags by about ten minutes. Despite this strong coupling with the tides, the well water maintains its temperature and chemical properties within narrow limits throughout the year (see Table 1). Therefore, the transients in the properties of the desalting plant's effluent reflect fluctuations in the plant's operation rather than in the source water. By way of comparison, the effluent of a desalting plant that drew its intake water directly from the sea would not only vary due to changes in plant operation, but would change in response to seasonal and daily variations in the source water's physical properties. Under these circumstances, it would be very difficult to identify changes in the effluent caused by changes in plant operation.

4. METHODS AND PROCEDURES

4.1 PHYSICAL MEASUREMENTS

Temperature, current direction and velocity were the physical measurements taken at ten of the stations established in the study area. During the initial seven months of the study, these measurements were taken in the morning and afternoon, Mondays, Wednesdays and Fridays weather permitting. Measurements were taken twice weekly, in the afternoons only, during the summer continuation of the study. Temperature profiles were made by taking measurements at intervals from surface to bottom at each of the physical stations using a rapid response electric underwater thermometer manufactured by Oceanics Enterprises, Inc. A second surface temperature reading was taken with a standard bucket thermometer manufactured by Kahl Scientific (Model No. 297 WA 105). These two instruments were checked against an accurate laboratory thermometer and were found to be mutually consistent within 0.1°C. Field measurements of temperature were made to the nearest 0.1°C.

Near-surface current direction was routinely measured at six of the stations outside the harbor by the following method. About one-quarter pound (113 grams) of powdered fluoroscein dye was placed in a small canvas bag. The bag was buoyed about a half meter below the water surface at each station during the morning survey and generally there was enough dye for both the morning and afternoon measurement. The visibility of the dye streaks and the distance over which they could be seen varied, depending on light conditions. The dye paths were recorded on field sheets and the current direction was derived by measuring the angle of the dye path drift relative to true north.

Bottom current speeds were also measured at these same stations using a small tripod supported Savonius-rotor current meter. The rotor was held about 35 cm above the bottom. Unfortunately, at the shallower stations, its true measurement of current velocity was obscured by surface wave induced water movements. Current information was not collected during the summer extension of the study.

In addition to the above measurements, a Hydro Products recording, Savonius-rotor current meter and temperature sensor system (Model No. 501B) was used to measure bottom currents and temperature in the basin at the entrance to Safe Harbor (Station 4). The rotor of this instrument was placed approximately one meter above the bottom for all periods of current measurement.

The temperature sensing portion of this instrument is not extremely sensitive or accurate, having a slow response time and an accuracy of ± 3% of the reading within its 0° to 40°C (32° to 104°F) range. This instrument recorded several five-day periods of continuous current and temperature data, on a self-contained strip chart recorder, but for most of the study it did not function due to mechanical and electrical difficulties.

A tide staff was placed on the seawall near the discharge pipe of the desalting plant and the water level was recorded by the field team during both the morning and afternoon surveys.

4.2 CHEMICAL MEASUREMENTS

Three properties of the seawater samples collected at the ten physical stations were measured; salinity, oxygen and alkalinity. Salinity determinations were made in the laboratory with a Hytech Salinometer (Model No. 62220), the reliable operation and accuracies of which are well documented (Brown and Hamon, 1961; Cox, 1965). Salinities determined by the conductivity method may be related to the older chlorinity determinations by

$$S\ (°/_{\circ\circ}) = 1.80655\ (Cl\ °/_{\circ\circ})\ ,$$

where S, the total dissolved solids in seawater, is defined empirically as:

$$S\ (°/_{\circ\circ}) = 0.08996 + 28.29720\ R = 12.80832\ R^2 - 10.67869\ R^3 + 5.98624\ R^4 - 1.32311\ R^5\ ,$$

and where R is the ratio of the conductivity of the unknown seawater sample to one having a salinity of exactly 35°/₀₀ when both are at 15°C. (Wooster, Lee and Dietrich, 1969).

A Hach Chemical Company oxygen determination kit was used for this study to measure the amount of dissolved oxygen in water samples. The determination is based on the so-called "dry Winkler method". The powdered reagents for this determination are packaged in individual, sealed polyethylene capsules. Each capsule contains the correct quantities of manganous sulfate, alkaline iodideazide and sulfamic acid for determining the oxygen content of an individual water sample. A new reagent, phenylarsene oxide, that is completely stable was used in the titrations rather than sodium thiosulfate, the usual reagent for the Winkler method (Thompson and Robinson, 1939).

A Hach Chemical Company alkalinity determination kit was used to measure the alkalinity of water samples collected during this study. Alkalinity is obtained directly as equivalent $CaCO_3$, in grains per gallon from buret readings at the end of titration (1.0 grain/gallon = 17.118 mg/liter = 17.118 ppm = 0.34205 milli-equivalents H^+ per liter.)

Alkalinity, which is a measure of the buffering capacity of the sea water, can be defined as the sum of the equivalent concentrations of weak acid anions minus the sum of the weak base cations. It was determined by titrating a sample with a standard solution of a strong acid to the recommended end point of about pH = 4.8 (Standard Methods 12th Edition). An indicator mixture of Brom-Cresol Green and Methyl Red changes, but not abruptly, from blue-green to pink in this range. The recommended end point occurs as the green color disappears; i.e., the solution turns a light pink-grey with a bluish cast.

The water samples from which the above chemical determinations were made, were collected with a two-liter plexiglass Van Dorn bottle manufactured by

Hydroproducts (Model No. 120). Sub-samples used for salinity and alkalinity determinations were decanted into polyethylene bottles having poly-seal stoppers. Sub-samples for dissolved oxygen measurements were placed in standard 300 milliliter BOD bottles with ground glass stoppers. The water samples for oxygen determinations were immediately "fixed" by adding manganous sulphate, alkaline iodideazide and sulphamic acid after being decanted from the main sample.

4.3 PROCEDURES FOR COLLECTING PHYSICAL AND CHEMICAL DATA

During the Phase-I study, a field team was maintained at the Key West site to collect the physical and chemical data. On Mondays, Wednesdays and Fridays of each week, weather permitting, field team investigators made physical measurements and collected water samples at Stations 1 through 10* (Figure 10). For the observations and measurements made at all of the stations see Table 2. A small (16 ft) outboard powered boat was used and the stations were occupied in the numerical order indicated in Figure 10. Temperature profiles were recorded on field sheets while they were being made at each station. Measurements were made at 0.3 m increments except at Stations 5, 6, and 7 where they were made at 0.6 m increments.

Current direction was determined from dye drift at the stations outside the harbor (Stations 4 through 10). Bottom current measurements were taken at these same stations. This information was also noted on field sheets.

Water samples were collected 0.5 m below the surface of the water and 0.5 m above the bottom except at Stations 8, 9, and 10 where the water was so shallow that the two samples would occur at nearly the same point in the water column. At Stations 1 through 4 a third water sample was collected at about mid-depth, 5.5 m below the surface. Subsamples for salinity, oxygen *and alkalinity determinations were decanted from the 2.0 liter water sample* immediately after its collection. The subsamples were then temporarily stored in compartmented cases for transport back to the laboratory. The chemical properties of these subsamples were analyzed the following day in a laboratory rented at the Florida Keys Junior College.

The Phase-I study, involving morning and afternoon surveys three times a week, ran from 11 November 1968 to 15 May 1969. During the summer extension of the program which ran from 26 May to 27 August 1969 surveys were run twice weekly only in the afternoons at Stations 1 through 4 in the harbor and Stations *8 and 9 on the shallow flats on either side of the* entrance to Safe Harbor.

4.4 BIOLOGICAL MEASUREMENTS

A wide variety of biological measurements were made during the Phase-I investigation. These included quadrat counts, plankton tows, settlement racks, gorgonian colony transplants, seawall invertebrate counts, fish occurrences in discharge and control areas, transect counts of lobsters and stone crabs in discharge and control areas, marine algae occurrences, in *discharge and control areas, and bottom* samples.

---

* Stations with letters after them are biological stations.

Table 2

OBSERVATIONS AND COLLECTIONS MADE AT EACH STATION DURING STUDY.

Station Number	1	1A	2	2A	3	3A	3B	4	4A	5	5A	6	7	8	8A	9	9A	10	10A
Physical Measurements (temperature, salinity, dissolved oxygen, alkalinity)	X		X		X			X		X		X	X	X		X		X	
Current Measurements								X				X	X	X		X		X	
Quadrat Monitoring	X			X	X		X		X			X		X	X	X	X	X	X
Plankton Tow (between stations)		Tow 1 1A-2		Tow 2 2-3		Tow 3 3-4				Tow 4 5-5A				Tow 5 8-8A		Tow 6 9-9A		Tow 7 10-10A	
Bottom Sample	X		X	X		X				X	X			X	X	X	X	X	X

4.4.1 Quadrat Counts

Quadrats 4 m^2 in area were located on the bottom at 12 of the biological Stations (1, 2A, 3, 3B, 4A, 6, 8, 8A, 9, 9A, 10, 10A) between 11 and 16 December 1968 (see Figure 10). A quadrat consisted of a polypropylene line arranged in a square, 2 m per side, and held in place at each corner by a large nail driven into the substrate. This marking technique provided the diving biologists a way of returning to the same areas on the bottom during each field visit. They selected the 4 m^2 quadrat size for two reasons: (1) they had been using this size quadrat along the southern California coast and staying with a common size permitted comparing the effectiveness of the method in two very different environmental areas; (2) the 4 m^2 quadrat is large enough to include significant numbers of attached organisms for studying changes in the density and composition of these organisms. To increase the accuracy of the counts, the divers placed a subdivided 1.0 m^2 reference frame over each quarter of the 4 m^2 quadrat when counting organisms.

During each visit to a quadrat, the field team counted the numbers of major organisms, where they could, and determined the percentage of plant cover when present. They kept records on plastic slates, plotting the positions of organisms on these slates while underwater. This information was transfered later to log sheets. Examples of log sheets, showing divers' observations during one field inspection of the quadrats are given in Appendix B.

4.4.2 Plankton Tows

Plankton tows were taken between Stations 1A and 2, 2 and 3, 3 and 4, 5 and 5A, 8 and 8A, 9 and 9A, and 10 and 10A. The locations of these tows are seen in Figure 10. The biologists used a 30-cm diameter net (125 meshes per inch, or 50 meshes per cm) for collecting plankton. The small diameter of the net was necessary to allow for towing over the shallow flats. Each tow was approximately 275 m long and lasted about 10 minutes. All of the tows were made near the surface during daylight hours. The plankton samples were preserved with four percent formalin immediately after collection.

The total volume of each plankton sample was measured in the laboratory by placing the sample in a 100-ml cylindrical graduate and allowing the plankton to settle within the fluid fraction for 15 hours.

The investigators took two aliquots of each sample for species analysis by the following method. They adjusted the whole plankton sample to a total volume of 100 ml, mixed it thoroughly and removed the aliquots. Each aliquot represented 1/100 of the total plankton sample. These samples, which were dominated by copepods, have been analyzed by Dr. A. Fleminger, a copepod specialist at the Scripps Institution of Oceanography.

4.4.3 Biological Settlement Racks

Settlement racks with eight disks attached (four of cement and four of rubber) were used during this program to study the effluent's effects on settlement and growth of attached organisms on new clean uncolonized substrates. On 3 October 1968, divers placed the first rack on the slope at the edge of the channel in 7 m of water, about 11 m below the discharge pipe and near the southern edge of the plume (near Station 3).

On 12 December 1968, the investigators put the second rack into position on the west side of Safe Harbor, opposite the desalting plant but closer to the harbor entrance, at a depth of 6 m. This location, near Station 3B, was selected as a control area because it was similar to the depth at Station 3 as well as the type of substrate and species of organisms inhabiting the area. Also the location was sufficiently removed from the effluent discharge point so as to not be visibly affected by the effluent.

Since 40 days elapsed between the placement of the first rack and the second, the investigators put new settlement disks on the rack near the discharge to make it comparable with the control for the rest of the study. The settling organisms had a choice of upper or lower surfaces as well as a choice of substrate -- rubber or cement.

A number of investigators have used artificial substrates to attract plants and animals in their settlement stages. Pearce (1968) attached disks of various materials -- cement, rubber and wood -- to a weighted rack that stood slightly off the bottom. The disks were approximately 0.25 m in diameter with a surface area of 0.05 m^2. He placed the racks in the environment and collected the disks at regular intervals for examination. The settlement disks are used to study species' substrate preference, the time and amount of settlement, growth, succession and competition for space.

Disks, similar to Pearce's, were used in the present study and samples were collected from settlement racks on 27 January, 31 March and 2 June 1969. Each disk was brought to the surface in a plastic bag, placed into a solution of 7.5% $MgCl_2$ for about 2 hours and then stored in 10% formalin for subsequent examination.

During analysis of the settlement disk, the unattached epifauna were washed off and size sorted by using U.S. Bureau of Standards 1.0- and 0.5-mm screens. The attached sessile organisms on each surface of the disk were counted using a method developed by Pearce (1968). A circular piece of plastic the same size as the settlement disk from which a wedge 1/10 of the surface area (0.005 m^2) had been cut, was randomly placed on the settlement disk. All of the organisms lying within the wedge were counted. Two counts were made on the upper and on the lower surfaces of the disk, giving a total of four counts per disk. Sample work sheets used for these counts are given in Appendix C.

4.4.4 Gorgonian Colony Transplants

On 14 December 1968, 18 gorgonian colonies were selected near Station 8A (see Figure 10) at a depth of about 2 m. Eleven transplants were *Pseudopterogorgia bipinnata*, two were *Plexaurella dichotoma* and five were *Pterogorgia anceps*. Three of the *Pseudopterogorgia bipinnata* colonies were transplanted at the original site (Station 8A) to serve as controls for the transplant method. The remaining 15 colonies were towed slowly behind the boat to near the desalting plant and placed around the discharge area at varying distances and depths.

The method used to hold the colonies in place at both the control and outfall sites was the following. A cement hemisphere 31 cm across the base was used as an anchor for each colony. The basal attachment of the colony was inserted into a hole passing through the cement hemisphere. The remaining space in the hole was filled with a non-toxic epoxy putty (Rosenthal, 1969) to fix the colony permanently in place (Figure 11).

The selection of gorgonian colonies for transplant experiments in the outfall region was based upon several factors: (1) the gorgonians are one of the more common sessile organisms in the Florida Keys; (2) colonies are easily transplanted (Cary 1914 and Grigg 1970); and (3) they are sensitive to changes in the environment (Grigg 1970).

The distribution of gorgonians is controlled by their physiological requirements and the availability of suitable substrates (Bayer, 1961). Some limiting factors are temperature, salinity, illumination, depth and substrate. Cary (1918) determined the upper temperature tolerances for twelve species of gorgonians growing on the reefs off the Dry Tortugas, Florida. He found that most species died when exposed to temperatures between 34.5°C to 38.2°C. Gorgonians are for the most part stenohaline and require salinities similar to those required for nearshore coral reefs. Where coral reefs are best developed, the surface salinity averages about 36°/₀₀ (Bayer, 1961). Gohar (1940, 1948) found that some species of gorgonians die if they are deprived of illumination. Grigg (1970), however, working with California gorgonians belonging to the genus Muricea, found that illumination was not a limiting factor. Depth distribution is dependent on the individual species (Bayer, 1961). The reef species used during this study generally occurred at depths between 2 and 10 m.

Figure 11. Gorgonian colony transplant attached to cement hemisphere.

Availability of suitable substrate within the depth range of the species is one major factor controlling gorgonian distributions in the Florida Keys (Bayer, 1961). The larvae of gorgonians require a rough and solid substrate for settlement (Carey, 1914).

None of the study team has yet found gorgonian colonies within Safe Harbor, although they have observed small, newly settled colonies on the rocky rim of the basin near the entrance of the harbor. The substrate within the harbor seems suitable for larval settlement in several areas, but other ecological factors such as pollution, turbidity, sediment deposition or space competition with other sessile organisms may have prevented the larvae from colonizing these regions. Since the larvae have not been successful in settling the area, the biologists wondered if adult colonies would survive in the harbor, particularly in the region of the discharge.

4.4.5 Seawall Invertebrate Counts

The desalting plant's concrete seawall, which runs along the east side of the entrance channel to Safe Harbor, provides a uniform substrate to study the distributions of organisms relative to the effluent field. The seawall extends 72 m north and 53 m south of the discharge pipe. Its construction forms rectangular sections below the surface of the water, 1.8 m long by approximately 0.8 m high, along the entire length of the seawall. Thus, it offered a series of sampling areas equal in size for contiguous density counts either side of the discharge pipe.

The subsurface portion of the seawall is densely colonized with organisms. Some of the more abundant forms are: the ascidians, Ascidia nigra and Botrylloides nigrum; the hydroid, Plumularia sp.; mollusks, Ostrea frons, Ostrea equestris, Cantharus tinctus and Thais haemastoma; a cheilostomatid bryozoan; a grapsoid crab, Grapsus grapsus; barnacles, Balanus amphitrite and Tetraclita squamosa stalactifera; the fishes, Gobiosoma sp. and clinids; as well as the green algae, Cladophoropsis membranacea.

The solitary black ascidian Ascidia nigra and the gastropod Cantharus tinctus were selected for density counts along the seawall. These two organisms were chosen because of their common occurrence throughout Safe Harbor and their different living habits -- filter feeding versus carnivorous feeding and sessile versus motile.

4.4.6 Fish Occurrences in Discharge and Control Areas

Two areas along the east side of the entrance channel to Safe Harbor were selected for studying the species inhabiting them. Both areas had similar types of substrate and equivalent depths of water. They also had rows of mooring dolphins placed at the break in slope at the edge of the channel. Each of these dolphins consists of 5 or 6 pilings surrounding a central piling, bound together at the top with cables. The biologists suspect that these dolphins provide a strong attraction for fishes. Sessile organisms, such as barnacles, oysters and serpulid worms, which have accumulated on the pilings may serve as food for some fishes. The arrangement of the pilings also provides shelter and hiding places in which reef fishes are often observed. Randall (1963) has demonstrated that tropical reef fishes require rough, irregular surfaces as part of their habitat.

The discharge area was situated along the seawall at the desalting plant while the control area was located about 170 m farther in the entrance channel to Safe Harbor at the site for the new Key West City Electric power plant. The dolphins at the latter site were emplaced in December 1968 whereas the dolphins at the desalting plant had been in place prior to the start of the study.

Dives were made in the two areas to determine if there were any significant differences in the fish populations inhabiting them. Species were noted first on a presence or absence basis. Secondarily, the species sighted were categorized as to whether they were common or uncommon. Notations were made on underwater slates by the biologist divers while swimming in the discharge and control areas. Some observations were also made regarding the behavior of different species of fish in the currents created by the discharge.

4.4.7 Transect Counts of Lobsters and Stone Crabs in Discharge and Control Areas

Two species of crustaceans, the Florida spiny lobster, *Panulirus argus*, and the stone crab, *Menippe mercenaria*, are common in Safe Harbor and at times occur in the discharge area. *Panulirus argus* ranges throughout the study area. They aggregate where the bottom is rocky and irregular or where man-made rubble litters the bottom. *Menippe mercenaria* also ranges throughout the study area, but in most cases tended to be less numerous than the lobsters.

A 50-m transect line in about 5 m of water was set up in the discharge area of the desalting plant and a similar one in the control area off the site of the new Key West City Electric power plant. The counts of lobsters and stone crabs were limited to a band 2 m wide along the line's total length. The discharge area transect was placed approximately 8 m from the end of the discharge pipe and extended 25 m either side of the pipe along the edge of the entrance channel. The other transect was located in the control area approximately 170 m up the entrance channel from the discharge pipe.

4.4.8 Marine Algae Occurrences in Discharge and Control Areas

The occurrence or absence of benthic algae was investigated in the discharge and control areas since it was noted that algae were lacking or very sparce in an irregularly shaped zone immediately around the discharge pipe. Two similar areas were selected in the discharge and control areas and the species of algae present were noted.

4.4.9 Bottom Samples

Bottom samples were taken at Stations 1, 2, 2A, 3A, 5, 5A, 8, 8A, 9, 9A, 10 and 10A (see Figure 10 and Table 2) on 29 June, July, and 12 through 14 October 1968. These samples were obtained with a scoop that takes a sample approximately 500 ml. in volume. These samples were placed in labeled jars and preserved immediately with a solution of formaldehyde.

At a later date the sediments were sifted through 1-mm and 0.5-mm sieves and the organisms removed. These organisms were subsequently identified to major group or sometimes down to genus and species.

4.5 PROCEDURES FOR COLLECTING BIOLOGICAL DATA

Unlike the field team for the physical program, the biological field team was not stationed in Key West and only payed periodic visits to the study area to collect data. Several of these trips were made prior to the actual contract. Biological investigations were conducted at Key West during the following time periods: 27 June to 2 July, 10 to 14 October, 8 to 17 December 1968, 22 to 28 January, 24 to 28 February, 29 March to 4 April, 28 May to 3 June, and 28 to 29 June 1969. During the field trip periods, the bottom quadrats were checked by divers, plankton tows were made using the 16 ft. outboard powered boat, and various other collections and measurements were made relating to the settlement racks, gorgonian colony transplants and transect counts. The field work generally took four to seven days to complete. Time of completion depended on weather and the types of experiments that were conducted. A certain amount of time on each trip was spent in exploratory diving to learn more about the shape and behavior of the effluent plume, the underwater topography in the study area, and to make representative study collections of the organisms occurring in the area.

5. RESULTS

5.1 PHYSICAL

Surface currents, which were measured routinely at the outside stations (Numbers 4, 6, 7, 8, 9, and 10), showed a strong dependence on wind direction. They generally flowed in the same direction that the wind was blowing. The relationship between wind and currents over the shallow flats is reflected in the histograms of current direction derived from the dye drift observations (Figure 12). The prevailing winds are predominently out of the east and the most common drift direction is to the west at all of these stations. Station 8 which is just to the east of the harbor entrance shows the least pronounced westerly trend as far as current direction and this is probably related to the presence of the eastern jetty of Safe Harbor which is a barrier to the westward flow of water across the shallow flats. Water flows out around the end of this obstruction in various patterns depending on wind conditions.

The observation of dispersed dye confirmed the conclusion that the currents over the shallow flats are primarily wind induced and that the tidal component is very weak at most of these stations. Station 7, located in the Boca Chica Channel, is an exception and currents observed there show a strong tidal influence. The greatest frequency of occurrences in current direction is along the axis of the channel. This channel cuts completely across the keys which makes it quite different from Safe Harbor where one end is closed off entirely.

Tidal currents are weak by comparison with wind-driven currents, and on the whole, the latter predominate in the study area. Under prevailing wind conditions, water enters the study area from the east and flows across the approach channel of Safe Harbor along the south side of Cow Key and then towards Key West. The movement of water in and out of the harbor is a combination of tidal exchange, wind-driven surface drift, and discharge from the desalting plant. There are differences, depending on the depth, in the paths of communication between the harbor waters and outer waters. Water in the upper 1.5 to 2.0 m communicates freely with that on the shallow flats. This has been demonstrated with dye releases and the drift of powdered aluminum on the surface waters. Water below these depths, because of its greater density, appears to communicate with the outer waters through the approach channel that cuts across the shallow flats at right angles to the prevailing surface flow. Thus, any surface flow of effluent would tend to drift west across the shallow flats under the prevailing wind conditions. The more dense and deeper portions of the effluent plume, however, can travel only in a north-south direction along the axis of the entrance and approach channels.

In the case of surface currents, the almost continuous island barrier north of the stations greatly reduces the probability of north drifting currents and this is reflected in the current histograms (Figure 12). The directions of the observed currents indicate that under normal weather conditions

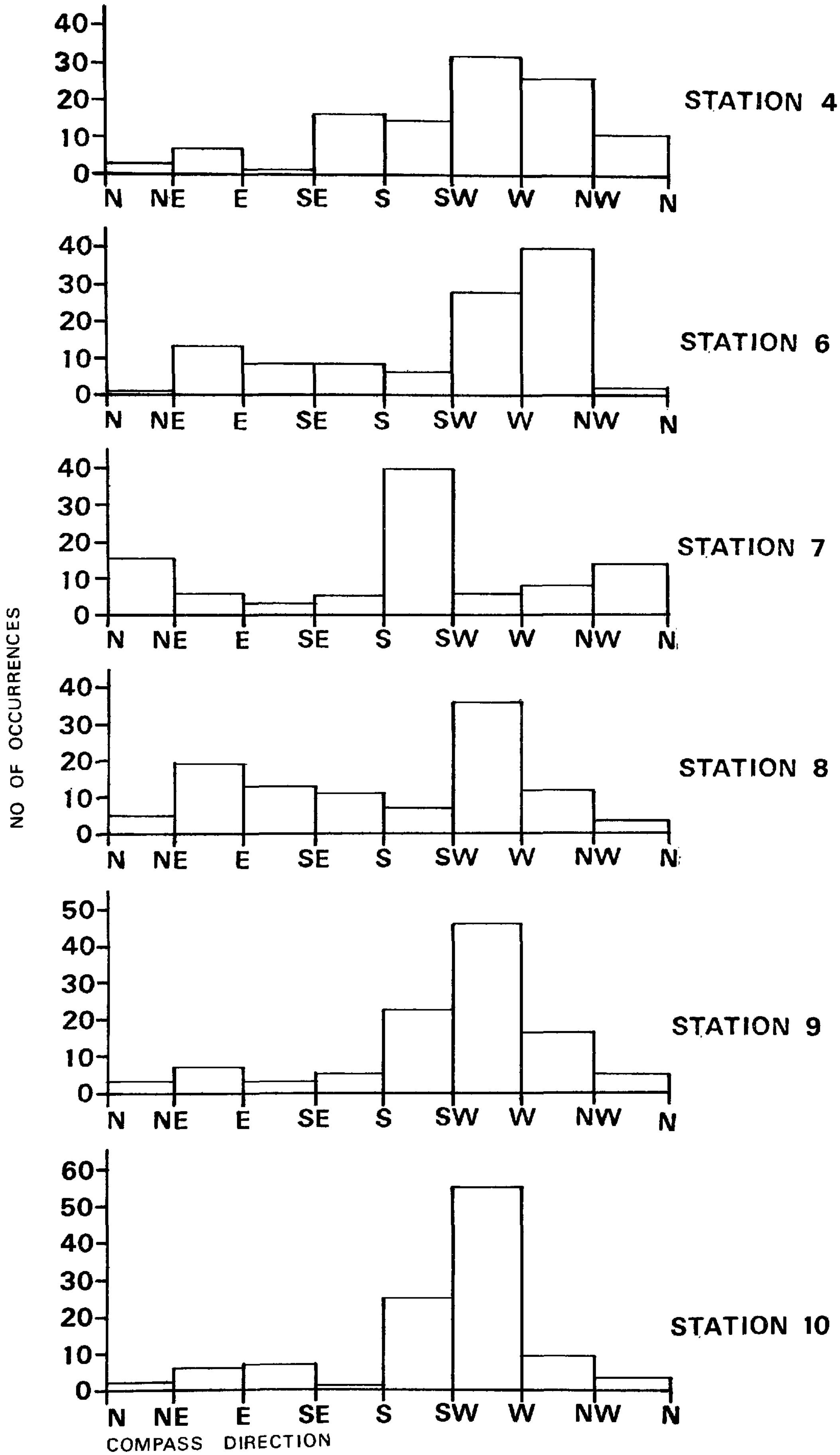


Figure 12. Histograms of current direction at Stations 4-10.

Station 6 off Boca Chica Island is the least likely to be affected by the effluent discharged from the desalting plant. This is because Station 6 is farthest geographically from the plant and under most conditions upcurrent from the point of discharge. Physical conditions at Station 6 therefore should represent normal conditions for the area.

Temperature data collected during the course of the study indicate that there is a strong correlation between all stations both for mean and extreme values. Surface and bottom temperatures (Figure 13) show the same seasonal trends and there is no marked skewing of values at stations nearest the discharge point. However, the mean bottom temperature at the station closest to the discharge point averaged about 0.5°C higher than bottom temperatures measured at equivalent depths at other stations, a very small difference when compared with the natural environmental fluctuation of temperatures.

The extremes in temperature values at all stations are less during the winter months of January and/or February; in the spring period the extremes are greater and temperature fluctuations are more variable. Towards the end of spring and entering into the summer months the temperatures again become more uniform and extreme values less divergent.

Humidity remains uniformly high the year around, impeding the evaporative cooling of the surface waters. Thus, air temperature and conduction from the atmosphere, radiative balance, and wind speed are the major factors controlling the temperature of the surface waters. Since the winter sunshine and wind conditions are fairly uniform, cold fronts advancing from the north make air temperature the most important factor contributing to rapid changes in surface water temperatures. Sudden abnormally low water temperatures in the Florida Keys have caused fish kills (Galloway, 1951). R. J. Rosenthal, one of the biological team members, observed a fish kill along Key West's Tower Beach during December 1968. No fish mortalities were observed in Safe Harbor during the same period. The deeper water of the harbor probably was the main factor, since fish kills are usually limited to shallow flats.

5.2 CHEMICAL

Salinity. like temperature, shows a strong correlation between stations. The harbor stations which are representative for all the stations are plotted in Figure 14. The mean salinity for all stations reached its lowest values during the month of January. This low corresponded with the heaviest period of winter rains. From January on, the mean salinity at all stations gradually increased through the spring months reaching its peak values in the month of May. In June, the mean salinity values dropped again corresponding with a period of increased rainfall. This drop is not quite as pronounced in the bottom values but can be detected at most of the stations. The salinity values for the next two months gradually increased and reached their highest values for the study in the month of August.

The greatest extremes in salinity values occurred in June during the summer period of increased rainfall. This can be seen at all of the stations monitored during the summer period. A second less pronounced divergence of the extreme values is seen during the winter rains.

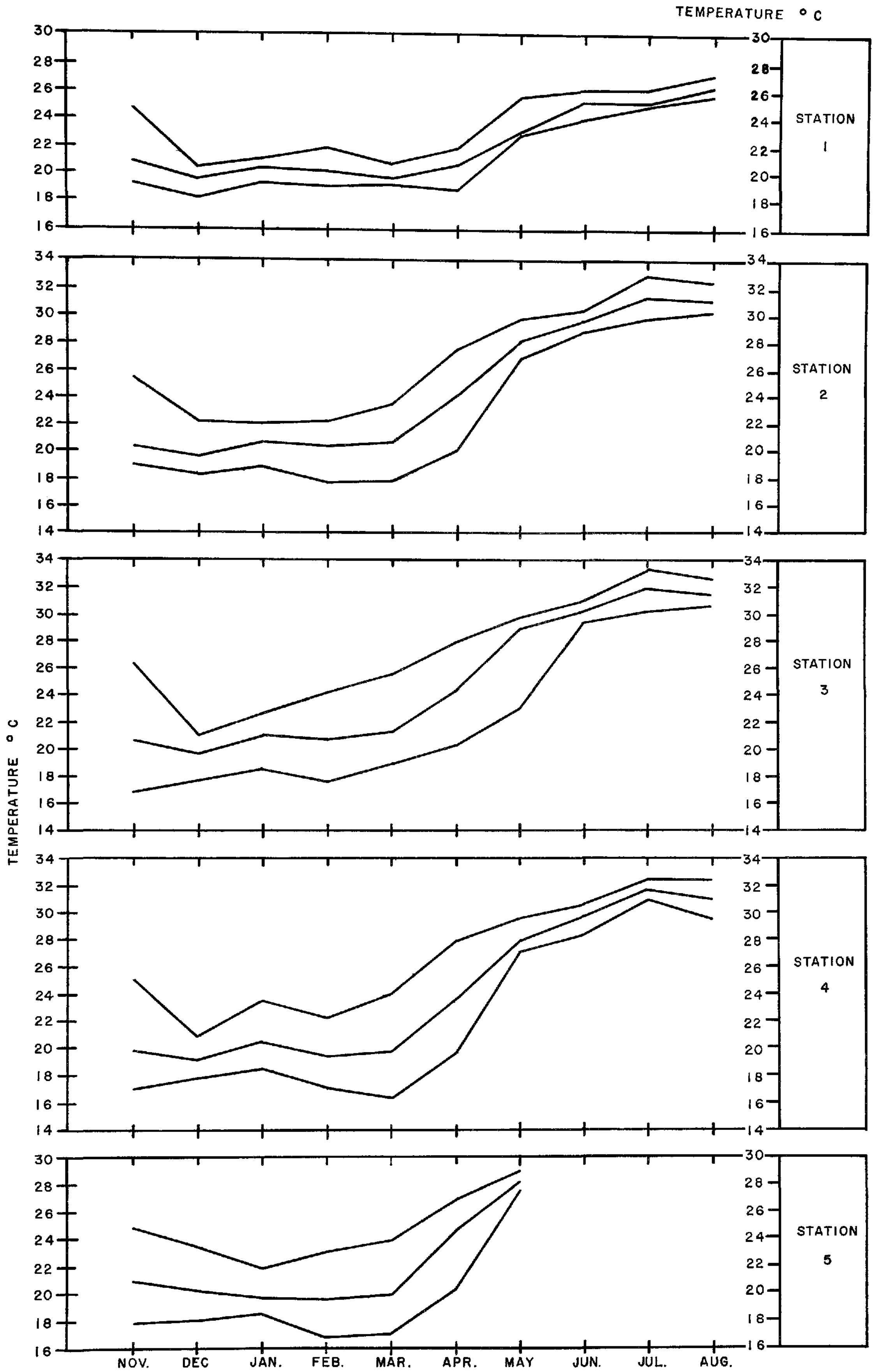


Figure 13. Monthly mean and extreme bottom temperatures for Stations 1-10.

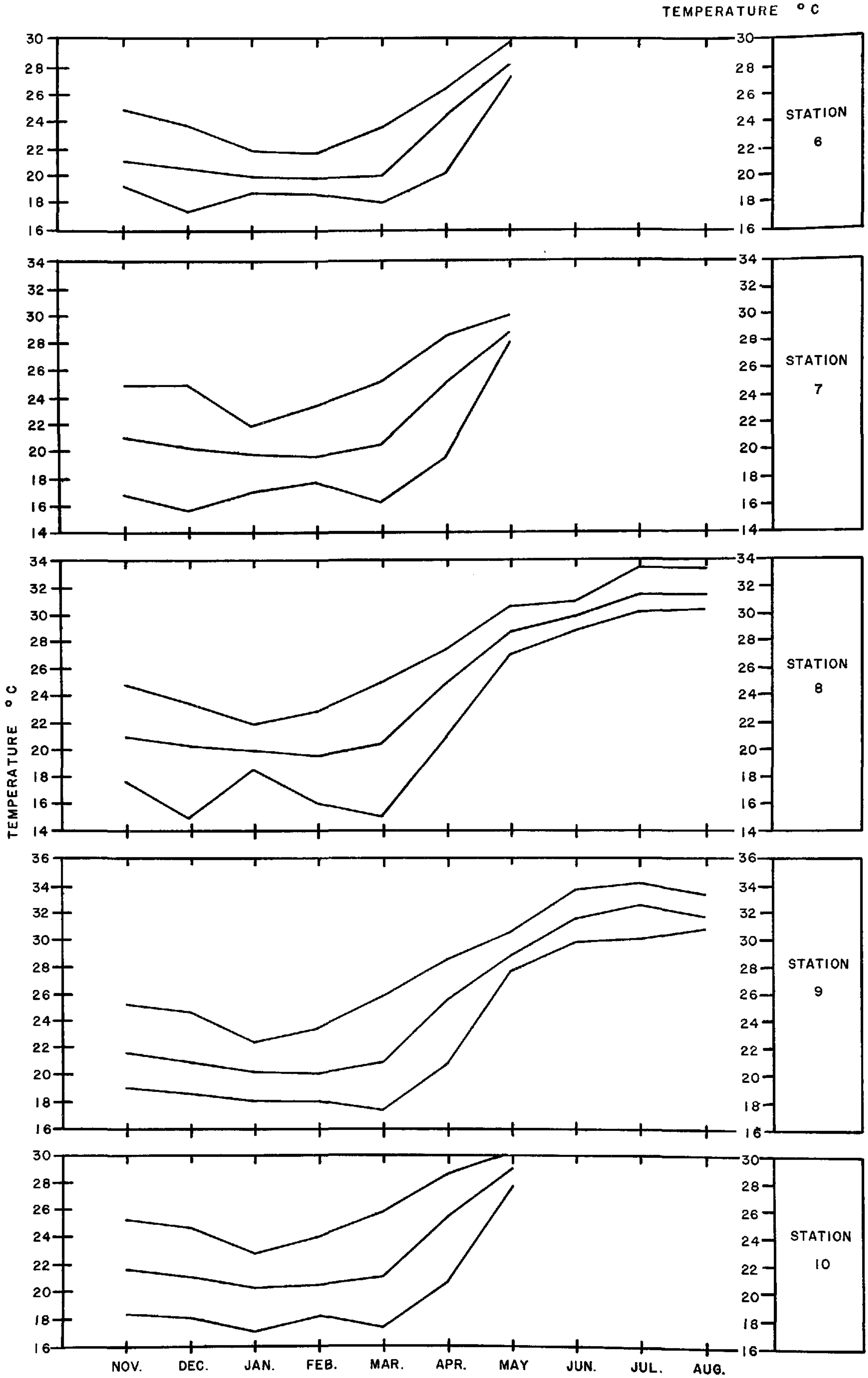


Figure 13. (continued)

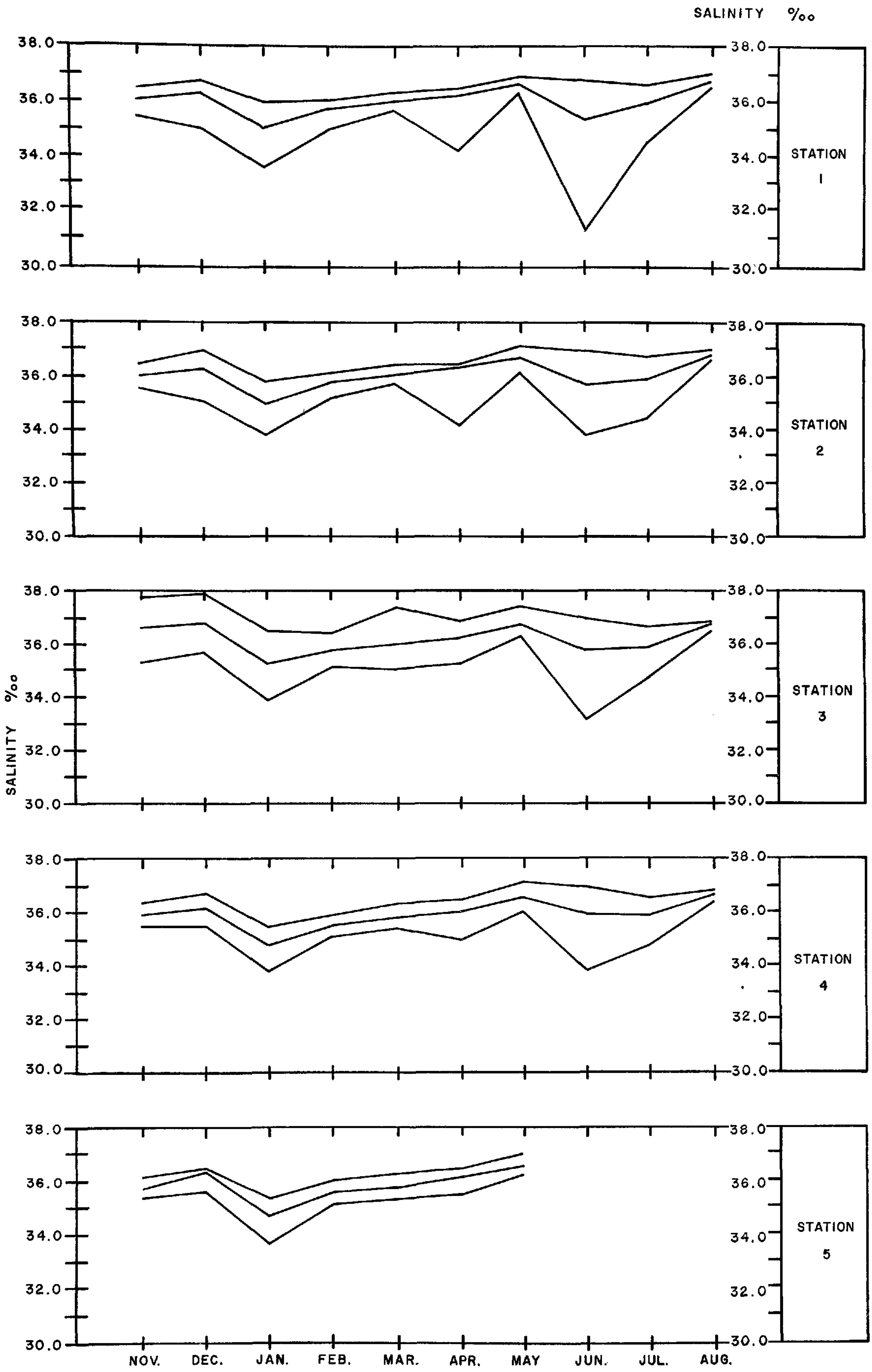


Figure 14. Monthly mean and extreme surface salinities for Stations 1-5.

Both surface temperature and salinity values were higher at Station 3 than neighboring stations during the winter months. The highest surface salinity value for the entire study was recorded at this station during the winter. Conversely, during the summer months, Station 3 values showed much less divergence from other station values for salinity and temperature, approaching more closely the environmental conditions found throughout the study area.

High salinity seems to be the controlling density property of the effluent since the greater portion of the plume sinks after it leaves the discharge pipe and seeks some intermediate depth in the water column. The dominance of salinity is indicated by the presence of thermal inversions at all of the harbor and entrance channel stations. Temperature profiles shown in Figure 15 were all made within an hour of one another and so are comparable with one another. The core of the effluent plume can be traced from station to station by its elevated temperature. As it moves away from the discharge point it becomes more dense through loss of heat and gradually sinks. It does not sink as deeply in the upper end of the channel (Stations 2 and 2A) because in general salinities are higher there as well as temperatures (Figure 15). On the other hand, the effluent plume sinks to the bottom on the seaward side of the discharge point because of the intrusion of less saline water from outside the harbor during tidal exchange. The sinking of the plume has been observed by watching the movement of fine suspended material and dye injected into the effluent at its source. Only a very small fraction of the effluent plume reaches the surface of the channel and this is buoyed to the surface by the rising bubbles of air entrained in the effluent when the blowdown and cooling waters are discharged into the sump (see Section 3 PLANT CHARACTERISTICS).

The effluent plume of the desalting plant differs significantly from the heated plumes discharged by power generation plants in that it sinks below the surface and there is little loss of heat directly to the atmosphere. Because the desalting plant effluent plume sinks and often comes in contact with the bottom, it is the benthic organisms that are most drastically affected. This has been confirmed by the biological investigations (see Section 5.3 BIOLOGICAL RESULTS).

The temperature and salinity data also indicate that the tidal exchange for Safe Harbor is not large. Looking at the values for Stations 2, 3, and 4 shows that some of the residual heat and salinity from the effluent remains in the harbor throughout the tidal cycle. Station 3, which is closest to the discharge point, generally has the highest temperature and salinity values, both surface (Figure 16) and bottom (Figure 17) of any of the stations located along the entrance channel or in the harbor proper. Station 2, closer to the head of the harbor, has the next highest values. Station 4, at the entrance to Safe Harbor, generally has values below those found at Station 2. The relative values at these stations indicate an asymmetry to the dispersion of the effluent in the harbor. The values of salinity and temperature are observed to be greater on the inner harbor side of the discharge point than on the outer. This asymmetry was also observed during dye injection experiments and in the distributions of organisms relative to the discharge point (see Section 5.3 BIOLOGICAL RESULTS).

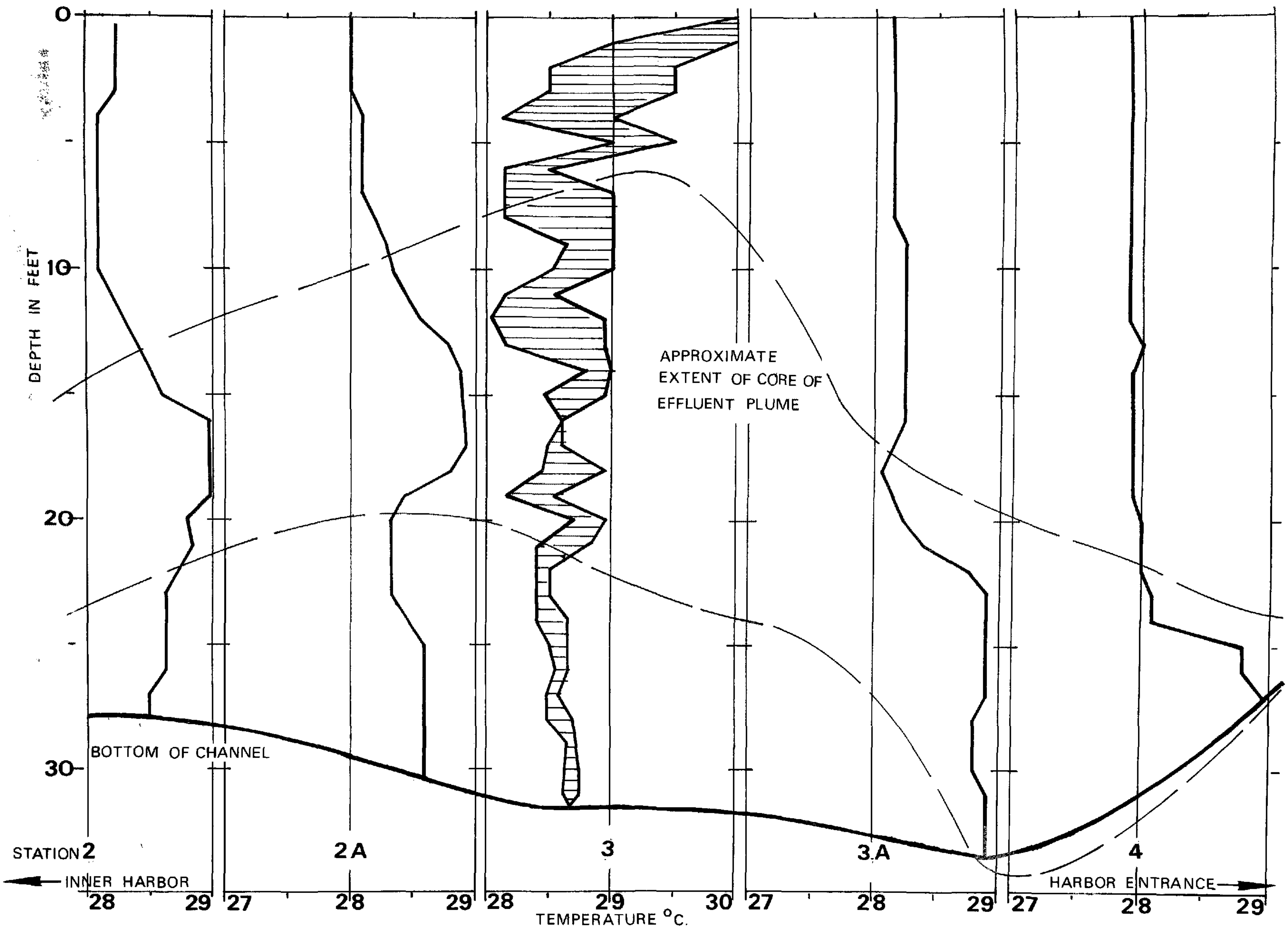


Figure 15. Temperature profiles for stations in entrance channel and harbor showing thermal inversions produced by effluent plume. The station 3 profile is in an area of turbulent mixing and the two lines show the highest and lowest temperatures recorded at each depth while the temperature profile was being made.

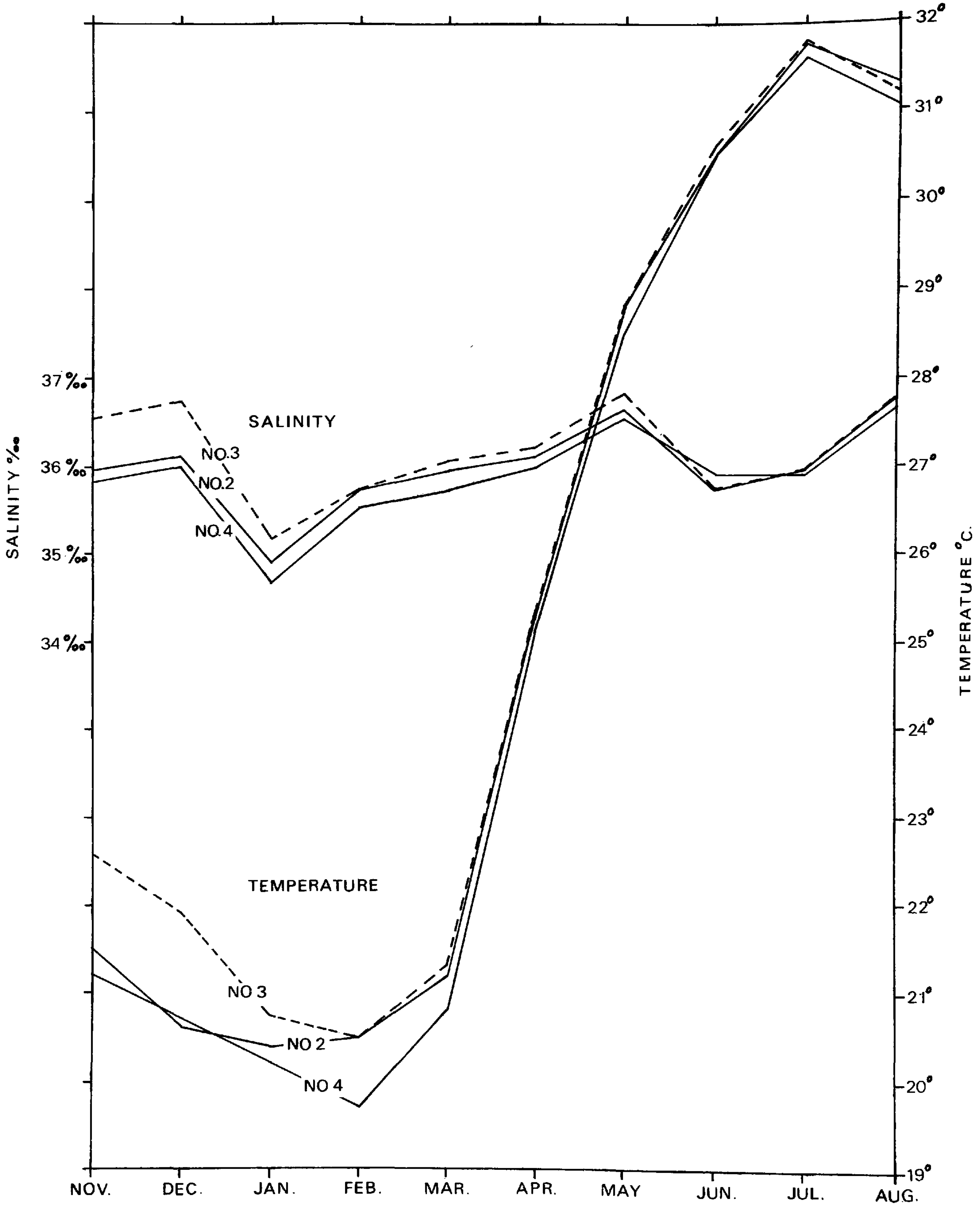


Figure 16. Surface temperature and salinity at Stations 2, 3, and 4.

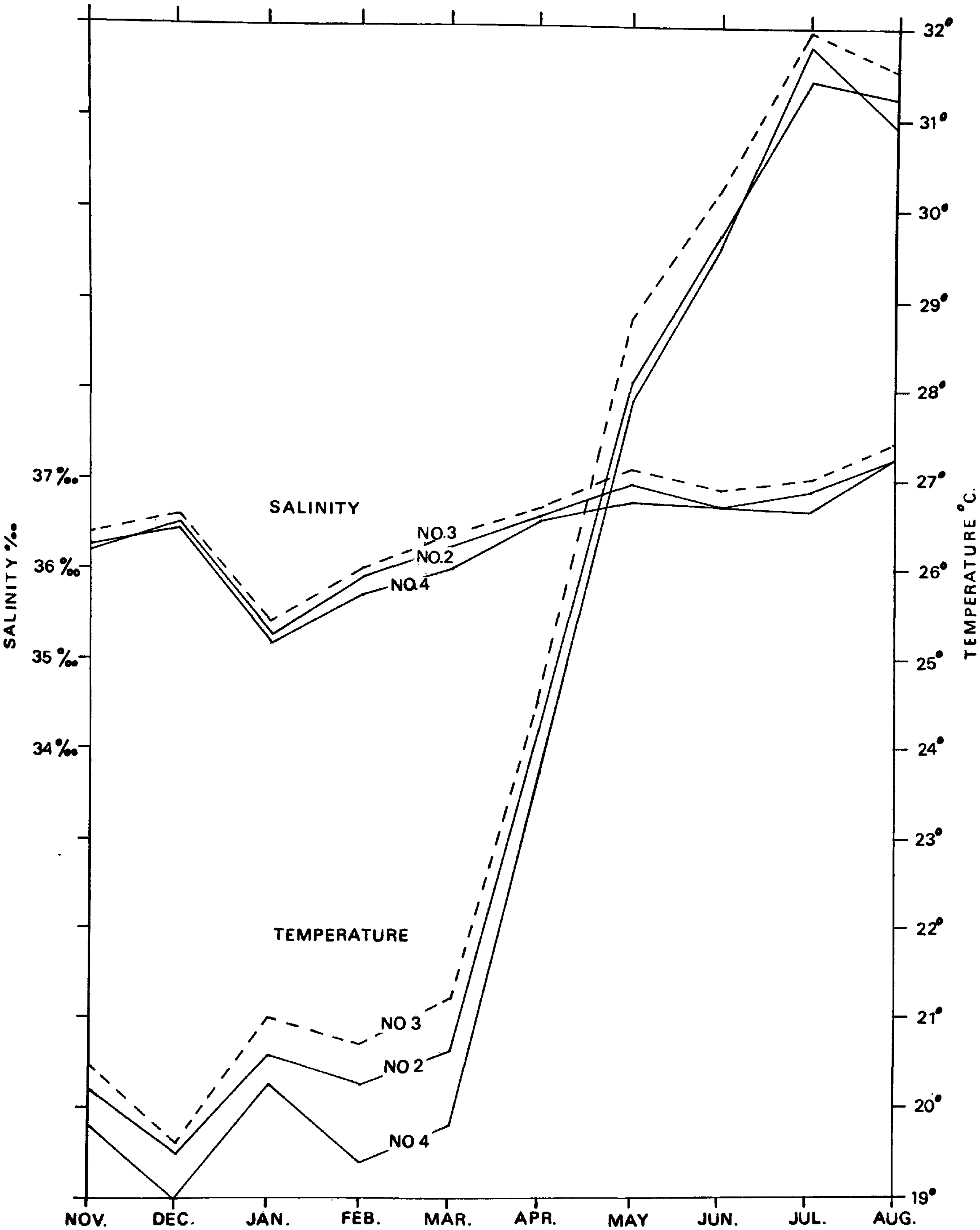


Figure 17. Bottom temperature and salinity at Stations 2, 3, and 4.

Oxygen determinations for the stations in the study area indicate that there is an overall correlation between stations. The average values for all stations follow fairly closely the same seasonal trends as temperature and salinity. However, unlike temperature and salinity, the pattern of distribution for the values does not relate to the effluent field. The most atypical values for dissolved oxygen were found at the head of Safe Harbor at Station 1. The extremely low bottom oxygen levels found at Station 1 are not typical of the harbor as a whole. The basin of the harbor marina, within which Station 1 is located, is isolated from the main harbor by a shallow sill only 2.75 m deep. The water exchange below sill depth is very limited. This was reflected in the low variance in bottom temperatures throughout the study, the build up of H_2S in the deeper waters of the basin, and the exclusion of organisms from this body of water once it became anoxic. Observations made by the biological team while diving at Station 1 also confirmed that there was minimal exchange. The pool of bottom water was observed by them to become discolored and charged with H_2S during the summers of 1968 and 1969. Benthic organisms as well as fishes were not found in the deeper parts of the basin during these times.

The highest oxygen values are found at stations on the shallow flats to the west of Safe Harbor. These high values are related to the abundant plant growth on the bottom. The divers on the biological team have observed tiny bubbles (presumably oxygen) rising from the underwater vegetation on warm sunny days. By way of contrast, the stations in the harbor do not have a well developed benthic vegetation even in the shallow areas along the edge of the entrance channel. The important point concerning the overall dissolved oxygen distribution in the study area is that the effluent from the desalting plant does not appear to either raise or lower the amount of oxygen in the area of discharge (Figure 18).

Alkalinity values like oxygen values showed little relationship to the effluent field. The mean values show that there is correlation between stations throughout the study period. The most anomalous extreme values were found at Stations 1 and 8. The extreme fluctuations at Station 1 are found in the bottom water which is to be expected based on the isolation of that basin from the rest of the harbor and the anoxic conditions that develop there. The extreme values at Station 8, which is on the shallow flats just east of the harbor entrance, are not readily explained. A similarly high extreme value was recorded at Station 10 during the same time period. The range in extreme alkalinity values was greatest in the winter months becoming less in the spring and summer months.

5.3 BIOLOGICAL

The biological measurements and observations used in this study showed that the effects of the effluent on organisms were not evident at distances as great as the effluent could be detected by the physical measurements employed in the study. This finding indicates that the amount of dilution of the effluent necessary to insure minimal impact on the local environment can be determined in future studies.

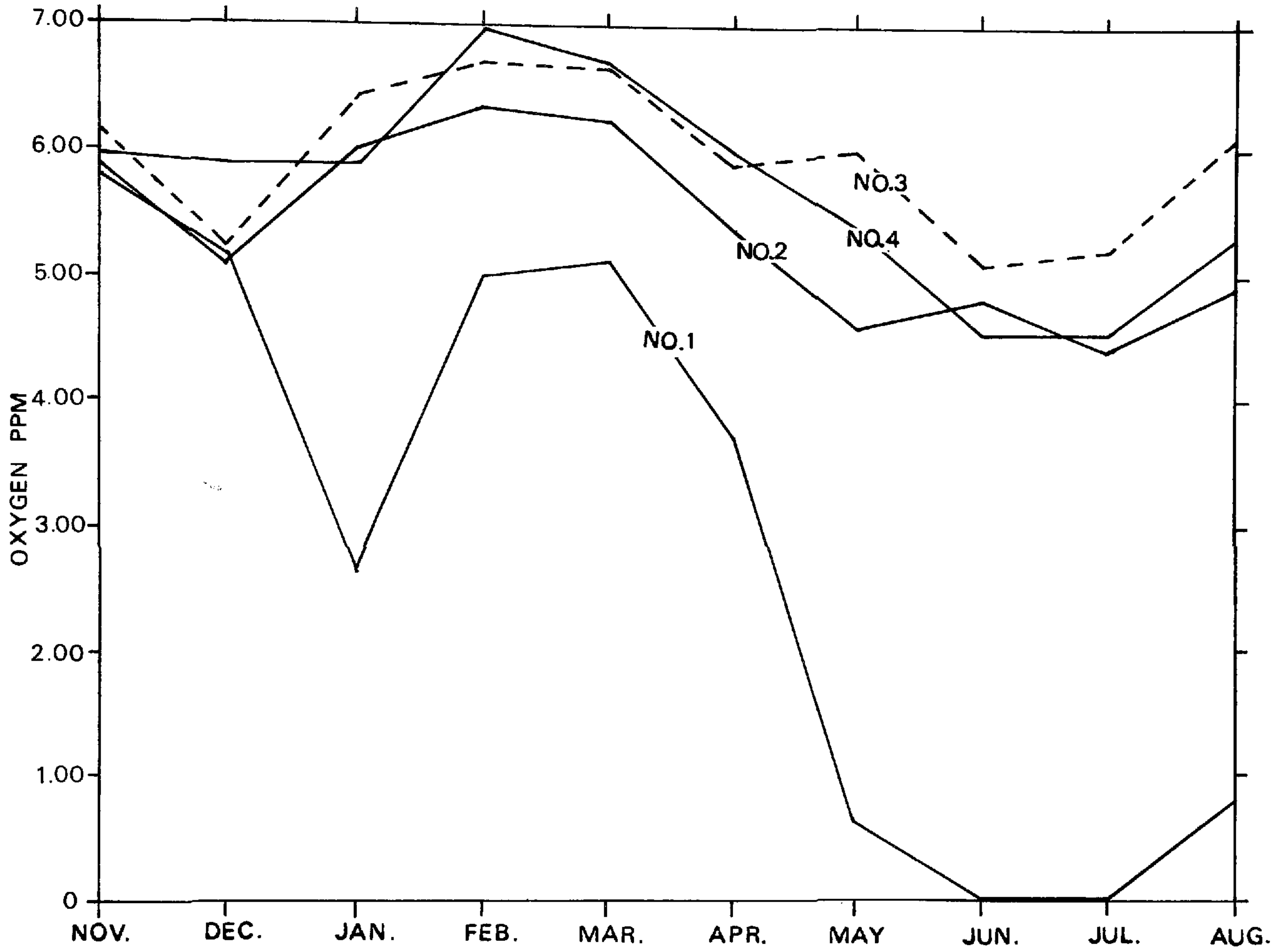


Figure 18. Monthly mean bottom dissolved oxygen values for Stations 1-4.

5.3.1 Quadrat Counts

The quadrats fell into two groups distinguished by the organisms inhabiting them, the harbor quadrats (Stations 1, 2A, 3, 3B and 4A) and the quadrats on the shallow flats (Stations 8, 8A, 9, 9A, 10 and 10A). The harbor quadrats were populated by the black tunicate *Ascidia nigra*, which attaches to hard substrates (Figure 19). This tunicate was found throughout the harbor area and occurred at all of the harbor quadrats except Station 3. This quadrat was continuously bathed by the plant discharge and was very different in appearance from the other harbor quadrats. There were no visible growths of red, green or brown algae on the rock surfaces. Bryozoans occurred sparingly. The most abundant organisms were barnacles and filter feeding tube worms.

The tunicate counts for the harbor quadrats remained exceptionally constant throughout the study (Table 3). The generally smaller numbers of tunicates in the upper portions of the quadrats are due to the placement of the quadrats near the top of the steep underwater banks that form the edge of the harbor and channel. Often these upper portions were partially covered with sand which prevented the settlement of the tunicates.

The spiny lobster, *Panulirus argus*, (Figure 20 and Table 4) and the stone crab, *Menippe mercenaria* (Table 5), were also regular occupants of these quadrats. The plants found in the harbor quadrats were typically small red, brown, and green algae which formed a thin carpeting over the rock surfaces. A species of sea lettuce, *Ulva lactuca*, was the only large plant occurring on these quadrats (see Section 5.3.8 *Marine Algae Occurrences in Discharge and Control Areas*).

The bottom quadrats on the shallow flats east and west of Safe Harbor (Station 8, 8A, 9, 9A, 10 and 10A) form another group of stations that are intercomparable. They are a mosaic of marine grasses and large green algae interspersed with areas of sand and rock outcroppings. The rocky areas are often colonized by gorgonians and small corals. Turtle grass, *Thalassia testudinum*, occurs in most of the quadrats on the flats. A number of attached large green algae, identified as *Penicillus capitatus*, *Caulerpa* sp., *Udotea conglutinati*, *Halimeda opuntia*, *H. tuna*, and *Sargassum pteropleuron*, also occur in the quadrats. The solitary coral, *Manicina areolata*, was found in the quadrats on the flats to the west but not in the quadrats on the flats to the east of Safe Harbor. Other common invertebrates were several species of sea urchins; *Diadema antillarum*, *Tripneustes ventricosus*, and *Lytechinus variegatus*; a small gastropod. *Astraea tuber*; pen shell clams, *Pinna carnea* and *Atrina rigida*; sponges and several species of sea cucumbers; *Stichopus badionotus*, *Holothuria floridana* and *Actinopyga agassizi*.

5.3.2 Plankton Tows

The results of the analyses of the plankton samples were rather inconclusive relative to the effects of the desalting plant effluent on species composition or collection volumes. The inconclusiveness of the results was probably due to the small number of samples taken during the study (35 plankton collections) and the fact that they were all daytime tows. The locations of the plankton tows were distributed so as to sample the harbor and entrance channel as well as the shallow flats either side of the harbor

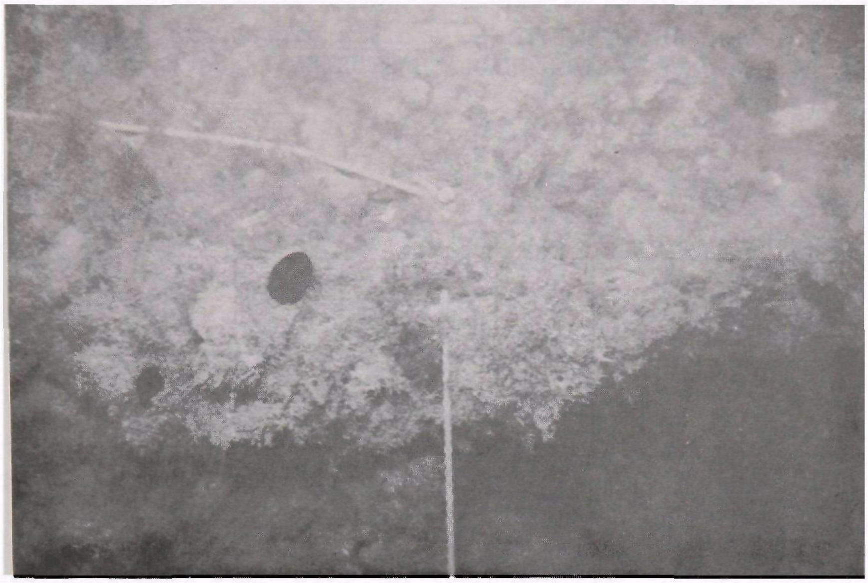


Figure 19. Upper right corner of quadrat at Station 4A. Dark objects are the black tunicate, Ascidia nigra.

Figure 20. Lower right quarter of quadrat at Station 1 showing a lobster, Panulirus argus, occupying hole under rock ledge.

Table 3

NUMBERS OF THE BLACK TUNICATE, *Ascidia nigra*, PER SQUARE METER IN THE FIVE BOTTOM QUADRATS STUDIED IN SAFE HARBOR.

Station	Date	Upper left	Upper right	Lower left	Lower right
Station 1	10 Dec. 1968	1	0	6	6
Station 2A	10 Dec. 1968	0	8	3	1
Station 3	10 Dec. 1968	0	0	0	0
Station 3B	15 Dec. 1968	0	4	4	12
Station 4A	12 Dec. 1968	3	11	12	13
Station 1	22 Jan. 1969	1	0	7	7
Station 2A	22 Jan. 1969	4	7	9	8
Station 3	22 Jan. 1969	0	0	0	0
Station 3B	28 Jan. 1969	0	4	4	12
Station 4A	24 Jan. 1969	11	8	11	17
Station 1	26 Feb. 1969	1	0	10	15
Station 2A	28 Feb. 1969	3	5	26	24
Station 3	26 Feb. 1969	0	0	0	0
Station 3B *	Feb. 1969	/	/	/	/
Station 4A	27 Feb. 1969	7	9	24	11
Station 1 *	4 April 1969	/	/	/	13
Station 2A *	3 April 1969	6	/	/	/
Station 3	29 March 1969	0	0	0	0
Station 3B	1 April 1969	8	16	21	17
Station 4A	1 April 1969	4	11	19	9
Station 1	3 June 1969	1	0	6	13
Station 2A	28 May 1969	3	6	19	10
Station 3	31 May 1969	0	0	0	0
Station 3B	3 June 1969	10	14	21	19
Station 4A	3 June 1969	5	11	16	15

* Not counted where / due to adverse weather conditions and underwater visibility.

Table 4

NUMBERS OF THE SPINY LOBSTER, Panulirus argus, PER SQUARE METER IN THE FIVE BOTTOM QUADRATS STUDIES IN SAFE HARBOR.

Station 1	Station 2A	Station 3	Station 3B	Station 4A
0 0 0 0 10 Dec. 1968	0 0 0 0 10 Dec. 1968	0 2 1 0 10 Dec. 1968	0 0 1 0 15 Dec. 1968	0 0 0 0 12 Dec. 1968
0 0 0 0 22 Jan. 1969	0 0 0 0 22 Jan. 1969	0 1 1 1 22 Jan. 1969	0 0 1 0 28 Jan. 1969	0 1 0 0 24 Jan. 1969
0 0 0 0 26 Feb. 1969	0 0 0 0 28 Feb. 1969	0 1 1 1 26 Feb. 1969	/ / * / / Feb. 1969	0 0 0 0 27 Feb. 1969
/ / * / 1 4 April 1969	0 / * / / 3 April 1969	2 0 1 0 29 March 1969	0 0 0 0 1 April 1969	0 1 0 0 1 April 1969
0 0 0 0 3 June 1969	0 0 0 0 28 May 1969	0 0 0 0 31 May 1969	0 0 0 0 3 June 1969	0 1 0 0 3 June 1969

* *Not counted where / due to adverse weather conditions and underwater visibility.*

Table 5

NUMBERS OF THE STONE CRAB, *Menippe mercenaria*, PER SQUARE METER IN THE FIVE BOTTOM QUADRATS STUDIED IN SAFE HARBOR.

Station 1	Station 2A	Station 3	Station 3B	Station 4A
0 0 0 0 10 Dec. 1968	0 0 0 0 10 Dec. 1968	0 0 0 0 10 Dec. 1968	0 0 0 0 15 Dec. 1968	0 0 0 0 12 Dec. 1968
0 0 0 0 22 Jan. 1969	0 0 0 0 22 Jan. 1969	0 0 0 0 22 Jan. 1969	0 0 0 0 28 Jan. 1969	0 0 0 0 24 Jan. 1969
0 0 0 1 26 Feb. 1969	0 0 0 0 28 Feb. 1969	0 0 0 0 26 Feb. 1969	/ / * / / Feb. 1969	0 0 0 0 27 Feb. 1969
/ / * / 0 4 April 1969	0 / * / / 3 April 1969	0 0 0 0 29 March 1969	0 0 0 0 1 April 1969	0 0 0 0 1 April 1969
0 0 0 1 3 June 1969	0 0 0 0 28 May 1969	0 0 0 0 31 May 1969	0 0 0 0 3 June 1969	0 0 0 0 3 June 1969

* Not counted where / due to adverse weather conditions and underwater visibility.

entrance. Tows 2 and 3 were located in the entrance channel (see Figure 3 and Table 2). Tow 1 was at the head of Safe Harbor, while tows 5, 6 and 7 were located on the shallow flats either side of the harbor entrance.

The plankton sample volumes varied considerably both in respect to time and location. The largest volume occurred in the inner harbor during the month of March (Figure 21). This may be a reflection of the organic loading at the head of Safe Harbor from the shrimp processing industry and sewage along with a general spring boom of plankton throughout the study area. Tows 2 and 3 which were closest to the discharge point showed no consistent relationship, as far as volume, to the effluent field. Perhaps with a more rigorous sampling program, a relationship might be found.

The species composition of the plankton sample aliquots did not show any appreciable differences whether collected near the effluent field of the desalting plant or far away. Table 6 shows the number of different types of plankters occurring in aliquots by plankton tow and by month. Summing these numbers horizontally gives a total number for each plankton tow (last column in Table 6) which is indicative of the diversity level for the tow for the total study period. Tows 2 and 3 which are closest to the discharge point have on this basis the next to the lowest and highest diversity levels respectively. These results may be a reflection of sample variation inherent in the small number of plankton samples taken during the course of the study. Summing of the columns in Table 6 gives a total indicative of the diversity level for each month that plankton sampling was conducted. It may be significant that the highest diversity level occurred in March of 1969 which coincides with the largest plankton volumes taken during the course of the study.

A second set of comparisons were made of the plankton sample aliquots in respect to the abundance of organisms in the discharge area and outside the discharge area. It was assumed that the effluent would either eliminate or enhance the numbers of some of the planktonic organisms similar to what was found to be the case with benthic organisms. (See 5.3.3 Biological Settlement Racks). Table 7 presents comparisons of plankton sample aliquots on a monthly basis relative to abundance or absence in the discharge area. The organisms appearing in the left column were selected on the basis of being abundant (over 150 individuals per aliquot) in the discharge area (plankton tows 2 or 3) and nowhere else in the study area during that month. The organisms appearing in the right column were selected on the basis that they were absent from the discharge area (plankton tows 2 and 3) but present elsewhere in the study area during that month. All of the organisms that were abundant only in the discharge area (left-hand column of Table 7) for the month indicated did occur abundantly elsewhere in the study area at other times (see Appendix D). The variability of occurrence of a particular organism in the plankton sample aliquots is exemplified in the case of the copepod, *Paracalanus crassirostris*. In December, it did not occur in the discharge area but was present elsewhere in the study area (right-hand column Table 7). By contrast, in April, it was abundant in the discharge area but was not abundant elsewhere (left-hand column Table 7).

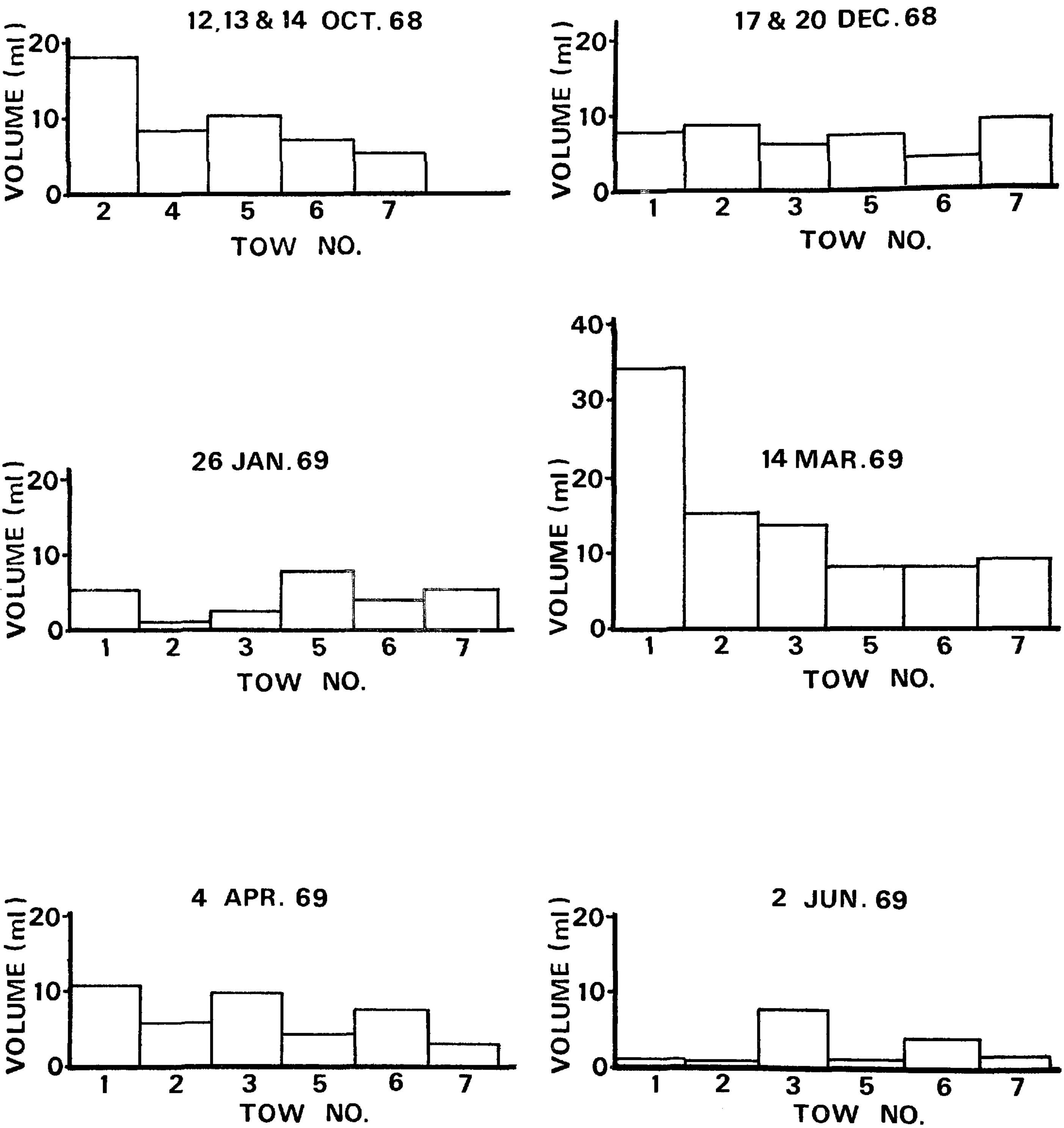


Figure 21. Plankton volumes for the six sets of tows made during the biological field trips to Key West. Tows 2 and 3 are closest to the discharge point. Tow 1 is at the head of Safe Harbor and Tows 5, 6 and 7 are over the shallow flats either side of the harbor entrance (See Figure 3 and Table 2 for additional information).

Table 6

NUMBER OF DIFFERENT KINDS OF PLANKTERS OCCURRING IN PLANKTON TOW ALIQUOTS BY MONTH AND TOW. (See text for explanation).

Plankton Tow No.	Dec.	Jan.	Mar.	Apr.	June	Tow Totals
1	7	11	13	11	9	51
2	10	8	14	14	8	54
3	11	10	12	18	14	65
5	9	16	16	9	8	58
6	8	11	14	15	14	62
7	11	12	16	12	6	57
Monthly Totals	56	68	85	79	59	

Table 7

OCCURRENCE AND ABSENCE OF PLANKTERS IN THE DISCHARGE AREA. (See text for explanation).

Month	Abundant in discharge area (tows 2 or 3) but not abundant elsewhere	Absent in discharge area (tows 2 and 3) but present elsewhere
Dec.	Calanoid nauplii	Acartia spinata Clausocalanus spp. juveniles Paracalanus crassirostris Oncaea sp. Microsetella rosea Tanaids
Jan.		Acartia spinata Labidocera spp. juveniles Calanopia americana Corycaeus spp. Crab larvae Shrimp larvae Polychaete larvae
Mar.	Acartia spp. juveniles	Clausocalanus spp. juveniles Oncaea sp. Microsetella sp. Euterpina sp. Barnacle cyprids
Apr.	Paracalanus crassirostris Barnacle nauplii	Labidocera mirabilis Clausocalanus furcatus Crab larvae Amphipods
June		Paracalanus parvus Temora turbinata Oncaea sp. Crab larvae

The plankters excluded from the discharge area for a particular month (right-hand column Table 7) with the exception of four types of organisms (the copepods; Labidocera mirabilis, Oncaea sp., tanaids and amphipods) occurred in the discharge area at other times. The four exceptions were organisms that occurred only in the waters over the shallow flats and generally were rare in the plankton sample aliquots. For the complete analysis of the plankton sample aliquots see Appendix D.

5.3.3 Biological Settlement Racks

The settlement disk studies were undertaken to establish whether a real difference existed between the environment in the effluent plume area at the desalting plant and a control environment located across the entrance channel of Safe Harbor. Any differences seen in the numbers or condition of organisms settling on the disks in the two areas should be relatable to differences in the two environments. The settlement rack in the discharge area is continually bathed by the effluent. This can be verified by following the movements of suspended or dissolve material (such as fine sediments or dye) in the discharged water. The presence of the effluent can also be detected by the warmer temperatures recorded at the settlement rack. The analyses of the organisms on the settlement disks from the discharge and control racks showed significant differences in the numbers and condition of the organisms in the two areas.

Two attached organisms were selected for comparison in the discharge and control areas, balanoid barnacles and a cheilostomatid bryozoans. Both of these organisms showed differences in their numbers in the two areas. The balanoid barnacles were more abundant on disks collected from the discharge area, averaging 50 individuals per 0.005 m^2 of disk surface with a range of 6 to 135 as opposed to 7 individuals per 0.005 m^2 of disk surface with a range of 0 to 17 in the control area. Thus, barnacles were on the average 7 times more abundant on disks bathed by the effluent than on disks in the control area. Their greater success in the discharge area would indicate an enhancement of the environment for barnacles in the near effluent field.

This same sort of enhancement is observed in the case of two species of snappers, Lutjanus griseus and L. apodus (see 5.3.6 Fish Occurrences in Discharge and Control Areas), as well as the stone crab, Menippe mercenaria (see 5.3.7 Transect Counts of Lobsters and Stone Crabs in Discharge and Control Areas). These fishes and the crab were observed to be more numerous in the near field of the effluent discharge than elsewhere.

A nonparametric statistical test, the Mann-Whitney U-Test, was run on the barnacle occurrence data. This test is a nonparametric ranking type analysis which is coming into greater use by ecologists. The results of this test showed that there was a significant difference at the 0.05 level in the barnacle populations of the discharge and control area. The formula and calculations for the Mann-Whitney U-Test are given in Appendix E.

The cheilostomatid bryozoan occurrences on the disks also showed significant differences between the discharge area and the control area. They were less abundant on disks collected from the discharge area, averaging 11 individuals per 0.005 m^2 of disk surface with a range of 0 to 34 as opposed to 34 individuals per 0.005 m^2 of disk surface with a range of 1 to 104 in the control area. Thus, cheilostomatid bryozoans were on the average 3 times more abundant on disks in the control area than on those bathed by the effluent. This finding alone would indicate that the effluent in the near field of discharge has a deleterious effect on the success of cheilostomatid bryozoan colonies. However, in addition, measurements of colony size in the two areas also substantiates the conclusion that the effluent has a deleterious effect. Colonies collected and measured on 27 January 1969 averaged only 3 mm high on disks from the discharge area as opposed to 34 mm high on disks from the control area. Two months later the respective mean heights of the colonies were 4 mm and 39 mm (Figure 22). The colonies in the control area during the same time period, therefore, grew ten times larger than those in the discharge area, strongly suggesting that the effluent was adversely affecting both the success and growth rate of the cheilostomatid bryozoan colonies. The Mann-Whitney U-Test was run on the bryozoan occurrences in the two areas and it indicated that the differences were significant at the 0.05 level (Appendix E).

Adverse or exclusion effects of the effluent were also detected in the near field discharge in some of the other biological investigations. The quadrat at Station 3 (nearest quadrat to the discharge point) was found to be different from the others in the Safe Harbor area in that it lacked the black tunicate, Ascidia nigra, and had no visible growths of red, green or brown algae. Bryozoans occurred only sparingly in this area and were small in size (see 5.3.1 Quadrat Counts). The gorgonian colonies transplanted into the discharge area (see following section) showed deleterious effects, particularly in the near field of the discharge. Some species of animals were also excluded from sections of the seawall immediately adjacent to the discharge point (see 5.3.5 Seawall Invertebrate Counts). Thus in some instances, the presence of the effluent appears to attract or favor the growth of organisms, whereas for others it excludes them or is deleterious to their growth and development.

5.3.4 Gorgonian Colony Transplants

The gorgonian colony transplants yielded considerable information on the effects of the effluent, particularly in the near field of the discharge. The methods used for transplanting were discussed earlier (see 4.4.4 Gorgonian Colony Transplants). Of the 18 colonies transplanted on 14 December 1968, three were left at the site of collection (Station 8A) to serve as controls and 15 were placed in the vicinity of the discharge pipe. Figure 23 and Table 8 give the locations of the transplants with respect to the discharge pipe and seawall.

On 27 January 1969, the transplanted colonies in the control area (Station 8A) appeared healthy. No visible differences in their condition from the naturally occurring colonies could be detected. The gorgonian colonies transplanted to the vicinity of the desalting plant varied considerably in condition depending on their location relative to the discharge.

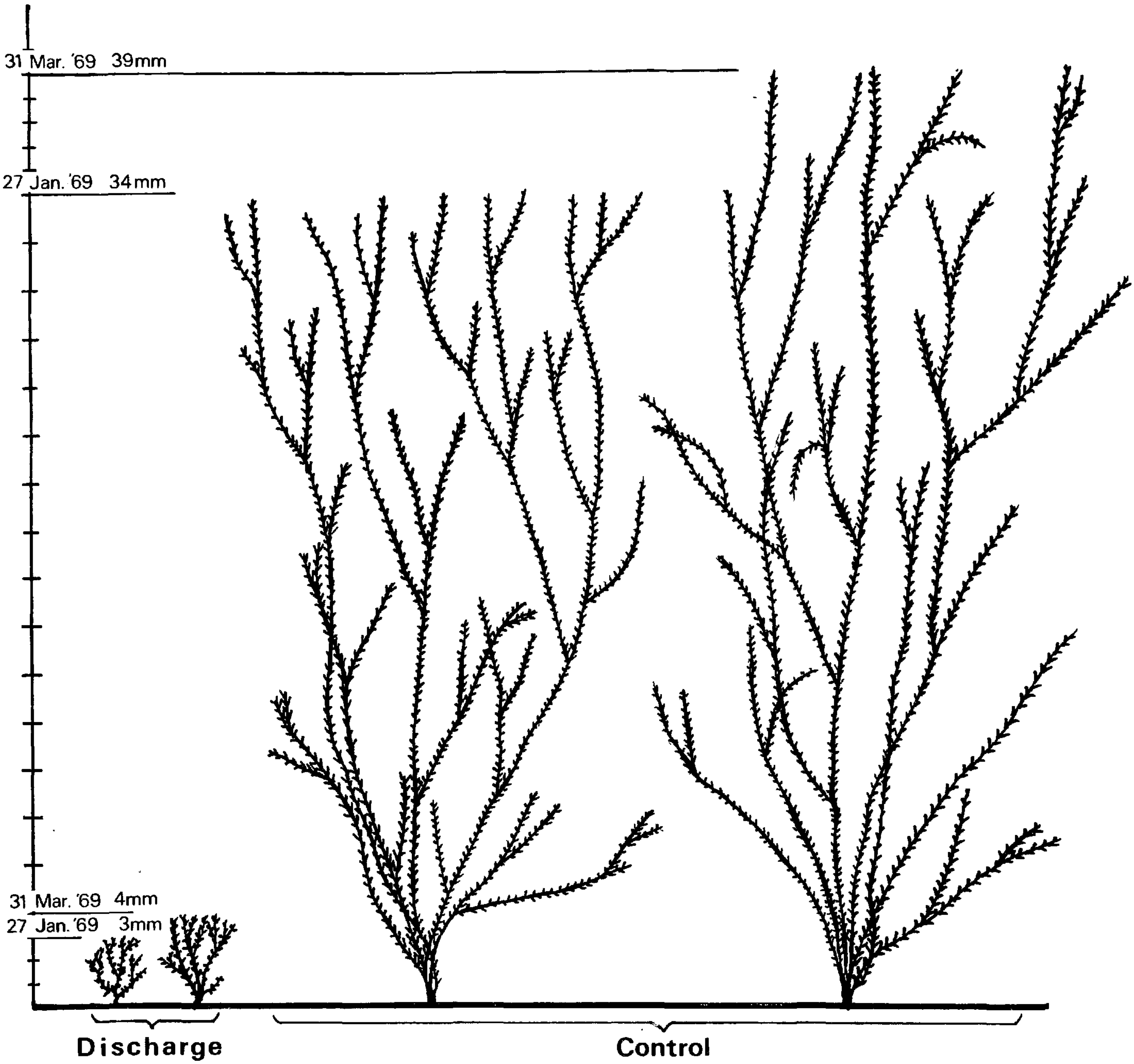


Figure 22. Mean growth attained by cheilostomatid bryozoans on the upper surfaces of settlement disks in the discharge and control areas. Disks were placed in the water 12 December 1968.

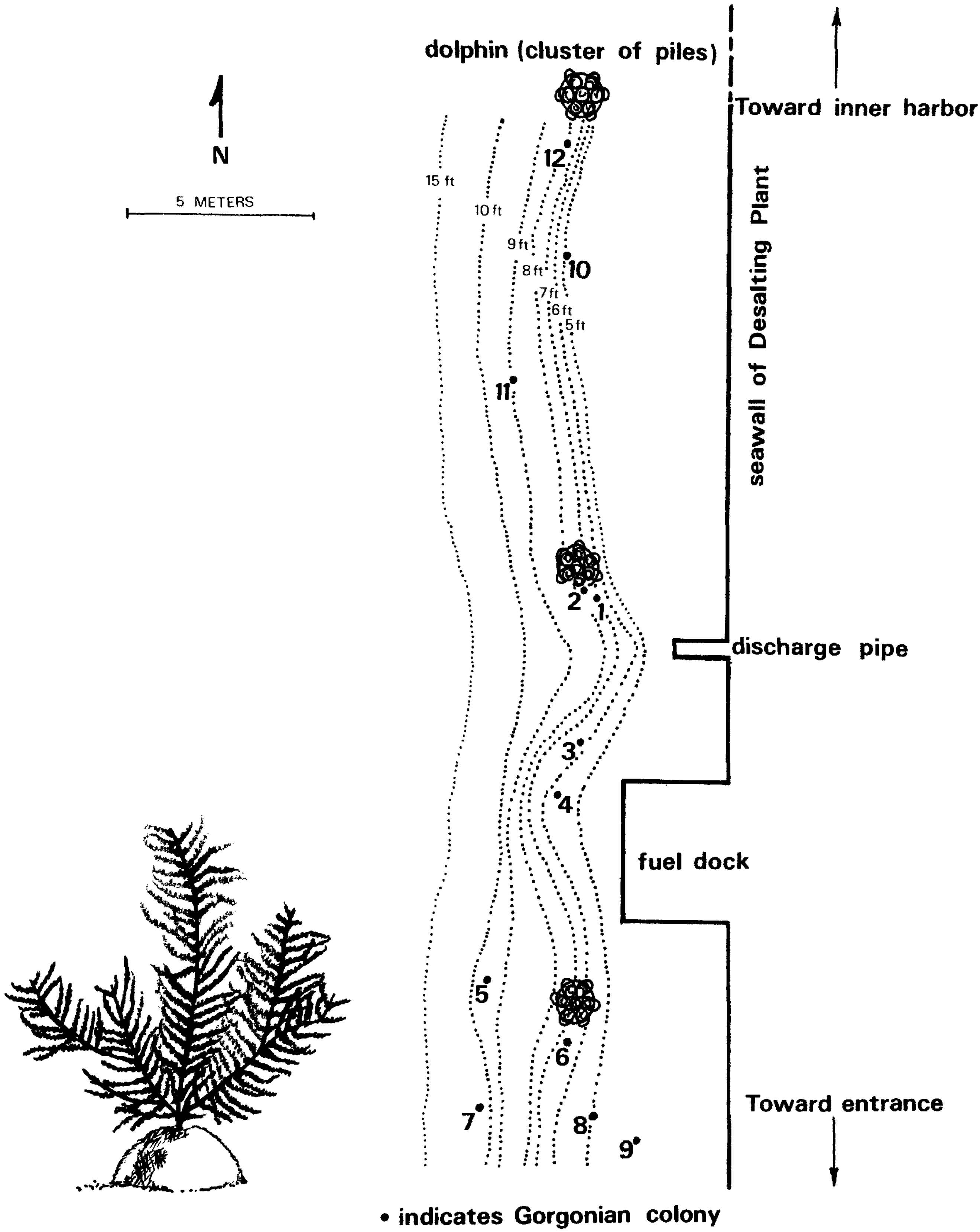


Figure 23. Locations of gorgonian colony transplants relative to the end of the discharge pipe. Detail insert shows method anchoring colonies.

Table 8

GORGONIAN COLONY TRANSPLANT EXPERIMENTS.

Discharge area

Species	Depth	Location		No. in Fig. 23	Condition
		Distance from Discharge Pipe	Distance from Seawall		
Pseudopterogoria bipinnata	8'0"	11'6" north	15'0"	1	Dead
P. bipinnata	8'0"	12'8" north	15'0"	2	Dead
P. bipinnata	6'4"	15'0" south	16'7"	3	Dead
P. bipinnata	9'10"	42'11" south	27'5"	5	Alive
P. bipinnata	6'6"	45'10" south	18'4"	6	Alive
P. bipinnata	10'8"	57'1" south	28'2"	7	Dead
P. bipinnata	5'0"	54'3" south	15'1"	8	Alive
P. bipinnata	9'0"	35'6" north	24'2"	11	Dead
Plexaurella dichotoma	5'0"	56'0" south	10'2"	9	Alive
P. dichotoma	8'0"	58'6" north	18'5"	12	(Lost)
Pterogorgia anceps	5'6"	21'5" south	19'4"	4	Dead
P. anceps	5'0"	46'4" north	18'2"	10	Dead
P. anceps		Three colonies lost before locations were plotted.			

Control area

	Depth	Location	Condition
1. *Pseudopterogorgia bipinnata*	8'0"	Station 8a; 45' east of station	Alive
2. *P. bipinnata*	8'0"	Station 8a; 45' east of station	Alive
3. *P. bipinnata*	8'0"	Station 8a; 45' east of station	Alive

The colony placed nearest the discharge pipe was severely damaged. The coenenchymal tissue was soft and sloughing off and no polyps were visible. Other colonies at distances out to about 10 m showed some signs of damage. Beyond 10 m all colonies appeared to be alive and healthy.

On 26 February 1969, the transplanted gorgonian colonies in the vicinity of the desalting plant were checked again. Colonies closer to the discharge pipe than 12 m were dead or damaged, those beyond 12 m appeared to be alive and healthy.

On 30 May 1969, the three control transplants near Station 8A were examined and photographed. These transplants appeared healthy, unaffected by the method of transplanting. The polyps were extended and the condition of the coenenchymal tissue was similar to that of other Pseudopterogorgia bipinnata colonies occurring naturally around Station 8A. The condition of most of the transplants at the discharge location was in marked contrast to the control situation. Only 4 out of the original 15 transplants were alive as of 30 May 1969, and these were all farther than 12 m from the discharge point.

The pattern of colony destruction relative to the discharge point showed a certain amount of asymmetry. The effects of the discharging effluent seems to extend farther to one side of the discharge pipe than the other. For colonies the same distance from the discharge pipe, those on the inner harbor side showed signs of damage or were killed before those on the entrance side of the harbor. Thus, the asymmetry of the effluent field is also indicated by the physical and chemical data (see 5.2 CHEMICAL RESULTS), as well as some of the biological investigations (see 5.3.5) Seawall Invertebrate Counts). Dye releases from the discharge pipe made by the biological field team confirmed the asymmetry of the effluent field. The resulting dye distribution over the shallow shelf along the seawall matched very closely the area from which ascidians and algae were excluded (Figure 24).

To account for the deaths of transplants, the following factors were considered:

1. Method of transplant: not a factor; control transplants are thriving.

2. Illumination: not a factor; all of the transplants were placed at depths similar to their original sites.

3. Salinity: probably not a factor; the salinity measurements taken around the discharge area showed only very small differences from those measured at other stations.

4. Temperature: probably not a factor during normal plant operation. The temperature of the effluent a short distance (3 m) from the discharge point was below the thermal death point of the species. Thermal shock might have been a problem during winter months when the ambient water temperatures were low. If the desalting plant shuts down and starts up again during these periods, the gorgonian

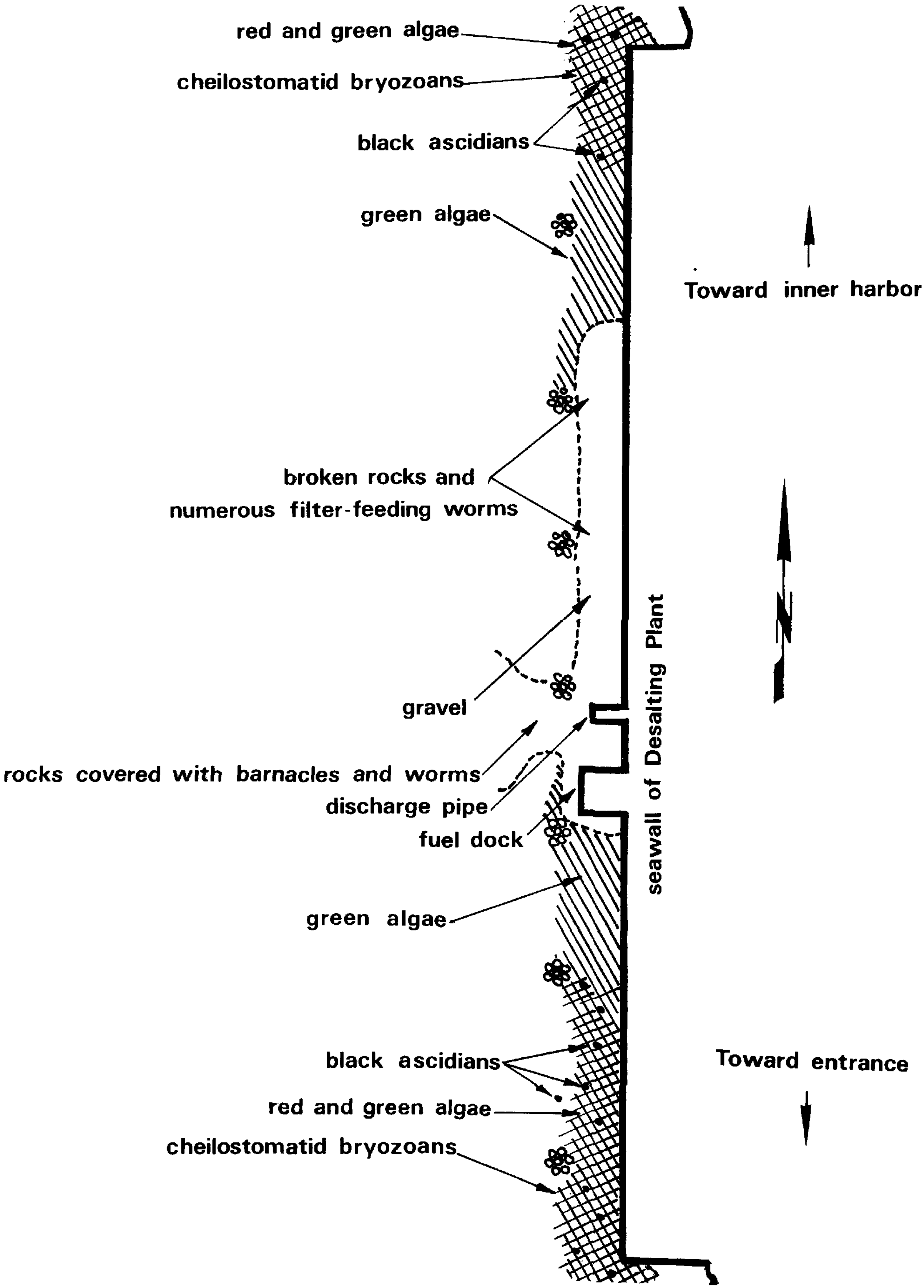


Figure 24. Floral and faunal zoning in the immediate vicinity of the discharge pipe.

colonies nearest the pipe may experience temperature changes greater than 10°C within a matter of minutes. Thermal shock would not be a problem during the summer months when ambient temperatures approach 30°C.

5. Availability of food: probably not a factor. This area is densely populated by other filter feeding organisms.

6. Scouring: possibly a major factor for the colonies transplanted directly in front of the discharge pipe. Scouring by sand and sediment entrained in the discharge plume can harm the polyps and prevent them from feeding.

7. pH factors: the release of extremely acid water (pH 2.0) from the discharge pipe during descaling operations could be the most harmful factor to the transplanted colonies. Unfortunately, the day-to-day condition of colonies could not be followed since the biological team was not stationed at Key West.

8. Fouling: a few of the transplanted colonies were covered moderately to heavily by serpulid worms, barnacles and algae. However, this does not appear to be a factor because the transplants that had the heaviest settlement of epizoans and epiphytes were still alive on 29 June 1969.

9. Trace metals: copper, iron, etc. contained in the effluent may be a factor, although the lethal limits for gorgonians are unknown at this time and measurements were not made of these effluent properties.

The transplants that died in the discharge area usually went through the following stages prior to complete loss of the colony:

1. Polyp retraction

2. Sloughing and necrosis of coenenchymal tissue

3. Death of individual polyps

4. Axial rod exposure

5. Complete polyp mortality

Many of these symptoms can be seen in Figure 25. This photograph was taken of a gorgonian colony transplant (Colony No. 3) placed about 5 m from the discharge pipe.

The value of the gorgonian colony transplants was that they provided a method of observing the biological effects of the effluent. These environmentally sensitive organisms placed at different points in the effluent field served as integrators of the long-term environmental conditions.

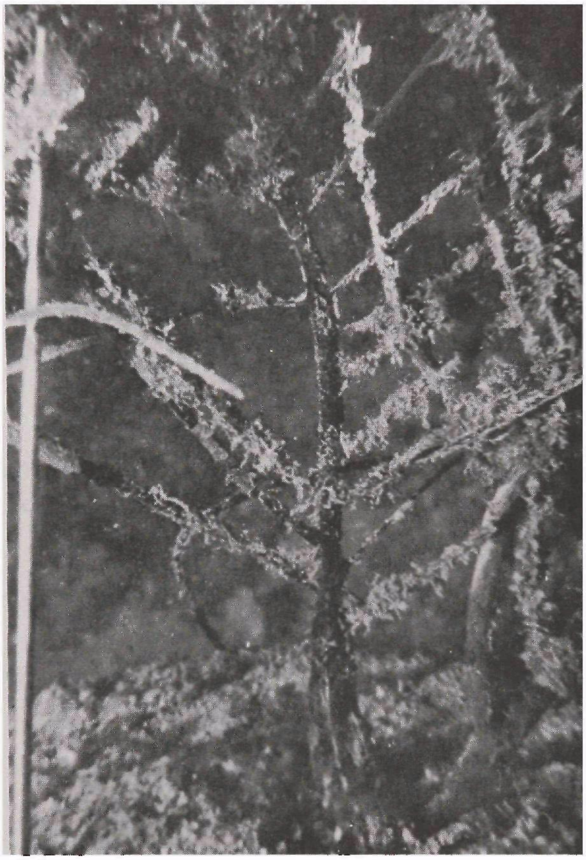


Figure 25. Detail of gorgonian colony transplant showing damaged condition resulting from exposure to effluent.

5.3.5 Seawall Invertebrate Counts

The two organisms selected for counting along the concrete seawall of the desalting plant were the black tunicate, Ascidia nigra, and the carnivorous gastropod, Cantharus tinctus. On 29 and 30 May 1969, counts were made within each contiguous rectangular area (1.8 m long by approximately 0.8 m-high, separated by 0.6 m-wide concrete buttresses). The water depth ranged between 0.5 m and 1 m (averaging about 0.8 m), depending upon the stage of the tide. Both the tunicate and the gastropod occurred abundantly along most of the seawall, but the effluent appeared to exclude them from those portions of the seawall nearest the discharge point. The exclusion of these organisms was not symmetrical about the discharge point. The tunicate was absent 43.2 m north (toward the inner harbor) of the discharge pipe and 19.2 m south (toward the harbor entrance) of the pipe (Figure 26). The gastropod was absent 36.0 m north of the outfall and 4.8 m south (Figure 27). The gastropod, Cantharus tinctus, through its motility, is capable of responding to changes in the effluent field; the tunicate, Ascidia nigra, cannot, because it is sessile. The occurrences of the gastropod closer to the discharge may reflect its ability to respond more quickly to effluent field changes.

The noticeably different north and south limits of exclusion for both organisms relative to the discharge point are seen in the distributions of other organisms such as the attached algae and in the pattern of gorgorian colony mortalities discussed in the previous section. The algae range closer to the discharge pipe on the south, or harbor entrance side, of the pipe than they do on the north or inner harbor side (see Figure 24). The reason for this difference was discovered by injecting fluoroscein dye into the effluent. A portion of the effluent was deflected by the nearest mooring dolphin so that it swung to the north over the shallow shelf along the edge of the seawall. There was no corresponding deflection of the effluent plume onto the shallow shelf on the opposite side, and the balance of the discharged water flowed directly out into the entrance channel.

5.3.6 Fish Occurrences in Discharge and Control Areas

Observations made in the discharge area during the early phases of the study suggested that the effluent was attracting many reef fishes. Closer investigation of this phenomenon, however, indicated that the situation was far more complicated than first suspected. The investigators realized that any of the following factors could be attracting the fish: the heat of the effluent, the currents and turbulence that the effluent created, the constant source of plankton brought into the area by the entrained water, or a combination of these factors. Still another environmental factor, completely independent of the effluent discharge, is the presence of a series of mooring dolphins that parallel the desalting plant seawall. Each of these dolphins consists of 5 or 6 pilings surrounding a central piling, bound together at the top with cables.

A second series of dolphins identical in construction with those at the desalting plant, was placed along the east side of the Safe Harbor entrance channel in December 1968 at the site for the new Key West City Electric Power Plant. Sessile organisms encrusted the pilings of the

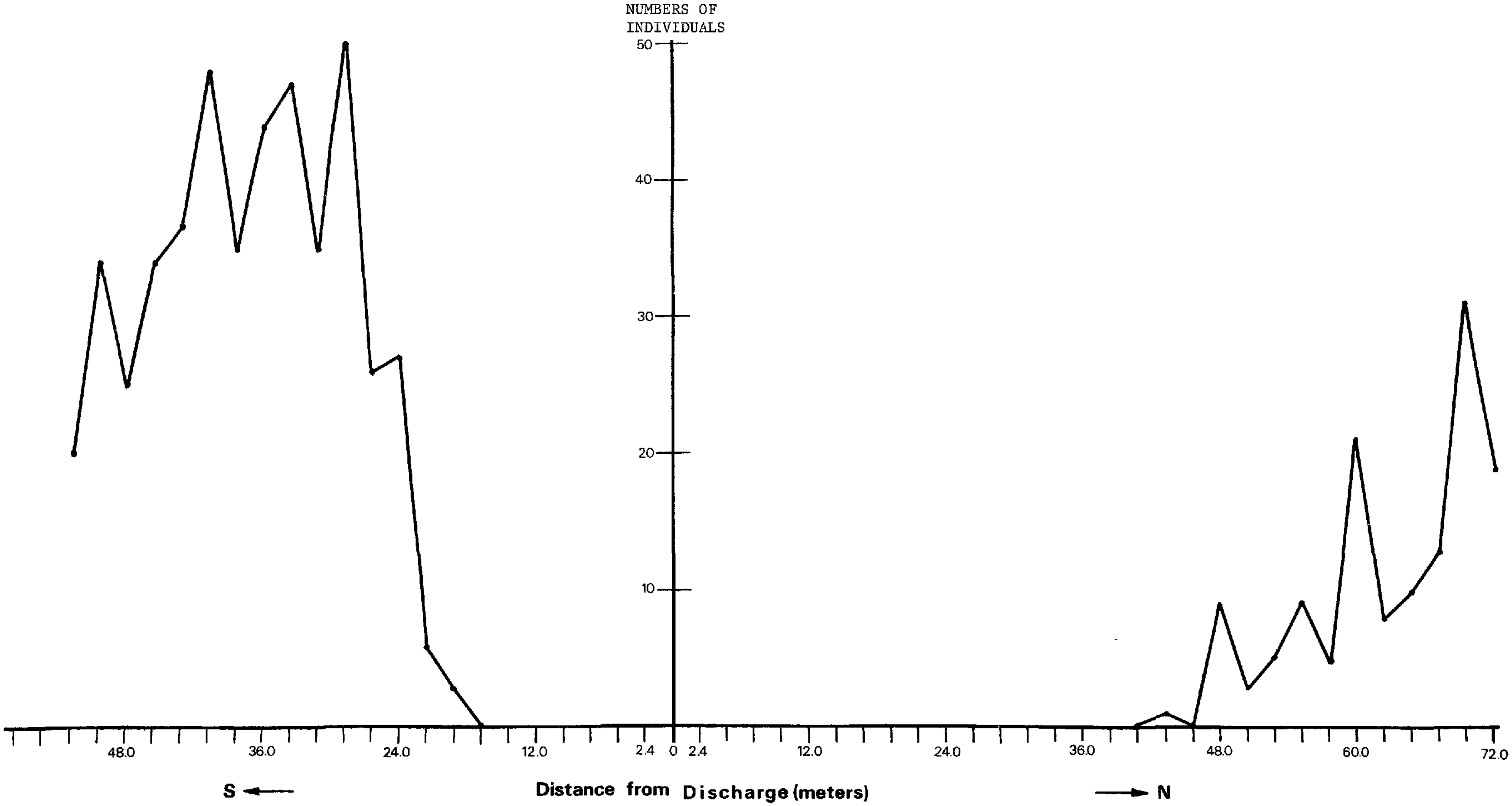


Figure 26. Occurrence of the black tunicate, *Ascidia nigra*, per vertical section of seawall as a function of distance from the discharge.

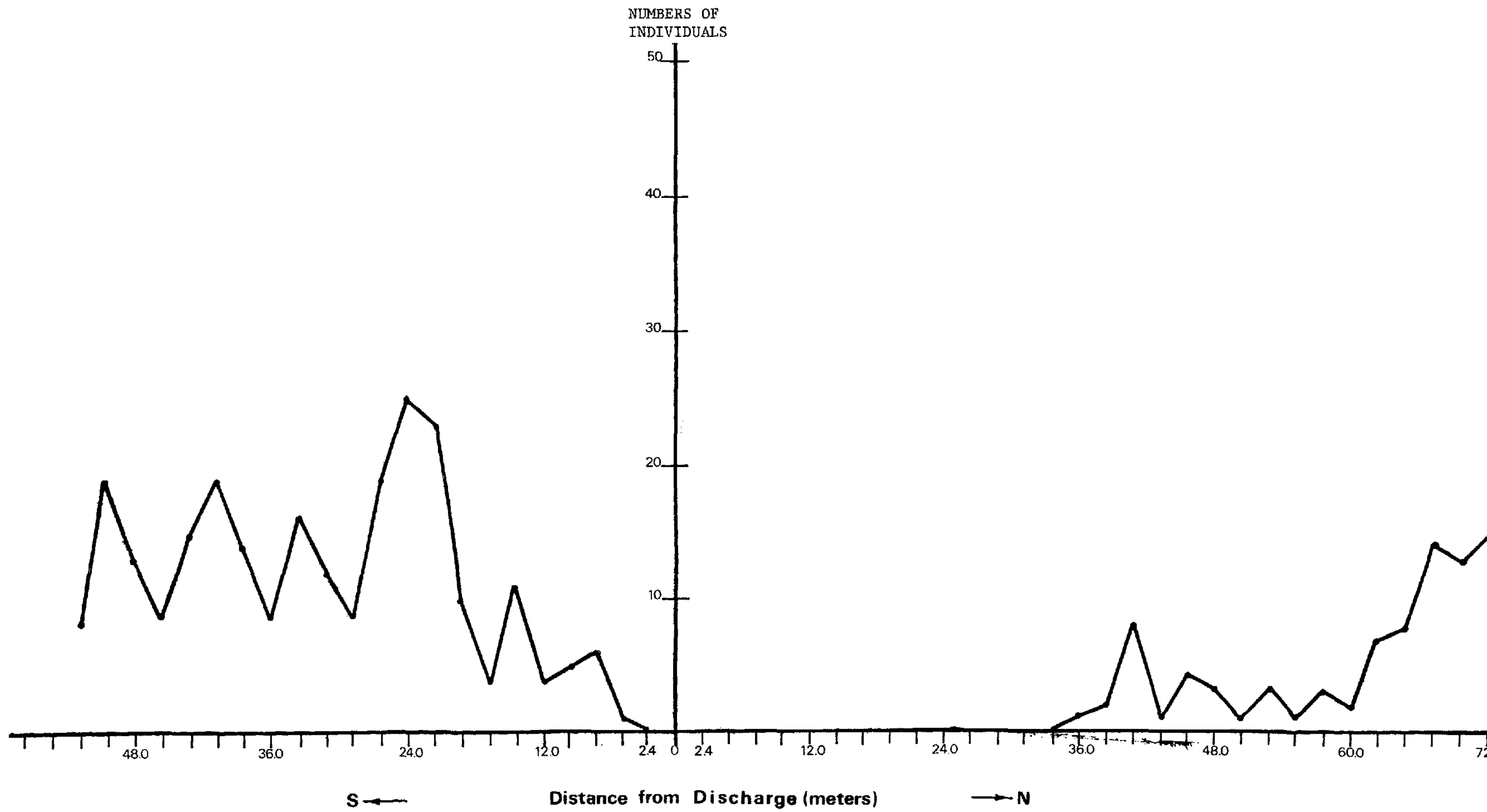


Figure 27. Occurrence of buccinid gastropod, *Cantharus tinctus*, per vertical section of seawall as a function of distance from the discharge.

new dolphins in a very short time and within a few months they looked the same as the desalting plant dolphins. The new dolphins lie approximately 170 m north of the discharge (Figure 28) and served as a control area for comparing fish occurrences. They are in similar depths of water and far enough from the desalting plant that no biological effects of the effluent could be detected there (see 5.3.8 Marine Algae Occurrences in Discharge and Control Areas).

The control dolphins began to attract fishes immediately after emplacement. By 29 June 1969, divers had identified 46 species of fishes in the control area, compared to 48 species identified around the desalting plant discharge area (Table 9). Many more hours were spent observing fish in the discharge area than in the control area. Since divers spent tens of hours in the discharge area as against a maximum of 4 to 5 hours in the control area, the chances of observing more species of fish in the discharge area was better.

The similarity of the species lists for the two areas suggests that the dolphins are a strong attractant to fish. It therefore seems likely that the dolphins may be, for most fishes, a more important environmental factor than the effluent.

A few species of fish do appear to be attracted to the effluent. Snappers (*Lutjanidae*) at times swim directly into the effluent and right up to the mouth of the discharge pipe where the temperature is close to 37°C. This behavior has been observed even during the winter when there is a temperature difference of as much as 20°C between the effluent at the injection point and the surrounding water. These excursions into the hottest part of the effluent are short in duration (< 10 sec.), yet the fishes do it repeatedly.

Two species of snappers, *Lutjanus griseus* and *L. apodus*, are more common in the discharge area than the control area. Schools of these fish often remain stationary relative to the bottom, swimming just hard enough to counter the current created by the discharge. At other times, they swim rapidly through the effluent plume, around the nearest dolphin and then back through the plume again. The numbers of these snappers diminish around the outfall when the plant is shut down and no effluent is being discharged.

Juvenile chaetodonts, (*Chaetodon capistratus*, *C. ocellatus*, *Pomocanthus arcuatus* and *Holacanthus ciliarus*) and the porkfish, *Anisotremus virginicus*, are more common along the irregular slope below the discharge pipe and around the bases of the nearest dolphins than elsewhere in Safe Harbor. In support of the greater availability of these fishes is the observation that tropical fish collectors use the discharge area regularly to collect small specimens of butterfly and angel fishes.

The juveniles of the porkfish, *Anisotremus virginicus*, along with many of the chaetodonts are known "cleaners". The investigators have observed

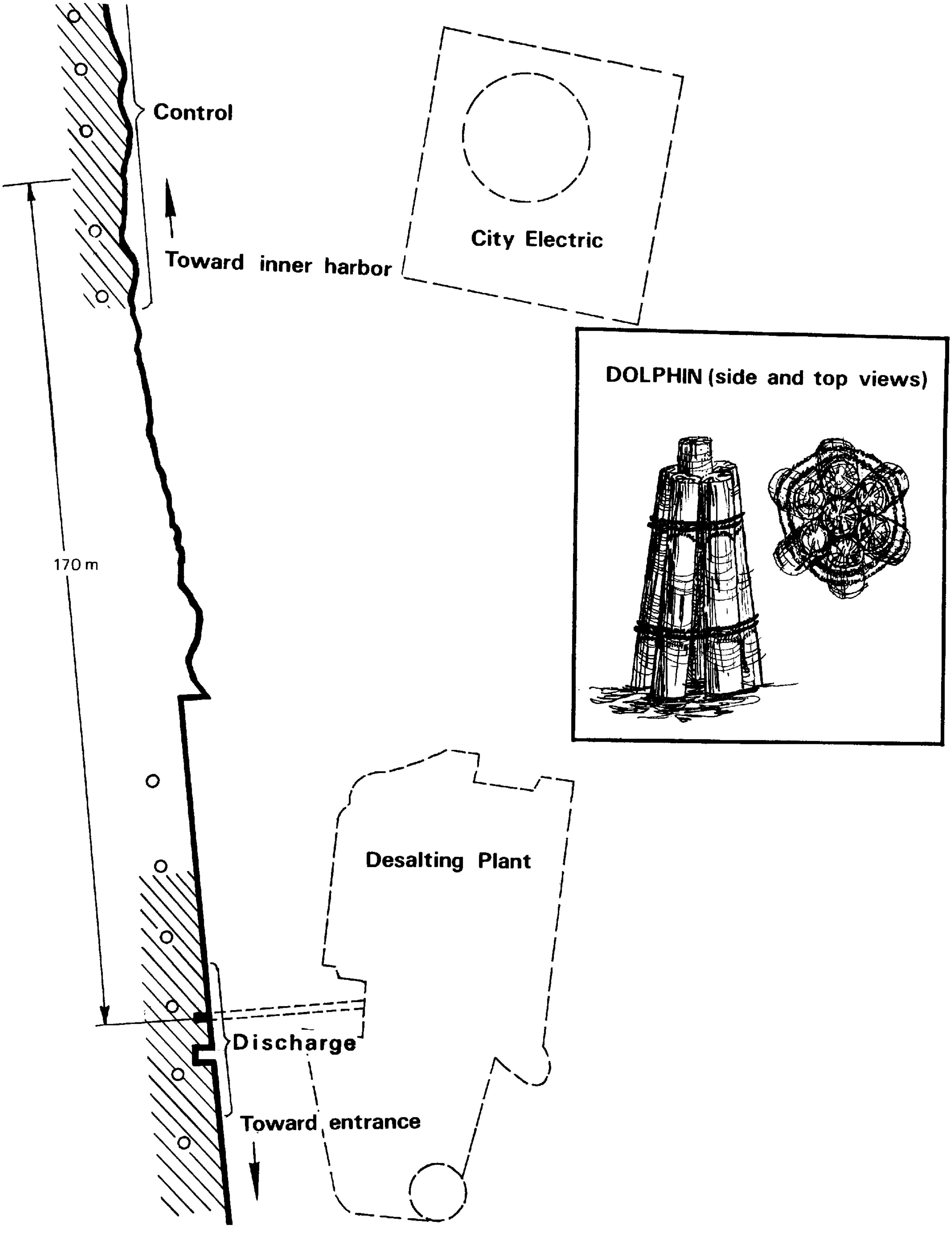


Figure 28. Discharge and control areas used for marine fish occurrences.

Table 9

FISH OCCURRENCES IN DISCHARGE AND CONTROL AREAS.

	Species	Discharge	Control
1.	Spadefish, *Chaetodipterus faber*	C	C
2.	Sergeant major, *Abudefduf saxatilis*	C	C
3.	Beau gregory, *Eupomacentrus leucostictus*	C	C
4.	Cocoa damselfish, *Eupomacentrus variabilis*	U	U
5.	Dusky damselfish, *Eupomacentrus fuscus*	U	U
6.	Foureye butterflyfish, *Chaetodon capistratus*	C	C
7.	Reef butterflyfish, *Chaetodon sedentarius*	U	U
8.	Spotfin butterflyfish, *Chaetodon ocellatus*	C	C
9.	Gray angelfish, *Pomacanthus arcuatus*	C	C
10.	Queen angelfish, *Holacanthus ciliarus*	C	C
11.	Blue angelfish, *Holacanthus isabelita-bermudensis*	C	C
12.	Slippery dick, *Halichoeres bivittatus*	C	C
13.	Bucktooth parrotfish, *Sparisoma radians*	-	U
14.	Striped parrotfish, *Scarus croisensis*	-	U
15.	Blue parrotfish, *Scarus coeruleus*	U	U
16.	Rainbow parrotfish, *Scarus guacamaia*	C	C
17.	Doctor fish, *Acanthurus chirurgus*	C	C
18.	Blue tang, *Acanthurus coeruleus*	U	U
19.	Ocean surgeonfish, *Acanthurus bahianus*	C	C
20.	Bar jack, *Caranx ruber*	C	C
21.	Crevalle jack, *Caranx hippos*	C	-
22.	Unid, jack, *Caranx* sp.	-	U
23.	Sheepshead, *Archosargus probatocephalus*	C	C
24.	Black grunt, *Haemulon bonariense*	-	U
25.	Tomtate, *Haemulon autolineatum*	U	U
26.	French grunt, *Haemulon flavolineatum*	C	C
27.	White grunt, *Haemulon plumieri*	C	C
28.	Bluestriped grunt, *Haemulon sciurus*	U	U
29.	Porkfish, *Anisotremus virginicus*	C	C
30.	Roundspot porgy, *Diplodus caudimacula*	U	U

C = Common U = Uncommon - = Absence

Table 9 (continued)

FISH OCCURRENCES IN DISCHARGE AND CONTROL AREAS.

	Species	Discharge	Control
31.	Mojarra, unid., f: Gerreidae	C	C
32.	Bermuda chub, *Kyphosus sectatrix*	C	C
33.	Barred cardinal fish, *Apogon binotatus*	U	-
34.	Flamefish, *Apogon maculatus*	-	U
35.	Great barracuda, *Sphyraena barracude*	C	C
36.	Needlefish, unid., f: Belonidae	C	C
37.	Halfbeak, *Hemiramphys* sp.	C	C
38.	Snook, *Centropomus undecimalis*	U	-
39.	Nassau grouper, *Epinephelus striatus*	U	U
40.	Grouper, *Mycteroperca* sp.	U	U
41.	Grouper, *Epinephelus* sp.	-	U
42.	Seabass, unid., f: Serranidae	U	U
43.	Tarpon, *Megalops atlantica*	U	-
44.	Schoolmaster, *Lutjanus apodus*	C	U
45.	Grey snapper, *Lutjanus griseus*	C	U
46.	Yellowtail snapper, *Ocyurus chrysurus*	U	U
47.	Mahogany snapper, *Lutjanus mahogoni*	U	-
48.	Neon goby, *Elacatinus oceanops*	U	U
49.	Goby, *Gobiosoma* sp.	C	C
50.	Crested goby, *Lophogobius cyprinoides*	U	-
51.	Goby, unid., f: Gobiidae	C	C
52.	Blenny, unid., f: Blennidae	C	C
53.	Spotted eagle ray, *Aetobatus narinari*	U	U
54.	Green moray, *Gymnothorax funebris*	U	U
55.	Spotted moray, *Gymnothorax moringa*	U	-

C = Common U = Uncommon - = Absence

juvenile porkfish cleaning parasites from the spadefish, Chaetodopterus faber. These cleaners may also draw fishes to the discharge area that would not otherwise be attracted.

5.3.7 Transect Counts of Lobsters and Stone Crabs in Discharge and Control Areas

The Florida spiny lobster, Panulirus argus, and the stone crab, Menippe mercenaria, were found to be quite abundant in the study area. Both of these species form the basis of valuable fisheries in the Florida Keys. Initially, the biologists thought that the warm effluent was attracting lobsters, but after having compared fish occurrences in the discharge area with those in the control area farther up the channel, they decided to make transect counts of the numbers of lobsters in the two regions. Counts of this organism made during quadrat observations revealed that the lobster is quite active and frequently moves from one area to another. Lobsters have been present in a quadrat one time and absent the next. Most of these observations were made during periods when the lobster fishery was closed, so human disturbance was a minimal influence on the presence or absence of the species in Safe Harbor.

Divers ran a 50-m transect line in about 5 m of water along the bottom in the discharge and control areas making counts of lobsters (Figure 29). On 3 June 1969, there were only 5 lobsters along the discharge transect, while there were 26 along the control transect. Repeating the same transect counts on 28 June 1969, the divers again found 5 lobsters along the discharge transect but 32 lobsters along the control transect (Table 10). On these two particular occasions, there seemed to be fewer lobsters in the effluent plume area than there had been during the biologists' earlier field trips. This difference could reflect a seasonal effect, since the effluent may attract lobsters in the colder months of the year.

The stone crab was far more common in the discharge area during the entire study period (Table 11). Both juvenile and adult crabs were found there, and gravid females were observed near the discharge pipe on 28 June 1969. Counts were made on 3 June 1969 and 28 June 1969 along the same two transect lines used for the lobster counts. The first count yielded 42 stone crabs in the discharge area as opposed to 3 in the control area, and the second count yielded 46 stone crabs in the discharge area as opposed to 15 in the control area. Stone crabs in the discharge area were found under practically every available rock and in every hole. One juvenile crab was living under the rim of the discharge pipe itself.

5.3.8 Marine Algae Occurrences in Discharge and Control Areas

There is a marked absence of attached marine algae in the immediate vicinity of the discharge pipe (see Figure 24). This area corresponds approximately with that from which the black tunicate, Ascidia nigra, is excluded. The bottom examined for algae in this barren area ranged between 1 and 9 m in depth. Only two species occurred sparingly, a red algae, Ceramium sp., and a green, Cladophoropsis membranacea. The latter was more common (Table 12).

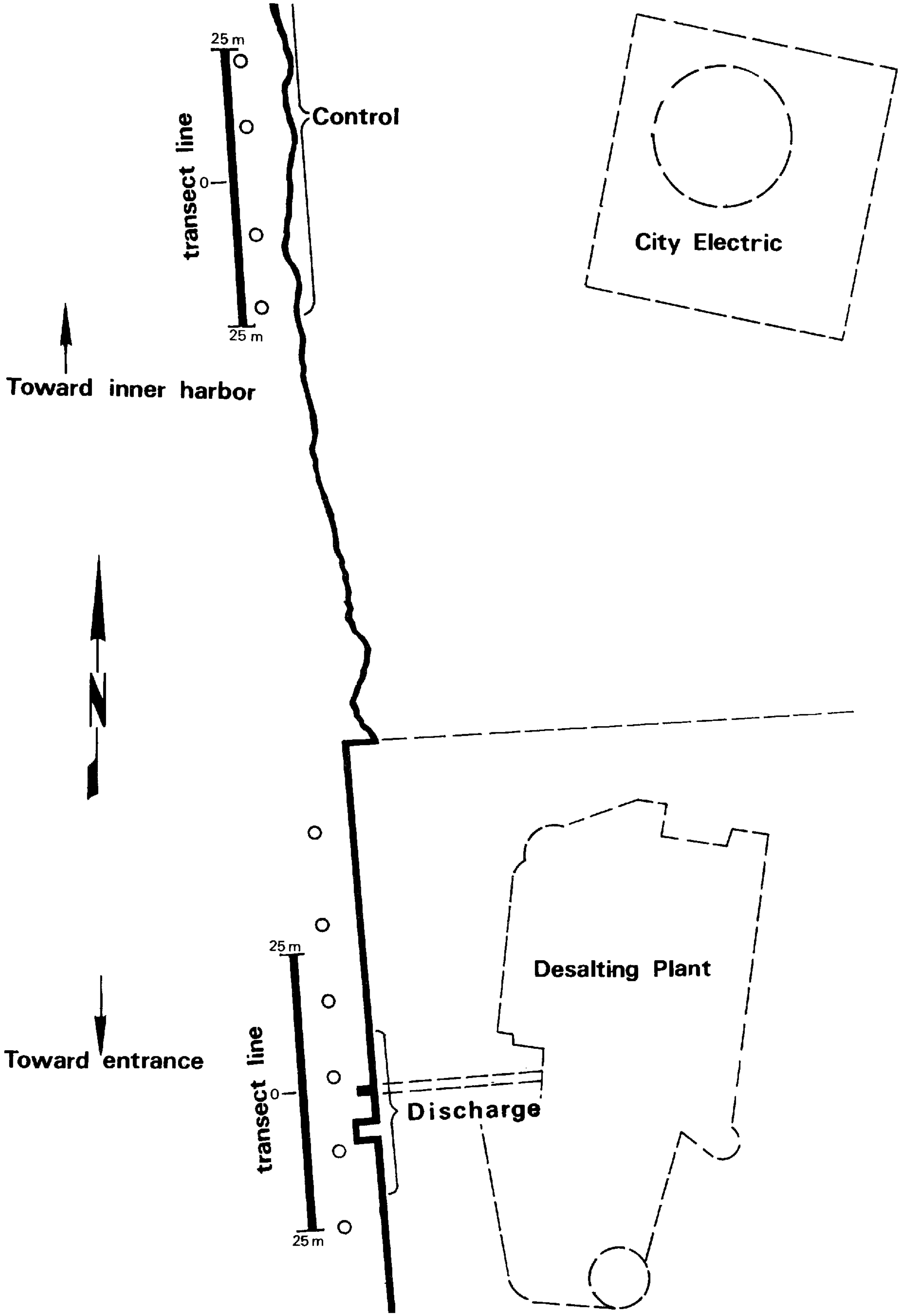


Figure 29. Locations of transect lines for lobster and stone crab counts in discharge and control areas.

Table 10

TRANSECT COUNTS OF THE SPINY LOBSTER, *Panulirus argus*, IN DISCHARGE AND CONTROL AREAS.

Discharge area

3 June 1969

North

0m–5m	5m–10m	10m–15m	15m–20m	20m–25m
0	0	1	2	0

South

25m–30m	30m–35m	35m–40m	40m–45m	45m–50m	
0	1	1	0	0	Total 5

28 June 1969

North

0m–5m	5m–10m	10m–15m	15m–20m	20m–25m
1	0	0	3	0

South

25m–30m	30m–35m	35m–40m	40m–45m	45m–50m	
0	0	1	0	0	Total 5

Control area

3 June 1969

North

0m–5m	5m–10m	10m–15m	15m–20m	20m–25m
2	9	0	3	0

South

25m–30m	30m–35m	35m–40m	40m–45m	45m–50m	
0	2	2	3	5	Total 26

28 June 1969

North

0m–5m	5m–10m	10m–15m	15m–20m	20m–25m
4	16	0	0	2

South

25m–30m	30m–35m	35m–40m	40m–45m	45m–50m	
0	0	0	10	0	Total 32

Table 11

TRANSECT COUNTS OF THE STONE CRAB, *Menippe mercenaria*, IN DISCHARGE AND CONTROL AREAS.

Discharge area

3 June 1969

North

0m–5m	5m–10m	10m–15m	15m–20m	20m–25m
5	6	7	4	5

South

25m–30m	30m–35m	35m–40m	40m–45m	45m–50m
9	2	1	2	1

Total 42

28 June 1969

North

0m–5m	5m–10m	10m–15m	15m–20m	20m–25m
4	4	6	0	9

South

25m–30m	30m–35m	35m–40m	40m–45m	45m–50m
9	0	5	6	3

Total 46

Control area

3 June 1969

North

0m–5m	5m–10m	10m–15m	15m–20m	20m–25m
1	0	0	1	0

South

25m–30m	30m–35m	35m–40m	40m–45m	45m–50m
1	0	0	0	0

Total 3

28 June 1969

North

0m–5m	5m–10m	10m–15m	15m–20m	20m–25m
3	1	1	3	1

South

25m–30m	30m–35m	35m–40m	40m–45m	45m–50m
2	1	1	1	1

Total 15

Table 12

OCCURRENCES OF MARINE ALGAE IN DISCHARGE AND CONTROL AREAS.

Species	Depth
Discharge area	
1. *Ceramium* sp.	1 m
2. *Cladophoropsis membranacea*	.05-3 m
Control area	
1. *Caulerpa floridana*	.05-1 m
2. *Caulerpa verticillata*	1-2 m
3. *Halimeda tuna*	1-2 m
4. *Cladophoropsis membranacea*	.05-3 m
5. *Penicillus capitatus*	1 m
6. *Ceramium* sp.	1 m
7. *Herposiphonia* sp.	2 m

In the control area off the proposed Key West City Electric power plant the biologists examined similar substrates at the same depths for attached algae. Within an equivalent area extending along the channel edge, they found seven species of algae (Table 12). The greater number of species in the control region suggests that algal colonization in the immediate vicinity of the discharge is being limited by factors related to the effluent.

5.3.9 Bottom Samples

The numbers of organisms contained in the bottom samples turned out to be exceedingly small, particularly for samples taken in the harbor and entrance channel. Diving observations also confirmed that there was little in the way of benthic or infaunal life in the fine mud sediments that covered the bottom of the harbor and channel. These sediments often smelled of H_2S and the presence of this poisonous gas may account for the scarcity of life in the collected samples. The only organisms observed on the harbor bottom were the jellyfish, Cassiopeia frondosa, an aplysiid, Bursatella sp., and the horseshoe crab, Xiphosura polyphemus. The jelly fish were very abundant during the winter and spring sometimes reaching densities of 3 to 4 individuals per m^2. These organisms were found from the head of Safe Harbor to the mouth of the entrance channel. The aplysiid was only seen abundantly during a winter field trip made in December 1968. At that time, it congregated in great numbers in the warm effluent on the channel bottom down slope from the discharge pipe. Many of the individuals were in tight clusters and copulating pairs were found in these aggregations. This aplysiid was seen on the bottom in other parts of the harbor and entrance channel. However, it was not as numerous, nor was the mating behavior as prevalent as that observed in the discharge area. It would appear from these observations that the effluent was acting as a stimulus for the reproductive behavior of this organism. The aggregation of gravid female and juvenile stone crabs in the discharge area fits into this same sort of behavior and may indicate that the effluent has a beneficial effect on some species by creating a more suitable breeding habitat.

Horseshoe crabs were only sighted a few times in the harbor. The distribution of these sightings did not show any relationship to the location of the effluent discharge.

The bottom samples from the stations on the shallow flats contained more organisms in them than the harbor ones. The sediments were coarser at these stations and H_2S was never detected in the samples. The bottom samples did not prove very useful to the study of the effects of the desalting plant effluent since they contained few organisms. Like the quadrats (see 5.3.1 Quadrat Counts) the harbor bottom samples formed one comparable group and the shallow flats samples another. The size of the sediments and the dissolved gases contained in these two sets of samples played a stronger environmental role as far as the species present than the effluent from the desalting plant. The organisms found in these samples are listed in Table 13.

Table 13

ORGANISMS FOUND IN THE BENTHIC SAMPLES.

Organisms	Number	Station	Date
Nemertea			
Rhynchocoela	1	4	29 June 1968
Rhynchocoela	1	10	12 Oct. 1968
Annelida			
Cirratulidae	1	9	29 June 1968
Cirratulidae	1	5	14 Oct. 1969
Flabelligeridae	1	9A	12 Oct. 1968
Maldanidae	1	9A	12 Oct. 1968
Nereidae	1	2	12 Oct. 1968
Nereidae	1	8A	13 Oct. 1968
Nereidae	1	9	12 Oct. 1968
Opheliidae	1	8A	13 Oct. 1968
Orbiniidae	1	9A	12 Oct. 1968
Orbiniidae	2	9A	29 June 1968
Orbiniidae	2	9	12 Oct. 1968
Phyllodocidae	1	8A	13 Oct. 1968
Polynoidea	1	9A	12 Oct. 1968
Serpulidae	1	1	12 Oct. 1968
Serpulidae	1	9A	29 June 1968
Syllidae	2	9A	12 Oct. 1968
unid. polychaete	1	10	29 June 1968
unid. polychaete	1	4	29 June 1968
unid. polychaete	1	9A	12 Oct. 1968
unid. polychaete	1	5	14 Oct. 1968
unid. polychaete	1	8	14 Oct. 1968
unid. polychaete	3	5	14 Oct. 1968
unid. polychaete frag.	1	9A	29 June 1968
Mollusca			
Gastropoda			
Astraea longispina	2	9	12 Oct. 1968
Astraea phoebia	2	9	29 June 1968

Table 13 (continued)

ORGANISMS FOUND IN THE BENTHIC SAMPLES.

Organisms	Number	Station	Date
Tegula lividomaculata	1	10	29 June 1968
Triphora melanura	1	10	29 June 1968
Atys sp.	6	5	14 Oct. 1968
Epitonium sp.	1	9	12 Oct. 1968
Epitonium sp.	1	10	12 Oct. 1968
Natica sp.	1	10	29 June 1968
Oliva sp.	2	5	14 Oct. 1968
Prunum sp.	1	5	14 Oct. 1968
Retusa sp.	5	8A	13 Oct. 1968
Vermicularia sp.	1	10A	12 Oct. 1968
Atyidae	1	10A	12 Oct. 1968
Naticidae	1	4	29 June 1968
Lamellibranchia			
Arca zebra	1	8A	29 June 1968
Divaricella quadrisulcata	1	9	29 June 1968
Divaricella quadrisulcata	1	10A	29 June 1968
Laevicardium laevigatum	1	10A	29 June 1968
Macoma constricta	4	4	29 June 1968
Macoma constricta	5	5	1 July 1968
Anadara sp.	1	2	12 Oct. 1968
Anadara sp.	1	10A	29 June 1968
Chione sp.	1	9A	12 Oct. 1968
Tellina sp.	3	5	14 Oct. 1968
Tellina sp.	2	8A	13 Oct. 1968
Cariidae	1	5	14 Oct. 1968
Lucinidae	1	5	14 Oct. 1968
Lucinidae	1	5	1 July 1968
Lucinidae	1	10	29 June 1968
Lucinidae	3	10A	12 Oct. 1968
Tellinidae	1	2	29 June 1968

Table 13 (continued)

ORGANISMS FOUND IN THE BENTHIC SAMPLES.

Organisms	Number	Station	Date
Scaphopoda			
unid. scaphopod	2	5	14 Oct. 1968
Echinodermata			
Holothuroidea			
unid. holothuroid	1	5	1 July 1968
unid. holothuroid	1	9A	12 Oct. 1968
Ophiuroidea			
unid. ophiuroid	1	9A	12 Oct. 1968
unid. ophiuroid	1	10	29 June 1968
Crustacea			
Ostracoda			
unid. ostracods	2	5	14 Oct. 1968
unid. ostracods	6	5	14 Oct. 1968
unid. ostracods	1	9A	12 Oct. 1968
Decapoda			
Pinnotheridae	1	5	14 Oct. 1968
unid. brachyuran megalopa	1	8	14 Oct. 1968

6. DISCUSSION OF RESULTS

The results of the physical, and chemical, studies have shown that several of the properties (temperature and salinity) of the effluent can be detected at greater distances from the discharge point than can gross changes in the biological communities. This means that the levels of effluent dilution necessary to produce minimal environmental modification can be determined in a subsequent study.

Of the physical and chemical parameters measured (temperature, salinity, oxygen, and alkalinity) only the distributions of temperature and salinity could be related to the effluent discharge. Values for these two parameters at harbor and channel stations increased as one approached the discharge point, and throughout the study temperature and salinity values averaged higher at Station 3 (immediately off the desalting plant) than at other stations. There is an asymmetry to the distribution of the effluent plume in that it conserves some of its properties farther up the entrance channel into the harbor than it does towards the entrance. Comparing values for temperature and salinity at Station 2, 3, and 4, which extend from the inner harbor to the entrance, the values are highest at Station 3, next highest at Station 2, and lowest at Station 4 (see Figures 16 and 17). This same asymmetry was observed in some of the biological investigations and during the dye injection experiments. Attached algae and several invertebrates were found to be excluded at greater distances towards the inner harbor side of the discharge point than towards the entrance side (see Sections 5.3.5 and 5.3.8). The gorgonian colony transplants also showed a mortality pattern of the colonies that related to the asymmetry of the effluent field (see Section 5.3.4). Finally, dye releases in the effluent of the desalting plant confirmed that a portion of the effluent plume swings in toward the inner harbor (see Section 5.3.5).

The averaged values for all the physical and chemical parameters showed that the stations in the study area were correlated and followed the same seasonal trends throughout the study period. Even the increasing or decreasing ranges of extreme values paralleled one another from station to station on a monthly basis. The plots of these extreme values indicated that summer seemed to be the most stable season as far as the environment, the only parameter showing exception to this was salinity, which became more variable than the other parameters during the early summer rains.

The effects of the desalting plant effluent on the general study area environment as measured by the methods employed in this study were small compared to the observed seasonal changes. However, the short duration of this preliminary study does not allow a definitive answer on the long-term effects of the desalting plant effluent on the environment or biota. The temperature and salinity differences caused by the effluent are greatest at the surface during the winter months. Plots for Stations 2, 3, and 4 show that these differences from the general environmental values diminish during spring and summer (see Figure 16). Near the bottom, the differences, however, are sufficient at Station 3 to exclude or limit the growth of some organisms.

The biological investigations have shown that the effects of the effluent in the near field can be either beneficial or detrimental, depending on the organism. Stone crabs were attracted to the area and were more numerous there than any other place investigated in Safe Harbor during the course of the study (see Section 5.3.7). Barnacles were found to be more successful and numerous on the settlement disks in the discharge area than on those outside the area (see Section 5.3.3). The juveniles of several species of fish were also observed to be more numerous in the discharge area (see Section 5.3.6). On the other hand, some organisms were adversely affected or excluded from the discharge area. A black tunicate widely distributed in Safe Harbor was excluded from the rocky surfaces and seawall near the discharge point (see Sections 5.3.1 and 5.3.5). A common carnivorous gastropod was also excluded from portions of the seawall (see Section 5.3.5). Bryozoan colonies did very poorly on settlement disks in the discharge area. Not only were there fewer of them, but they only grew to one-tenth the size of those on the control settlement disks (see Section 5.3.3). Gorgonian colony transplants did not survive when placed closer than 12 m to the discharge point (see Section 5.3.4). Finally, marine algae were sparse or absent from an area immediately around the discharge point (see Section 5.3.8).

The exclusion, mortality, or stunting of organisms near the discharge point would appear relatable to properties of the effluent. Whether or not they are specifically temperature and/or salinity cannot be determined from the present study. Other factors, such as metal ions or chemical discharges during descaling operations, may be critical to the organisms living in the area and those factors should be investigated in the next study. It can be seen from the small area of exclusion that the amount of dilution necessary to minimize biological effects is not great and could be determined by measuring some conservative property of the effluent.

Why some organisms are attracted or do better in the discharge area is harder to explain. In some cases, such as the stone crabs and juvenile cleaner fishes, it would appear that the warmer temperatures are responsible, particularly in winter when these organisms are not found elsewhere in Safe Harbor or on the shallow flats outside the harbor. Temperature also seemed to be responsible for attracting the aplysiid sea slug and inducing it to mate.

The presence of the many species of fish in the discharge area did not seem to be related to the effluent field and in this case the physical presence of the mooring dolphins seemed to be a more important environmental factor (see Section 5.3.6). The success of barnacles and filter feeding worms in the discharge area would seem to be related to several factors, first their tolerance to the higher temperatures and salinities and secondly, the large supply of planktonic food entrained and brought to them in the currents generated by the discharge of the effluent. Barnacles in this area feed simply by extending their cirri and do not rake the water with typical feeding motions as they do in other parts of Safe Harbor.

Thus, the problems of attraction or of growth enhancement of organisms in the discharge area must be studied more carefully to determine the environmental factors that are responsible. In summary, the gross biological effects from the effluent discharge are limited to a small area and may be detrimental or beneficial depending on the organism.

7. CONCLUSIONS AND RECOMMENDATIONS

The Phase-I work has shown that some of the properties of the effluent can be detected by physical and chemical measurements well beyond the area that visible effects can be detected in the bottom communities. While the effluent produces some beneficial effects such as attracting certain species of fish and the stone crab, Menippe mercenaria, it has also been shown to have deleterious effects for other organisms. Algae, tunicates, and gastropods were excluded from the near-field of the effluent discharge and bryozoan colonies were not as numerous in the discharge area nor did they grow as well as they did outside of the area. Quantitative investigations of the physiological and ecological effects of the desalting plant effluent in future studies could lead to predictive capabilities as far as the amount of environmental stress that can be tolerated at a given locality. The Key West municipal government is considering locating a power plant and additional desalination facilities at the Safe Harbor site. The additional discharges can be used to test the predictive models developed during the Phase-II study.

For the Phase-II study, it is recommended that the main emphasis of the study be to investigate biological alterations resulting from the effluent of the desalting plant and to develop quantitative criteria for predicting and assessing the impact of a heated, hypersaline effluent on the biota of the receiving waters. Probably even more important to the Phase-II study is determining the effects of descaling operations on the environment and biota.

All of the physical data for Phase-I work have been placed on magnetic tape and punched cards. It is recommended that these data be analyzed more completely.

8. REFERENCES

Bayer, F. M. 1961. The shallow-water Octocorallia of the West Indian region. Martinus Nijhoff, Hague: 373 pp.

Brown, N. L. and B. V. Hamon 1961. An inductive salinometer. Deep-Sea Research. 8(1): 65-75.

Cary, L. R. 1914. Observations upon the growth-rate and ecology of gorgonians. Carnegie Inst. Wash. Pub. 182: 79-90.

Cary, L. R. 1918. The Gorgonaceae as a factor in the formation of coral reefs. Carnegie Inst. Wash. Pub. 213: 341-362.

Cox, R. A. 1965. The physical properties of sea water. In Chemical Oceanography. Edited by J. P. Riley and G. Skirrow, Academic Press, N. Y. Vol. 1, pp. 73-120.

Gohar, H. A. F. 1940. Studies on the Xeniidae of the Red Sea. Pub. Marine Biol. Sta. Ghardaqa (Red Sea) 2: 25-118.

Gohar, H. A. F. 1948. A description and some biological studies of a new alcyonarian species *Clavularia hamra* Gohar. Pub. Marine Biol. Sta. Ghardaqa (Red Sea) 6: 3-33.

Grigg, Richard 1970. Doctoral thesis - University of California at San Diego, Scripps Inst. of Oceanography.

Pearce, Jack 1968. Saucers in the sea. Bull. Amer. Littoral Soc. 5 (1): 14-19.

Randall, J. E. 1963. An analysis of the fish populations of artificial and natural reefs in the Virgin Islands. Carib. J. Sci. 3 (1): 1-16.

Rosenthal, R. J. 1969. A method of tagging mollusks underwater. Veliger 11: 288-289.

Wooster, Warren S., Arthur J. Lee and Gunther Dietrich 1969. Redefinition of salinity. Limnology and Oceanography. 14 (3): 437-438.

APPENDIX A

DOW CHEMICAL DEFOAMING AGENT, POLYGLYCOL 15-200, PHYSICAL PROPERTIES AND TOXICOLOGICAL DATA

PHYSICAL PROPERTIES OF DEFOAMING AGENT POLYGLYCOL 15-200 DISCHARGED IN DESALTING PLANT EFFLUENT*

Average Molecular Weight	2600
Specific Gravity at 25/25°C.	1.063
at 75/25°C.	1.026
Pounds per Gallon at 25°C.	8.85
Refractive Index at 25°C.	1.460
Viscosity at 100°F., Centistokes	206
at 210°F., Centistokes	32.3
at 32°F., Centistokes	2056
Viscosity Index	138
Flash Point, °F.	470
Fire Point, °F.	550
Pour Point, °F.	-40
Specific Heat at 25°C., cal/g/°C.	0.47
Surface Tension	
at 25°C. dynes/cm.	34.3
at 75°C. dynes/cm.	32.4

* Information obtained from Dow Chemical Company

TOXICOLOGICAL DATA FOR DEFOAMING AGENT, POLYGLYCOL 15-200*

Polyglycol 15-200 has a low acute oral toxicity. The LD is approximately 20 g/kg. of body weight for rats, rabbits, and guinea pigs. Direct eye contact results in only traces of any irritating effect. Undiluted material is only very slightly irritating to the rabbit skin on prolonged and repeated contact. Polyglycol 15-200 is not absorbed through the skin in toxic amounts. Rabbits survive single massive doses of 30 g/kg. of body weight, and repeated application of several grams per day over a three month period was without evidence of adverse effect.

The material has also been tested extensively on human subjects; skin patch tests with the undiluted material gave completely negative results by both continuous and repeated insult technique. Polyglycol 15-200 is neither a primary irritant nor a skin sensitizer.

These data are sufficient to suggest that Polyglycol 15-200 is a safe, suitable material for use in cosmetic applications where intimate contact with the skin can be expected.

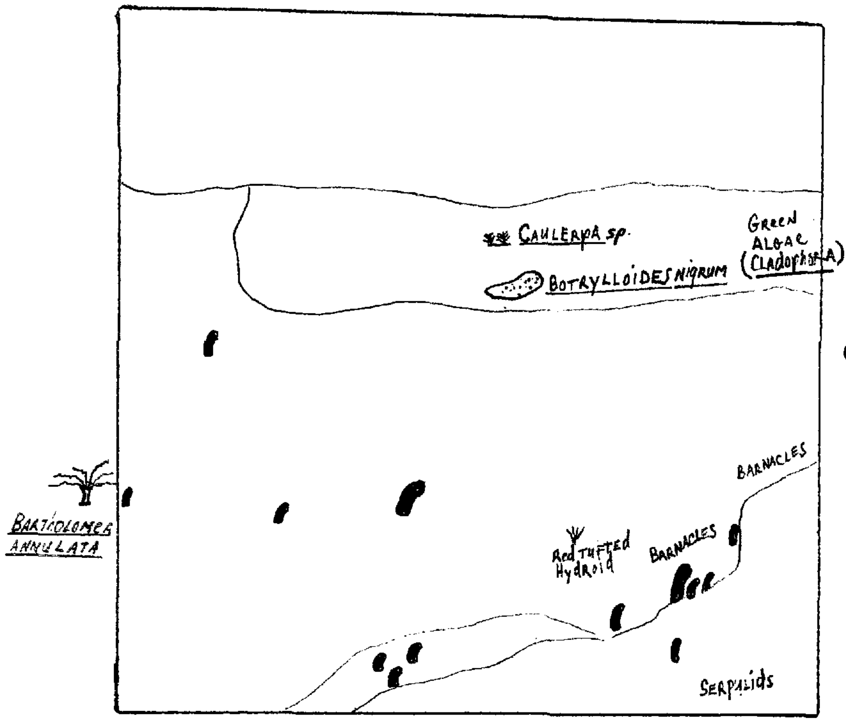
* Information obtained from Dow Chemical Company

APPENDIX B

QUADRAT LOG SHEETS

KEY WEST STUDY

F.W.P.C.A.



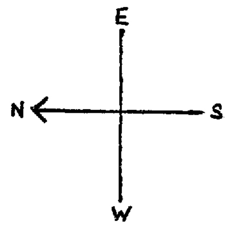
Station No.: 1

Location: SAFE HARBOR

Date: 10 DECEMBER 1968

Depth: ~20'

Quadrat Size: $4M^2$



SYMBOLS:

- Ascidia nigra
- Diadema antillarum
- Halimeda discoidea
- Manicina areolata
- Panulirus argus
- Penicillus sp.
- Pterogorgia sp.
- Short-spined urchin
- Thalassia testudinum
- Udotea sp.

NOTES:

THE ANOXIC "FALSE BOTTOM" LAYER had disappeared FROM THE MARINA basin. THE UNDERWATER visibility Approached ~8 METERS. Hydrogen sulfide was detected ONLY ON THE bottom in the SUBSTRATE.

Fishes:

POMACANTHUS AUREUS
HOLACANTHUS sp.
SCARUS sp.
LUTJANUS sp.
ANISOTREMUS VIRGINICUS
Abudefduf saxatilis
HAEMULON sp.
Sphyraena sp.
ARCHOSARGUS PROBATOCEPHALUS

INVERTEBRATES:

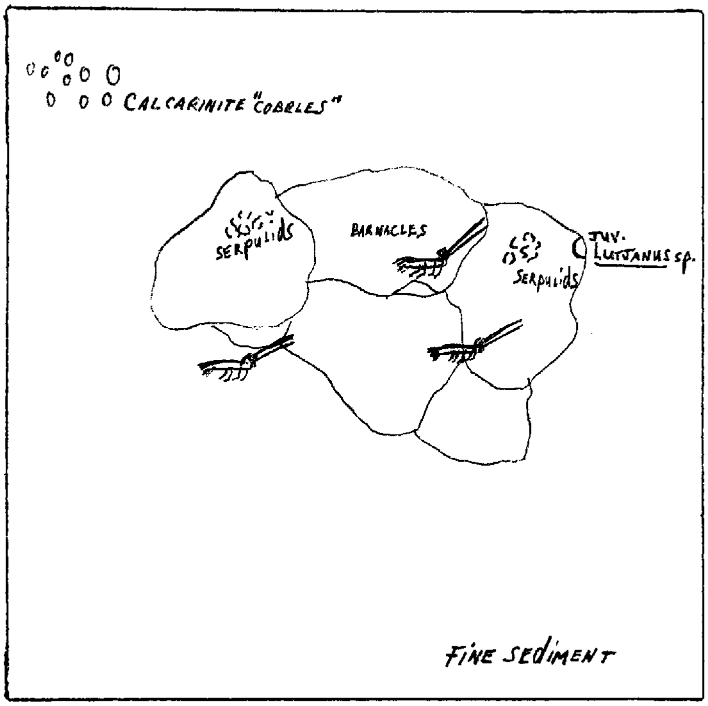
GONODACTYLUS sp.
CASSIOPEIA sp.
OSTREA FRONS
PANULIRUS ARGUS

ALGAE:

ENTEROMORPHA sp.
ULVA sp.

KEY WEST STUDY

F.W.P.C.A.



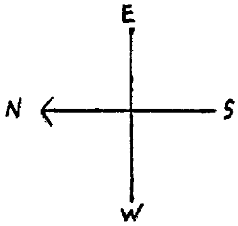
Station No.: 3

Location: Safe Harbor - Outfall

Date: 10 December 1968

Depth: 22'-25'

Quadrat Size: $4M^2$



SYMBOLS:

- Ascidia nigra
- Diadema antillarum
- Halimeda discoidea
- Manicina areolata
- Panulirus argus
- Penicillus sp.
- Pterogorgia sp.
- Short spined urchin
- Thalassia testudinum
- Udotea sp.

NOTES:

The rocks are covered with barnacles and Serpulid worm tubes. The Panulirus argus move around a great deal, these three are not always found within this quadrat. One of the lobsters is missing both antenna (making it quite distinct from others.)

Fishes:

Epinephelus striatus

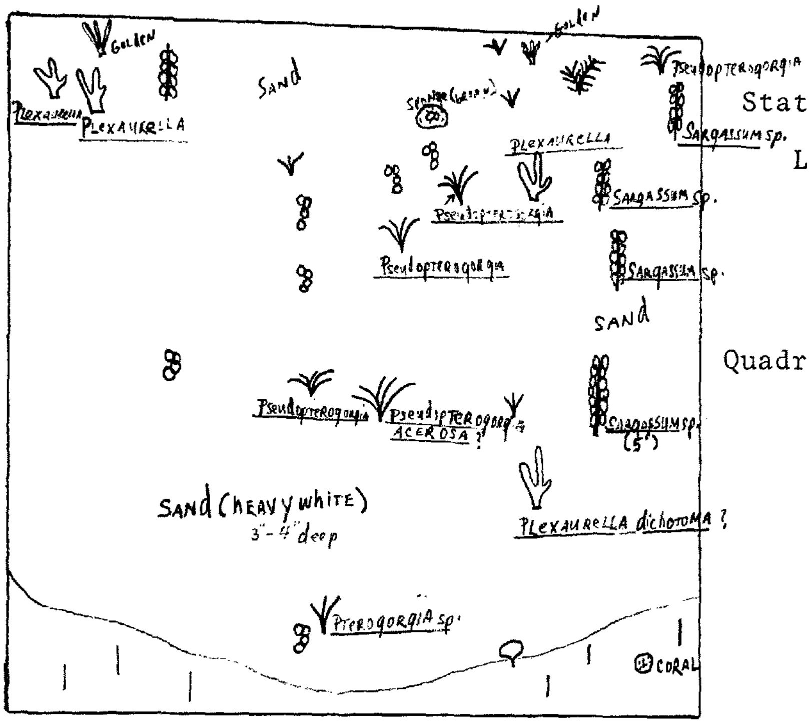
Hemiramphus sp. - halfbeak

Aetobatus narinari - spotted eagle ray was observed jumping in the channel.

Centropomus undecimalis - large school of snook was seen near the outfall.

KEY WEST STUDY

F.W.P.C.A.



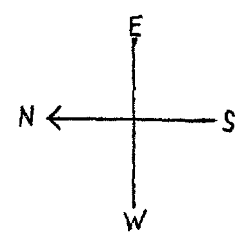
Station No.: 8A

Location: FLATS N. OF Boca Chica

Date: 15 DECEMBER 1968

Depth: ~8'

Quadrat Size: 4 M²



SYMBOLS:

- Ascidia nigra
- Diadema antillarum
- Halimeda discoidea
- Manicina areolata
- Panulirus argus
- Penicillus sp.
- Pterogorgia sp.
- Short spined urchin
- Thalassia testudinum
- Udotea sp.

NOTES:

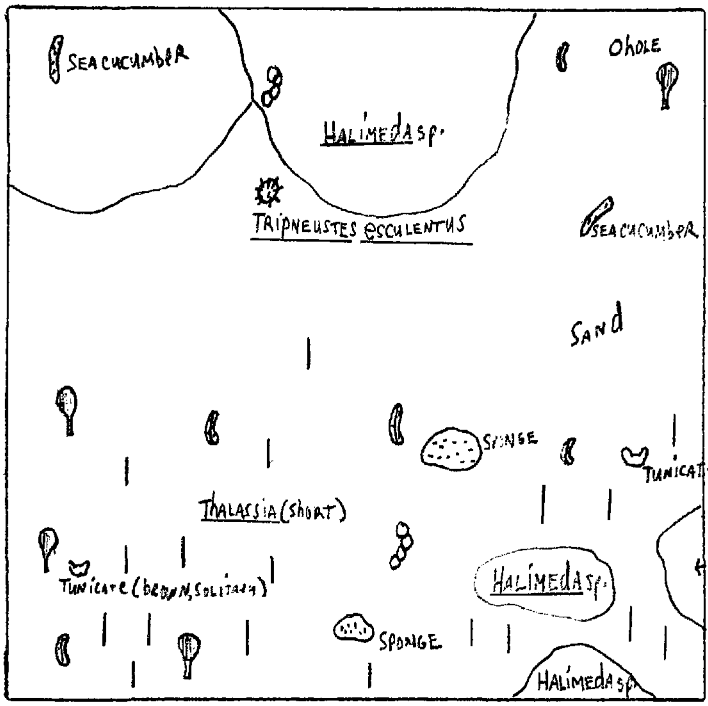
INVERTEBRATES:

Loggerhead sponge, Spheciospongia vesparia

Oreaster reticulatus, large Asteroid

KEY WEST STUDY

F.W.P.C.A.



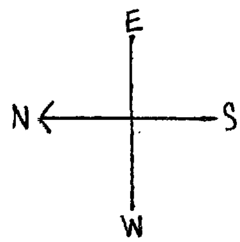
Station No.: 9

Location: COW KEY

Date: 11 DECEMBER 1968

Depth: 5'-6'

Quadrat Size: 4M²



SYMBOLS:

- Ascidia nigra
- Diadema antillarum
- Halimeda discoidea
- Manicina areolata
- Panulirus argus
- Penicillus sp.
- Pterogorgia sp.
- Short spined urchin
- Thalassia testudinum
- Udotea sp.

NOTES:

FISHES:

SPHYRAENA BARRACUDA

INVERTEBRATES:

DIADEMA ANTILLARUM

PANULIRUS ARGUS (CONCRETE BLOCK)

ASTRAEA SP.

CLYPEASTER ROSACEUS

APPENDIX C

DATA SHEETS FOR SETTLEMENT DISKS

Settlement Rack Data Sheet

STUDY: F W P C A

Date: 4 December 1968

Rack No. 1

Location Discharge, Safe Harbor

Disc Rubber

Surface Upper

Days in water ____

Depth 24 ft.

Aliquot No. 1 (wedge 0.05m^2)

Organism	Number
barnacle	15
serpulid worm	38
Ostrea sp.	0
bryozoan	present

Aliquot No. 2 (wedge 0.05m^2)

Organism	Number
barnacle	~12
serpulid worm	46
Ostrea sp.	0
bryozoan	0

Settlement Rack Data Sheet

STUDY: F W P C A

Date: 4 December 1968

Rack No. 1

Location Discharge, Safe Harbor

Disc Concrete

Surface Lower

Days in water ____

Depth 24 ft.

Aliquot No. 1 (wedge 0.05m^2)

Organism	Number
barnacle	12
serpulid worm	~63
Ostrea sp.	~17
colonial tunicate(clear)	1
polychaete	1
eggs	2 sets
aeolid nudibranch	1

Aliquot No. 2 (wedge 0.05m^2)

Organism	Number
barnacle	6
serpulid worm	~59
Ostrea sp.	~24

APPENDIX D

SPECIES COMPOSITION OF PLANKTON SAMPLE ALIQUOTS

Date	17 Dec. 1968		26 Jan. 1969		14 Mar. 1969		4 April 1969		2 June 1969	
Plankton Tow	1		1		1		1		1	
Aliquot	1	2	1	2	1	2	1	2	1	2
Calanoids										
Acartia spinata	O	O	O	R	R	R	O	O	O	O
A. tonsa	C	C	A	A	A	A	A	A	O	O
Acartia spp. juveniles	C	C	O	O	O	O	O	O	R	R
Labidocera scotti	O	O	O	O	O	O	O	O	O	O
L. mirabilis	O	O	O	O	O	O	O	O	O	O
Labidocera spp. juveniles	O	O	O	O	O	O	O	O	O	O
Clausocalanus furcatus	O	O	O	O	O	O	O	O	O	O
Clausocalanus spp. juveniles	O	O	O	O	O	O	O	O	O	O
Paracalanus crassirostris	R	R	R	R	C	C	C	C	O	O
P. parvus	O	O	O	R	R	R	R	R	O	O
Paracalanus spp. juveniles	O	O	O	O	O	O	O	O	R	R
Temora turbinata	O	O	O	O	O	O	O	O	O	O
Calanopia americana	O	O	O	O	O	O	O	O	O	O
Pseudodiaptomus sp.	O	O	O	O	O	O	O	O	O	O
calanoid nauplii	O	O	C	C	C	C	O	O	C	C
Cyclopoids										
Oithona spp.	A	A	A	A	A	A	A	A	C	C
Corycaeus spp.	O	O	O	O	O	O	O	O	O	R
Oncaea sp.	O	O	O	O	O	O	O	O	O	O
Harpacticoids										
Microsetella rosea	O	O	O	O	O	O	O	O	O	O
Euterpina sp.	O	O	R	R	O	O	R	R	O	O
Macrosetella sp.	O	O	O	O	O	O	O	O	O	O
harpacticoid nauplii	A	A	R	C	C	C	A	A	C	C
Crustacean larvae										
crab larvae	R	R	O	O	R	R	O	R	O	O
shrimp larvae	O	O	O	O	O	O	O	O	O	O
barnacle nauplii	R	O	C	C	A	A	C	C	R	R
barnacle cyprids	O	O	O	O	R	R	O	O	O	O
Amphipods	O	O	O	O	O	O	O	O	O	O
Tanaids	O	O	O	O	O	O	O	O	O	O
Larvaceans	O	O	C	C	R	R	R	R	O	R
Chaetognaths	O	O	R	R	R	R	R	C	O	O
Echinoplutei	O	O	O	O	O	O	O	O	O	O
Polychaete larvae	O	O	O	O	C	C	R	C	R	R

A = abundant > 150 per aliquot
C = common 20-150 per aliquot
R = rare <20 per aliquot
O = absent from aliquot

Date	12 Oct. 1968		17 Dec. 1968		26 Jan. 1969		14 Mar. 1969		4 April 1969		2 June 1969	
Plankton Tow	2		2		2		2		2		2	
Aliquot	1	2	1	2	1	2	1	2	1	2	1	2
Calanoids												
Acartia spinata	O	O	O	O	O	O	R	R	O	R	O	O
A. tonsa	A	A	C	C	C	C	A	A	A	A	O	O
Acartia spp. juveniles	O	O	O	O	O	O	A	A	O	O	O	O
Labidocera scotti	O	O	O	O	O	O	O	O	O	O	O	O
L. mirabilis	O	O	O	O	O	O	O	O	O	O	O	O
Labidocera spp. juveniles	O	O	O	O	O	O	O	O	O	O	O	O
Clausocalanus furcatus	O	O	O	O	O	O	O	O	O	O	O	O
Clausocalanus spp. juveniles	O	O	O	O	O	O	O	O	O	O	O	O
Paracalanus crassirostris	A	A	O	O	C	C	C	C	C	C	O	R
P. parvus	C	C	O	O	O	O	R	R	C	C	O	O
Paracalanus spp. juveniles	O	O	O	O	O	O	O	O	O	O	R	R
Temora turbinata	O	O	R	R	O	O	O	O	O	O	O	O
Calanopia americana	O	O	O	O	O	O	O	O	R	R	O	O
Pseudodiaptomus sp.	O	O	O	O	O	O	O	O	O	O	O	O
calanoid nauplii	O	O	A	A	C	C	A	A	R	R	C	C
Cyclopoids												
Oithona spp.	A	A	A	A	A	A	A	A	A	A	C	C
Corycaeus spp.	O	O	O	O	O	O	O	O	R	R	O	O
Oncaea sp.	O	O	O	O	O	O	O	O	O	O	O	O
Harpacticoids												
Microsetella rosea	O	O	O	O	O	O	O	O	O	O	O	O
Euterpina sp.	O	O	O	R	O	R	O	O	R	R	O	O
Macrosetella sp.	O	O	O	O	O	O	O	O	O	O	O	O
harpacticoid nauplii	O	O	A	A	O	R	C	C	A	A	C	C
Crustacean larvae												
crab larvae	O	O	O	O	O	O	O	R	O	O	O	O
shrimp larvae	O	O	R	R	O	O	R	R	O	O	O	O
barnacle nauplii	C	C	C	C	O	R	C	C	A	A	C	C
barnacle cyprids	R	R	O	O	O	O	O	O	O	O	O	O
Amphipods	O	O	O	O	O	O	O	O	O	O	O	O
Tanaids	O	O	O	O	O	O	O	O	O	O	O	O
Larvaceans	R	R	R	R	C	C	R	R	C	C	R	R
Chaetognaths	R	R	O	O	O	O	R	R	R	R	R	R
Echinoplutei	O	O	O	O	O	O	O	O	O	O	O	O
Polychaete larvae	R	R	O	O	O	O	R	R	R	R	O	O

A = abundant > 150 per aliquot
C = common 20-150 per aliquot
R = rare <20 per aliquot
O = absent from aliquot

Date	17 Dec. 1968		26 Jan. 1969		14 Mar. 1969		4 Apr. 1969		2 June 1969		14 Oct. 1968	
Plankton Tow	3		3		3		3		3		4	
Aliquot	1	2	1	2	1	2	1	2	1	2	1	2
Calanoids												
Acartia spinata	O	O	O	O	R	R	O	R	R	R	C	C
A. tonsa	R	O	C	C	C	C	A	A	O	O	C	C
Acartia spp. juveniles	R	R	O	O	C	C	O	O	R	R	O	O
Labidocera scotti	O	O	O	O	O	O	O	O	O	O	O	O
L. mirabilis	O	O	O	O	O	O	O	O	O	O	R	R
Labidocera spp. juveniles	O	O	O	O	O	R	O	O	O	R	O	O
Clausocalanus furcatus	O	O	O	O	O	O	O	O	R	R	O	O
Clausocalanus spp. juveniles	O	O	O	O	O	O	O	O	R	R	O	O
Paracalanus crassirostris	O	O	A	A	A	A	A	A	R	R	A	A
P. parvus	O	O	R	R	C	C	R	R	O	O	C	C
Paracalanus spp. juveniles	C	C	O	O	O	O	O	O	O	O	O	O
Temora turbinata	R	R	O	O	O	O	R	R	O	O	O	O
Calanopia americana	O	O	O	O	O	O	R	R	O	O	O	O
Pseudodiaptomus sp.	O	O	O	O	O	O	R	R	O	O	O	O
calanoid nauplii	O	O	R	R	C	C	C	C	A	A	O	O
Cyclopoids												
Oithona spp.	C	C	A	A	A	A	A	A	C	C	A	A
Corycaeus spp.	O	O	O	O	R	R	R	R	R	R	R	R
Oncaea sp.	O	O	O	O	O	O	O	O	O	O	O	O
Harpacticoids												
Microsetella rosea	O	O	O	O	O	O	R	R	O	O	R	R
Euterpina sp.	O	O	R	R	O	O	R	R	O	O	R	O
Macrosetella sp.	O	O	O	O	O	O	O	O	O	O	O	O
harpacticoid nauplii	A	A	C	C	A	A	C	C	A	A	O	O
Crustacean larvae												
crab larvae	R	R	O	O	O	O	O	O	O	O	R	R
shrimp larvae	O	O	O	O	O	O	O	R	O	O	C	C
barnacle nauplii	O	O	C	C	C	C	C	C	C	C	O	O
barnacle cyprids	C	C	O	O	O	O	O	O	O	O	O	O
Amphipods	O	O	O	O	O	O	O	O	O	O	O	O
Tanaids	O	O	O	O	O	O	O	O	O	O	O	O
Larvaceans	C	C	R	R	O	O	R	R	R	R	R	R
Chaetognaths	O	O	R	R	C	C	C	C	R	R	R	R
Echinoplutei	R	R	O	O	O	O	O	O	O	O	O	O
Polychaete larvae	R	R	O	O	O	O	R	R	R	R	R	R

A = abundant > 150 per aliquot
C = common 20-150 per aliquot
R = rare <20 per aliquot
O = absent from aliquot

Date	13 Oct. 1968		17 Dec. 1968		26 Jan. 1969		14 Mar. 1969		4 Apr. 1969		2 June 1969	
Plankton Tow	5		5		5		5		5		5	
Aliquot	1	2	1	2	1	2	1	2	1	2	1	2
Calanoids												
Acartia spinata	O	O	R	R	O	O	O	R	O	O	O	O
A. tonsa	C	C	O	R	A	A	R	R	C	C	O	O
Acartia spp. juveniles	C	C	R	R	O	O	R	R	O	O	R	O
Labidocera scotti	R	O	O	O	O	O	O	O	O	O	O	O
L. mirabilis	O	O	O	O	O	O	O	O	O	O	O	O
Labidocera spp. juveniles	O	O	O	O	O	R	O	O	O	O	O	O
Clausocalanus furcatus	O	O	O	O	O	O	O	O	O	O	O	O
Clausocalanus spp. juveniles	O	O	O	O	O	O	O	O	O	O	O	O
Paracalanus crassirostris	A	A	O	R	A	A	A	A	C	C	O	O
P. parvus	R	R	O	O	C	C	C	C	O	R	O	O
Paracalanus spp. juveniles	O	O	R	R	O	O	O	O	O	O	O	O
Temora turbinata	R	O	O	O	O	O	O	O	O	O	O	O
Calanopia americana	O	O	O	O	R	R	O	O	O	O	O	O
Pseudodiaptomus sp.	O	O	O	O	O	O	O	O	O	O	O	O
calanoid nauplii	O	O	O	O	A	A	C	C	A	A	R	R
Cyclopoids												
Oithona spp.	A	A	C	C	A	A	A	A	C	C	C	C
Corycaeus spp.	R	R	O	O	R	R	C	C	O	R	O	O
Oncaea sp.	O	O	O	O	O	O	C	C	O	O	R	O
Harpacticoids												
Microsetella rosea	O	O	O	R	O	O	O	O	O	O	O	O
Euterpina sp.	O	O	O	O	R	R	C	C	O	O	O	O
Macrosetella sp.	O	O	O	O	O	O	O	O	O	O	O	O
harpacticoid nauplii	R	R	C	C	A	A	C	C	A	A	C	C
Crustacean larvae												
crab larvae	R	R	O	O	R	R	O	R	O	O	O	O
shrimp larvae	R	O	O	O	R	R	R	R	O	O	O	O
barnacle nauplii	O	O	O	O	C	C	C	C	C	C	R	R
barnacle cyprids	O	O	O	O	O	O	O	O	O	O	O	O
Amphipods	O	O	O	O	O	O	O	O	O	O	O	O
Tanaids	O	O	O	R	O	O	O	O	O	O	O	O
Larvaceans	R	R	O	O	C	C	O	O	O	O	R	R
Chaetognaths	R	R	O	O	R	R	C	C	R	R	O	O
Echinoplutei	O	O	O	O	O	O	O	O	O	O	O	O
Polychaete larvae	O	O	O	O	O	R	O	O	O	O	R	R

A = abundant > 150 per aliquot
C = common 20-150 per aliquot
R = rare <20 per aliquot
O = absent from aliquot

Date	12 Oct. 1968		17 Dec. 1968		26 Jan. 1969		14 Mar. 1969		4 Apr. 1969		2 June 1969	
Plankton Tow	6		6		6		6		6		6	
Aliquot	1	2	1	2	1	2	1	2	1	2	1	2
Calanoids												
Acartia spinata	O	O	O	O	O	O	O	O	O	O	O	O
A. tonsa	R	R	O	O	C	C	R	R	C	C	O	O
Acartia spp. juveniles	C	C	O	O	O	O	C	C	O	O	R	R
Labidocera scotti	O	O	O	O	O	O	O	O	O	O	O	O
L. mirabilis	R	R	O	O	O	O	O	O	O	R	O	O
Labidocera spp. juveniles	O	O	O	O	O	O	O	O	O	O	R	R
Clausocalanus furcatus	O	O	O	O	O	O	O	O	O	R	O	O
Clausocalanus spp. juveniles	O	O	O	O	O	O	R	R	O	O	R	R
Paracalanus crassirostris	A	A	C	C	C	C	A	A	C	C	C	C
P. parvus	R	R	O	O	R	R	R	R	R	R	R	O
Paracalanus spp. juveniles	O	O	O	O	O	O	O	O	O	O	R	R
Temora turbinata	O	O	O	O	O	O	O	O	O	O	R	R
Calanopia americana	O	O	O	O	R	R	O	O	O	O	O	O
Pseudodiaptomus sp.	O	O	O	O	O	O	O	O	O	O	O	O
calanoid nauplii	O	O	C	C	C	C	C	C	C	C	A	A
Cyclopoids												
Oithona spp.	A	A	C	C	A	A	A	A	C	C	C	C
Corycaeus spp.	O	O	O	O	O	R	O	O	O	R	O	O
Oncaea sp.	O	R	O	R	O	O	C	C	O	O	O	O
Harpacticoids												
Microsetella rosea	O	O	O	O	O	O	O	O	O	O	O	O
Euterpina sp.	O	O	R	O	R	R	R	R	C	C	O	O
Macrosetella sp.	O	O	O	O	O	O	O	O	O	O	O	O
harpacticoid nauplii	R	R	C	C	O	O	A	A	C	C	A	A
Crustacean larvae												
crab larvae	C	C	O	R	O	O	R	R	R	R	R	O
shrimp larvae	O	O	O	O	O	O	O	O	O	O	O	O
barnacle nauplii	R	R	O	O	R	R	C	C	C	C	O	O
barnacle cyprids	O	O	O	O	O	O	O	O	O	O	O	O
Amphipods	O	O	O	O	O	O	O	O	O	O	O	O
Tanaids	O	O	O	O	O	O	O	O	O	O	O	O
Larvaceans	R	R	O	O	R	R	O	O	R	R	R	R
Chaetognaths	R	R	O	O	O	O	R	R	R	R	R	R
Echinoplutei	O	O	O	O	O	O	O	O	O	O	O	O
Polychaete larvae	R	R	R	R	R	R	R	R	R	R	R	R

A = abundant > 150 per aliquot
C = common 20-150 per aliquot
R = rare <20 per aliquot
O = absent from aliquot

Date	12 Oct. 1968		20 Dec. 1968		26 Jan. 1969		14 Mar. 1969		4 Apr. 1969		2 June 1969	
Plankton Tow	7		7		7		7		7		7	
Aliquot	1	2	1	2	*1	2	1	2	1	2	1	2
Calanoids												
Acartia spinata	0	0	0	0		0	0	0	0	R	0	0
A. tonsa	C	C	0	0		C	R	R	C	C	0	0
Acartia spp. juveniles	C	C	R	R		0	R	R	0	0	R	R
Labidocera scotti	0	0	0	0		0	0	0	0	0	0	0
L. mirabilis	R	R	0	0		0	0	0	0	0	0	0
Labidocera spp. juveniles	0	0	0	0		0	0	0	0	0	0	0
Clausocalanus furcatus	0	0	0	0		0	0	0	0	0	0	0
Clausocalanus spp. juveniles	0	0	C	C		0	R	R	0	0	0	0
Paracalanus crassirostris	A	A	R	R		A	A	A	C	C	0	0
P. parvus	C	C	0	0		R	R	R	R	R	0	0
Paracalanus spp. juveniles	0	0	R	R		0	0	0	0	0	0	0
Temora turbinata	R	R	0	0		0	0	0	0	0	0	0
Calanopia americana	0	0	0	0		R	0	0	R	R	0	0
Pseudodiaptomus sp.	0	0	0	0		0	0	0	0	0	0	0
calanoid nauplii	R	R	C	C		C	C	C	0	0	C	C
Cyclopoids												
Oithona spp.	A	A	C	C		A	A	A	C	C	C	C
Corycaeus spp.	0	0	R	R		R	R	R	0	0	0	0
Oncaea sp.	0	0	C	C		0	0	0	0	0	R	R
Harpacticoids												
Microsetella rosea	0	0	0	0		0	0	0	0	0	0	0
Euterpina sp.	0	0	0	0		R	R	R	R	R	0	0
Macrosetella sp.	0	0	R	R		0	0	0	0	0	0	0
harpacticoid nauplii	R	R	C	C		A	A	A	C	C	C	C
Crustacean larvae												
crab larvae	R	R	0	0		0	R	R	0	0	0	0
shrimp larvae	0	0	0	0		0	0	0	0	0	0	0
barnacle nauplii	R	R	0	0		R	A	A	C	C	0	0
barnacle cyprids	0	0	0	0		0	0	R	0	0	0	0
Amphipods	0	0	0	0		0	0	0	R	0	0	0
Tanaids	0	0	0	0		0	0	0	0	0	0	0
Larvaceans	0	0	C	C		R	R	R	R	R	0	0
Chaetognaths	R	R	0	0		R	R	R	0	R	0	0
Echinoplutei	0	0	0	0		0	0	0	0	0	0	0
Polychaete larvae	0	0	0	0		0	0	R	0	0	R	R

A = abundant > 150 per aliquot
C = common 20-150 per aliquot
R = rare <20 per aliquot
0 = absent from aliquot

* Aliquot lost

APPENDIX E

MANN-WHITNEY U-TEST CALCULATIONS

Formula for the Mann-Whitney U-Test

The formula for the Mann-Whitney U-Test is:

$$U = n_1 n_2 + \frac{n_1(n_2+1)}{2} - R_1$$

n_1 = The number of samples in the effluent plume environment.

n_2 = The number of samples in the control environment.

R_1 = The sum of the ranked counts.

$$z = \frac{U - \mu_u}{\sigma_u}$$

μ_u = The mean value of U.

σ_u = The standard deviation of the values of U.

The counts from the 24 sampled aliquots of the disks were combined into 2 independent series of random samples, one for the discharge and the other for the control. The counts for two sessile organisms (a barnacle and bryozoan), were used in this test. The data from each location were combined into a single ordered series and tested (see following two pages). The performed tests indicated that there was a significant difference between the two areas as far as these organisms were concerned. Barnacles were more common in the discharge area, and bryozoans were more common in the control area.

Mann-Whitney U-Test for Balanoid Barnacles on Settlement Disks

Date	27 January 1969	31 March 1969	2 June 1969
Material	Concrete	Rubber	Concrete
Discharge Counts	21,21,3,14	10,6,25,10	135,122,106,132
Control Counts	8,8,0,3	0,0,6,16	3,4,16,17

Ranked Counts	0	0	0	3	3	3	4	6	6	8	8	10	10	14	16	16	17	21	21	25	106	122	132	135
Area	Co	Co	Co	Co	Di	Co	Co	Di	Co	Co	Co	Di	Di	Di	Co	Co	Co	Di	Di	Di	Di	Di	Di	Di

Di=Discharge Co=Control

Rank in Discharge	5	8	12	13	14	18	19	20	21	22	23	24	Sum of Ranks=199
Rank in Control	1	2	3	5	5	7	9	10	11	15	16	17	Sum of Ranks=101

$$U=(12)(12) + \frac{(12)(13)}{2} - R_1$$

$$= 144 + 78 - R_1$$

$$U_{discharge}=144 + 78 - 199=23$$

$$U_{control}=144 + 78 - 101=121$$

$$Z_{discharge}=\frac{23-72}{17.3} = - \frac{49}{17.3} = -2.89$$

$$Z_{control}=\frac{121-72}{17.3} = \frac{49}{17.3} = 2.89$$

Value of 2.89 refutes the Null Hypothesis that there is no significant (0.05 level of significance) difference between the discharge and the control.

Mann-Whitney U-Test for Cheilostomatid Bryozoans on Settlement Disks

Date	27 January 1969	31 March 1969	2 June 1969
Material	Concrete	Rubber	Concrete
Discharge Counts	4,10,23,26	3,3,34,28	0,0,0,0
Control Counts	6,2,75,72	38,44,104,48	7,4,1,4

Ranked Counts	0	0	0	0	1	2	3	3	4	4	4	6	7	10	23	26	28	34	38	44	72	75	104	118
Area	Di	Di	Di	Di	Co	Co	Di	Di	Di	Co	Co	Co	Co	Di	Di	Di	Di	Di	Co	Co	Co	Co	Co	Co

Di=Discharge   Co=Control

Rank in Discharge	1	2	3	4	7	8	10	14	15	16	17	18	Sum of Ranks = 115
Rank in Control	5	6	10	10	12	13	19	20	21	22	23	24	Sum of Ranks = 185

$$U=(12)(12) + \frac{(12)(13)}{2} - R_1$$

$$=144 + 78 - R_1$$

$$U_{discharge}=144 + 78 - 115 = 107$$

$$U_{control}=144 + 78 - 185 = 37$$

$$Z_{discharge}=\frac{107-72}{17.3} = \frac{35}{17.3} = 2.09$$

$$Z_{control}=\frac{37-72}{17.3} = - \frac{35}{17.3} = -2.09$$

Value of 2.09 refutes the Null Hypothesis that there is no significant (0.05 level of significance) difference between the discharge and the control.

☆ U.S. GOVERNMENT PRINTING OFFICE : 1970 O - 405-031