BIOLOGICAL EFFECTS OF RUM SLOPS IN THE MARINE ENVIRONMENT

by

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FOREWORD

The Environmental Research Laboratory of the U.S. Environmental Protection Agency is located on the shore of Narragansett Bay, Rhode Island. In order to assure the protection of marine resources, the laboratory is charged with providing a scientifically sound basis for Agency decisions on the environmental safety of various uses of marine systems. To a great extent, this requires research on the tolerance of marine organisms and their life stages as well as of ecosystems to many forms of pollution stress. In addition, a knowledge of pollutant transport and fate is needed.

This report describes a three-month study of the geographical, hydrological and biological characteristics of the waters of the Atlantic Ocean on the north coast of Puerto Rico near the municipality of Arecibo, receiving water for effluents from Puerto Rico Distillers, Ltd. and of the terrestrial environment. Also described is a briefer examination of the Ensenada de Boca Vieja near San Juan, receiving water for effluents from the Bacardi Corporation's Cataño distillery. An effort was made to assess the effects of the rum effluent through a series of field investigations at and near the outfall site, and laboratory tests with several indigenous species. These were the urchin *Echinometra lucunter*; the mussel *Brachydontes exustus*; and the "coat-of-mail" shellfish *Chiton squamosus*.

Eric D. Schneider
Director, ERLN

PREFACE

Two of the largest rum distilleries in Puerto Rico discharge the waste resulting from the fermentation and distillation of molasses in the production of alcohol directly into the marine environment. The plume of waste (rum slops) is thereafter influenced by oceanographic parameters such as waves, tides, currents, and wind. Because the coastal waters are teeming with different forms of life it was necessary to determine the response of these organisms to the possible disturbing action of rum slops. Consequently, a short term research program was organized to study its impact on marine ecosystems of two sites on the north coast of Puerto Rico: Arecibo (the most intensively studied) and Palo Seco.

The study encompassed the period between May and August 1978.

ABSTRACT

During the three and a half months, between May and August 31, 1978, the staff of the Marine Ecology Division of the Center for Energy and Environment Research carried out an extensive field and laboratory study to examine the effects of rum slops (mosto in Spanish) on the marine environment. The major emphasis of the program was directed to the area east and west of the outfall of the Puerto Rico Distillers, Inc. in Arecibo, Puerto Rico. Islote, an area thoroughly studied in the past (only 6 km east of the study site), and considered essentially free of man-induced stresses was chosen as a reference ("control") area. A less intensive study was carried out off Palo Seco, Puerto Rico, where the Bacardi Corporation discharges similar wastes resulting from rum production.

It was obvious from general observations (later confirmed by the Physical Oceanography phase of the study) that the water mass at the Arecibo shore hugs the coastline and moves in a westerly direction, helped by the prevailing surf and winds. Because of the physical behavior of the plume it was decided to study the intertidal ecosystems of the region.

The biological field studies indicated that the rum slops has an adverse effect on low intertidal organisms in the immediate area around the discharge. Some organisms were impacted more severely than others, particularly some of fundamental importance in the ecosystem. The area is active and prone to change, depending on the sea condition, a fact which was considered in the interpretation of the results.

Laboratory bioassays confirmed much of the information gathered in field observations. It was surprising that the effect was noticeable at extremely low concentrations of mosto. It was also observed that rum slops at low concentrations appears to stimulate growth of some species of algae. This was observed in the field and corroborated by laboratory results.

The results of the chemical analyses of seawater indicated that the impact was not of local importance only, but could be observed several kilometers downstream from the outfall. Studies of the physical characteristics and organic composition of sediments showed them holding little organic matter. This would be expected given the coarseness typical of these high energy beaches. Consequently, it was hypothesized that the organic matter might be found in the water column. Measurements indeed showed high turbidity in the waters confirming that particulate organic matter remains in suspension.

Phytoplankton productivity measurements were not high even in the reference area, as expected in a tropical open sea environment. Measurements of primary productivity in other similar areas off Puerto Rico have yielded low values. This explains the high visibility in areas of low turbulence where there are no industrial discharges or rivers flowing out to sea.

The abbreviated studies at the Bacardi discharge site (Ensenada de Boca Vieja, a protected cove) indicated a greater impact from the rum effluent there than at the Arecibo discharge site. Bottom sediments as well as the surrounding water are apparently anoxic and hydrogen sulfide bubbling is observed continuously. In our visits to the area, and from studies of aerial photographs, it was observed that the current pattern in the bay is erratic. Under these circumstances anoxic water laden with organic matter is transported to other regions, thus exposing more ecosystems to conditions deleterious to their ecological functions. Much could probably be learned from a long-term study in this cove.

An assessment of the major geographical features was conducted concurrently with the rum slops studies. The survey characterized Arecibo as a comfortable place to live, with a subhumid tropical maritime climate; beaches are small, seas are traditionally rough, and bold cliffs dominate a considerable portion of the waterfront. Due to the extensive marsh to the east of the city, Arecibo is developing mostly towards the west. Fishing constitutes a minor part of the economic activities of the area and marine sports are totally absent.

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SECTION I

MOSTO FIELD STUDIES

INTRODUCTION

Nearshore marine communities are affected by a number of natural and man-associated environmental factors. Certainly it is difficult to determine the effect of any given variable, such as mosto without determining and separating out the effects of other environmental variables. The effect of a given factor, moreover, may be manifested through its interaction with other environmental variables and would have to be interpreted in this regard. With these considerations in mind the field studies were designed to enable a baseline overview of the ecology of nearshore marine communities. Within this conceptual framework an attempt was made to determine the effect of mosto.

Partly due to the broad conceptual scope of such a study, results are usually in the form of correlational evidence; causal mechanisms are largely a matter of interpretation. This is the case in this particular instance. Field tests coupled with the appropriate laboratory work, however, can identify the nature of the underlying causal mechanisms. Thus, the field and bioassay studies are complementary in nature; each of which deals with different aspects of the same problem. The bioassays substantiate findings of the field studies, while the field studies provide a basis to interpret the ecological ramifications of the bioassays.

Emphasis was placed on the rocky intertidal zone in this study because the maximum impact of mosto occurs in this region. (See section on Physical Oceanography.) It was not possible to select a reference site which differed only in the presence of mosto. Consequently, a number of intertidal areas were surveyed in order to determine the effects of other environmental factors. The effect of mosto was then evaluated by separating out the influences of other environmental variables.

In addition to the rocky intertidal habitat, preliminary surveys were made of subtidal algal, subtidal and tidepool fish, and sandy beach macro-invertebrate populations.

STUDY SITES

Locations of the field sties and communities sampled are shown in Figures 1 and 2*.

*For figures refer to original report.

Figure 1. Benthic stations

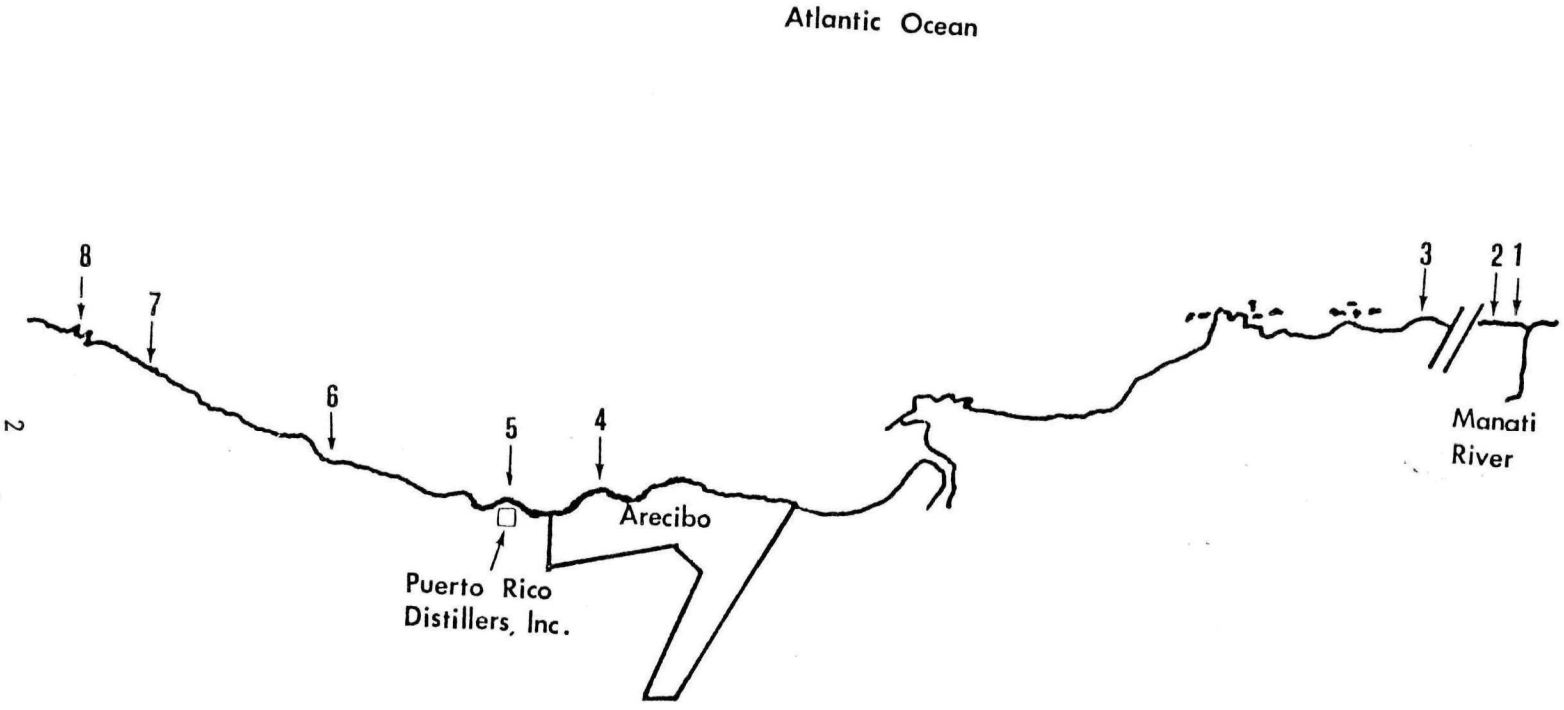
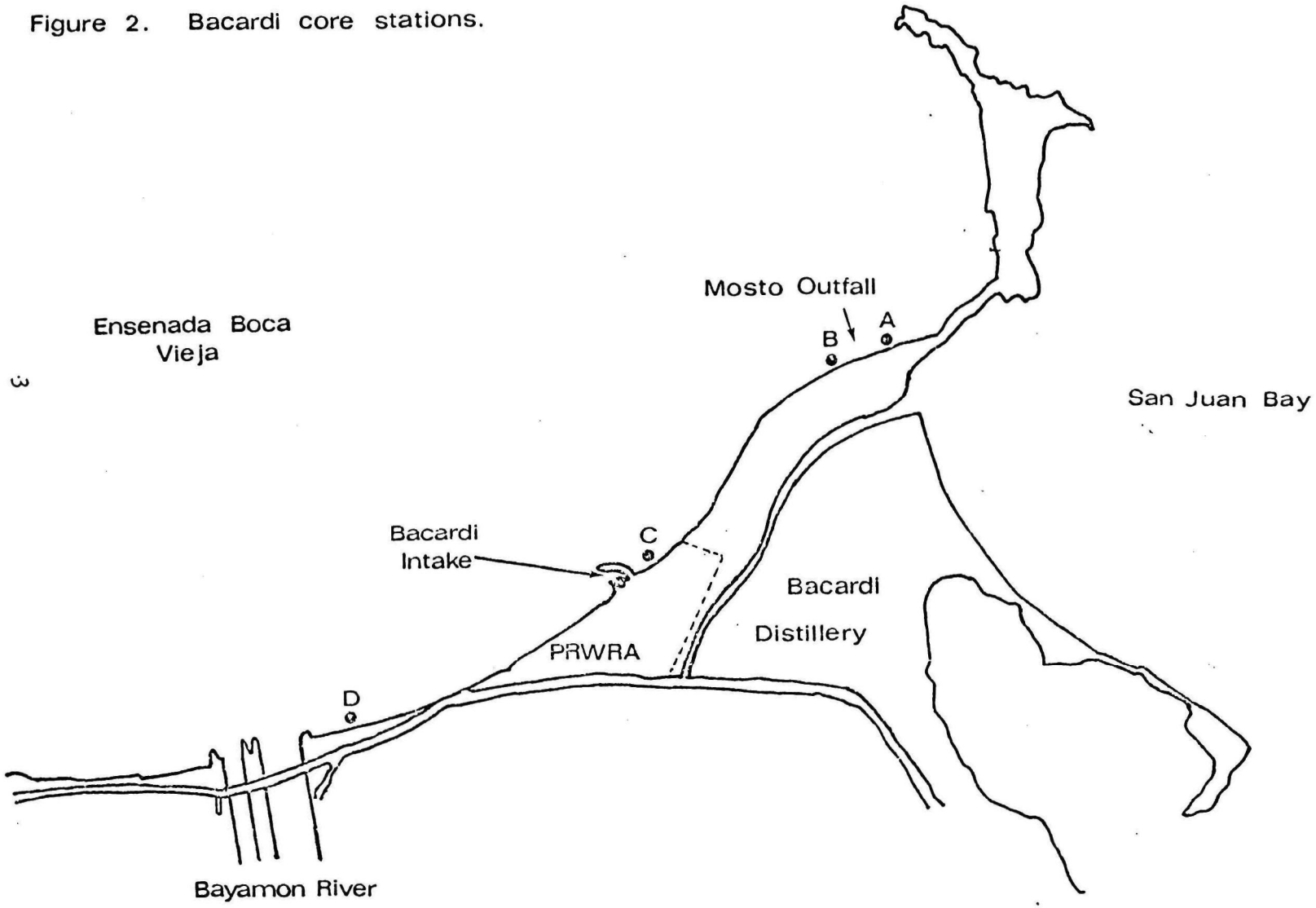


Figure 2. Bacardi core stations.



The Arecibo beachfront near the rum effluent outfall is influenced by a number of natural and man-associated activities including freshwater from rivers and storm drains, landfill operations and domestic sewage. Consequently, the sites were chosen so that the possible effect of these factors at the test site could be evaluated. In order to reduce sampling variability due to natural environmental factors, the sites were chosen for sampling that possessed physical characteristics, such as beach contour, relief, and exposure to wave action, etc. similar to the test site.

FIELD METHODS

Sandy Beach Invertebrates

Samples were obtained with a 16 cm (i.d.) corer and washed through a 2.0 mm sieve. Organisms were picked out and preserved in formalin. Fifteen cores were usually taken in the wash zone.

Fish Observations

The presence and relative abundance of subtidal and tidepool fish were noted whenever possible at the test site. No fish collecting was attempted due to its possible effect upon subsequent observations. Attempts were made to monitor specific locales (i.e., the same tidepools, subtidal rock formations, etc.). However, during the course of the study, sand had buried many of the tidepools and subtidal rock formations used for the observations.

Rocky Intertidal Organisms

The extent of each sampling site was delimited at the upper edge of the high intertidal and two points were selected using a random number table. Transects were then laid from these points to the low intertidal zone. These transects were then divided into appropriate intertidal zones, and one point was randomly selected in each zone (i.e., a stratified random sampling scheme). Samples were taken with the aid of a 1/16 m^2 quadrat and were preserved in formalin.

LABORATORY METHODS

The samples were washed through a 0.5 mm sieve, and preserved in a 4% formalin solution with rose bengal added as a stain. The samples were then sorted and the organisms identified to the lowest feasible taxonomic category. The wet weights of the algae and larger invertebrates were recorded. Algal identifications were confirmed by an algal taxonomist. The numbers of smaller invertebrates were also recorded.

RESULTS AND DISCUSSION

Sandy Beach Invertebrates

Samples from all sites indicated low numbers of species and individuals (with one exception) in all the sandy intertidal stations (Table 1). This feature is commonly attributed to the harshness and instability of this environment (Glynn, 1964; Ricketts and Calvin, 1969). In addition, Davis (1975) found low species diversity and abundances in subtidal as well as intertidal habitat in a nearby pristine area (Islote).

A total of two species, the clam *Donax denticulatus* and a crab *Lepidopa scutellata*, and eight individuals were found in 60 cores taken in the Arecibo area.

No organisms were found at Bacardi stations A and B located about 100 meters east and west, respectively, of the mosto outfall. One polychaete species, *Scolelepis squamata*, with average densities of 160 individuals per core was found at station C. The highest number of species (four) was found at station D, which was furthermost from the outfall.

Due to the rarity of individuals, a Poisson distribution was used to calculate confidence limits of abundances (except for Bacardi station C). As can be seen, many of the comparisons of species abundances are not statistically significant (i.e., although 2 individuals of *Emerita* were found at Bacardi station D and none at station A, this difference is not statistically significant at the 0.05 level). This lack of significant differences can be attributed to the low natural abundances of organisms in this habitat. The detection of statistically significant difference, if any, would require examination of an inordinantly large number of samples.

Field Observations

Fish species observed at the Arecibo test site are listed in Tables 2 and 3. Subtidal fish observations were severely limited by adverse surf conditions. The number of fish species observed subtidally did not appreciably change before and during the period of mosto discharge. Fish observations were made below or at the edge of the mosto plume due to low visibility within the plume itself. Nevertheless, these results show the fish will at least remain in the vicinity of the mosto plume.

The presence of tidepool fish species was apparently adversely affected by mosto (Table 3). The number of tidepool fish species declined from about 12 before discharge resumed to 2 thereafter. This difference is significant as the .006 level (Fisher Exact Probability, one-tailed). (One of these species, juvenile mullet *Mugil*, was largely confined to a tidepool apparently fed by freshwater springs.) This change was quite drastic in two cases: the sargeant major *Abudefduf saxatilis* and the surgeon fish *Acanthurus sp.* Literally, hundreds of individuals of both species were observed in the tidepools prior to discharge. After discharge both species were either absent or represented only by a few individuals (<10) when present.

TABLE 1. Numbers of Individuals and 95% C.L. per 15 Cores. *Individuals per Core, Confidence Limits Derived from +-Statistics.

	Arecibo-Test 5 July	Arecibo-Control 5 July	Arecibo-Test 18 July	Arecibo-Control 18 July	Bacardi Sta.A	Bacardi Sta.B	Bacardi Sta.C	Bacardi Sta.D
Donax denticulatus	0	0	2	0	0	0	0	1
95% C.L.	0-3	0-3	.2-7.2	0-3	0-3	0-3	0-3	.03-5.1
Emerita puertoricensis	0	0	0	0	0	0	0	2
95% C.L.	0-3	0-3	0-3	0-3	0-3	0-3	0-3	.2-7.2
Lepidopa scutellata	2	2	0	2	0	0	0	6
95% C.L.	.2-7.2	.2-7.2	0-3	.2-7.2	0-3	0-3	0-3	2.2-13.0
Scolelepis squamata	0	0	0	0	0	0	160*	4
95% C.L.	0-3	0-3	0-3	0-3	0-3	0-3	70-250*	1.1-10.2
Σ Individuals	2	2	2	2	0	0	2400	13
Σ Species	1	1	1	1	0	0	1	4

TABLE 2. Subtidal Fish Observations.

	4 MAY	23 MAY	14 JUNE
Clupeidae			
Harengula humeralis	+		+
Grammistidae			
Rypticus sp.		+	
Carangidae			
Caranx sp.		+	+
Lutjanidae			
Lutjanus synagris		+	
Pomadasyidae			
Anisotremus surinamensis	+	+	+
Haemulon sp.	+	+	+
Gerreidae			
Gerres cinereus	+	+	
Sciaenidae			
Umbrina coroides	+	+	
Chaetodontidae			
Chaetodon striatus	+		
Pomacentridae			
Abudefduf saxatilis	+	+	+
Abudefduf taurus			+
Eupomacentrus variabilis	+	+	+
E. leucostictus			+
Labridae			
Thalassoma bifasciatum	+	+	+
Bodianus rufus		+	
Scaridae			
Unid. parrotfish	+	+	+
Acanthuridae			
Acanthurus sp.	+	+	+
Acanthurus coeruleus	+		+
Σ Species	12	13	12

TABLE 3. Tide Pool Fish Observations.

	May 3	May 9	May 19	May 23	May 29	May 30	June 2	June 6	June 14	July 4	July 5
Opichthidae											
Chlorhinus svenson							+*				
Carangidae											
juv. jack	+	+	+								
Pomadasyidae											
juv. grunt	+										
Kyphosidae											
Unid. chub		+									
Chaetodontidae											
Chaetodon striatus	+	+	+	+							
Pomacentridae											
Eupomacentrus leucostictus	+	+									
E. variabilis	+	+	+	+							
Abudefduf saxatilis	+	+	+	+	+	+	+*			+	
A. taurus	+		+		+	+	+*			+	+
Mugilidae											
juv. mullet	+	+		+	+	+		+	+	+	+
Labridae											
Thalassoma bifasciatum	+	+	+	+							
Unid. wrasse		+									
Clinidae											
Paraclinus fasciatus							+*				
Blennidae											
Unid. blenny	+	+	+	+	+	+	+	+	+	+	+
Blennius cristatus							+*				
Gobiidae											
Bathygobius sp.							+*				
Acanthuridae											
Acanthurus sp.	+	+	+	+	+						
Acanthurus coerulus	+	+	+	+		+					

TABLE 3. (continued)

	May 3	May 9	May 19	May 23	May 29	May 30	June 2	June 6	June 14	July 4	July 5
Bothidae											
Bothus lunatus			+								
Balistidae											
juv. filefish			+								
Σ Species	12	12	11	8	5	5	7	2	2	4	3
			Mosto dumping starts				Fish kill			Mosto dumping stops	

*Dead or exhibiting abnormal behavior.

Coincident with discharge, however, sand was being transported into the test area until by July many of the tidepools used for observations were completely sanded in. Thus, it is possible that the decrease in fish species diversity is at least partially due to the elimination of suitable habitat. Nevertheless, two considerations indicate that this factor alone was not responsible for this decrease. First, in the few remaining tidepools a slight increase in species diversity was noted after the interruption in discharge, and during the period at maximum sand cover. Second, and more importantly, a fish and invertebrate kill was observed at the study site on June 2, 1978 (about 10 days after the commencement of discharge). The slight increase in species diversity (see Table 3) on this date is attributable to dead (or apparently dying) cryptic species such as the worm eel *Chlorinus* and the clinid *Paraclinus fasciatus* which would not be observed under normal conditions.

A fish kill was also observed at the Palo Seco Bacardi site on July 7, 1978. In this instance large numbers of the anchovy *Anchoa sp.* were observed either dead or dying. Also included were a few individuals of the half-beak *Hemiramphus brasiliensis*. (Fish kills or evidence thereof were noted on all three occasions when this site was visited.)

Rocky Subtidal Habitat

Aspects of the Puerto Rico northshore subtidal habitat have been studied by Davis (1975), Black and Veatch *et al.* (1975) and Yoshioka (1975a). In general, shallow subtidal areas (30 m in depth) are dominated by algal communities. This is probably a reflection of high wave action and its accompanying sand movements which prevent the establishment of many corals, sponges, and gorgonians. Significantly, communities dominated by the latter organisms and similar assemblages found in the more moderate south coast environment, can be found in areas protected from wave action as Tortuguero (Yoshioka, 1975a).

Qualitative samples of the subtidal algal community at the test site before the period of mosto discharge and reference station 3 are given in Table 4A. A large number (>20) of algal species were found at both sites. Unfortunately, a comparison with the algal community after discharge could not be made because sand had completely buried the substrate in the interim. Thus the effect, if any, of mosto on this subtidal algal community could not be evaluated.

ROCKY INTERTIDAL HABITAT

A-Before-After Comparisons

Paired samples were taken within a few centimeters of each other before and after mosto discharge at the test site and at reference station 3 (see Fig. 1). The "before" samples were taken about 1.5 months after the previous discharge period had ceased. Results are shown in Tables 4A and 4B.

TABLE 4A. Intertidal Samples Taken at the Test Site Before and After Mosto discharge

	STATION 1					
	Transect 1-B		Transect 2-B		Transect 1-W	
	Before	After	Before	After	Before	After
ALGAE						
Ulva	0	Tr	0.6	Tr	1.4	0
Padina	27.2	0	4.6	0	0	0
Chaetomorpha	12.3	Tr	29.8	Tr	105.6	0
*Cladophora**	Tr	Tr	19.6	0	23.6	0
Hypnea	0	0	1.2	0	4.75	0
Gracilaria	Tr	Tr	1.0	0	0	0
Caulerpa	0	0	19.29	Tr	0	0
Amphiroa	0	0	Tr	0	0	0
Bryocladia	0	0	Tr	0	1.25	0
Enteromorpha	0	0	0	0	0	Tr
INVERTEBRATES						
Fissurella sp.	10	0	4	0	0	0
Polychaets**	25	0	100	0	58	0
Gastropods	28	1	4	0	62	0
Amphipods	11	3	33	0	52	0
Pelecypods	170	16	57	9	112	0
Crabs	0	0	2	0	0	0
Chiton	0	0	0	0	8	0

*Includes *Centroceras* and *Polysiphonia*

**Includes nematodes

ALGAE in g wet weight

INVERTEBRATES in numbers of individuals

Tr = Trace

TABLE 4B. Intertidal Samples at Station 3 Before and After Mosto

	STATION 3							
	Transect 1-B		Transect 2-B		Transect 1-W		Transect 2-W	
	Before	After	Before	After	Before	After	Before	After
ALGAE								
Sargassum	31	28.3	55.4	24.6	21.9	Tr	87.5	14.6
Padina	Tr	Tr	.1	0	.4	Tr		
Laurencia	6.8	Tr	97	70.2	1.4	Tr	121.2	111.3
Cladophora	78	31.6	21.9	0	42.6	Tr	0	Tr
Dictyopteris	Tr	0	0	0				
Halymenia	3.2	7.4	0	0				
Spyridia	Tr	0	0	0	3.6	0	0	Tr
Enantiocladia	6.6	0	0					
Jania	Tr	0	0	0				
Dictyota	0	Tr	0.1	0	.4	0	6.7	0
Anadyomene	0	Tr	Tr	Tr	0	Tr	2.0	Tr
Champia	0	0	Tr	0				
Digonia	0	Tr	0	0	184.2	170.2		
Valonia	0	Tr	0	0				
Stypopodium	0	0	0	0				
Bryothamnion	0	0	0	0	18.7	0		
Heterosiphonia	0	0	0	0	8	0		
Caulerpa	0	0	0	0	.5	0		
Amphiroa	0	0	0	0	.7	0		
Coelothrix	0	0	0	0	.1	0		
Cladophoropsis	0	0	0	0			0	Tr
INVERTEBRATES								
Echinometra	21	11	19	10	1	0	0	17
Isostichopus	1	3	2	2	1	0	0	
Fissurella	2	0	0	0	0	4	1	1
Polychaets	50	16	168	9	100	17	84	34
Gastropods	100	281	21	23	93	910	16	21
Amphipods	133	27	267	10	382	59	150	67
Chiton	3	0	0	0	0	1	0	1
Sipunculids	9	11	0	0	0	0	0	0
Pelecypods	0	2	0	0	10	2	0	1
Crabs	0	0	0	0	0	10	5	1

Only the low intertidal break and wash zones were considered since sand had covered the sampling sites in the mid and upper intertidal zones during the period of discharge. The scarcity of large individuals of many upper intertidal species as the gastropods, *Nerita*, *Littorina*, and *Tectarius*, at the test site may be due to this factor rather than mosto. (Seasonal mortality due to sand cover may prevent the survival and growth of individuals of these species.) Vermeij and Porter (1971) have discussed the importance of sand movement on intertidal mollusk assemblages. Thus, as with the rocky subtidal habitat the overwhelming seasonal effect of this natural environmental factor prevented an evaluation of the effects of mosto on this community.

Thirty-three of the 36, or 92%, of the paired comparisons which showed a change at the test site decreased in abundance after the commencement of discharge. Two instances where abundances increased involve *Enteromorpha*, a colonizing species characteristic of disturbed conditions. Similarly, 67% of the comparisons at the reference site (station 3) showed decreased abundance, suggesting a general seasonal decline throughout the area. However, the decline at the test site was significantly greater than the reference, ($P<.05$, Chart 4, Tate and Clelland 1959), strongly suggesting an additional adverse effect of mosto on this community. This interpretation is strengthened by an observation of a mass mortality on June 2, 1978. Polychaetes, limpets, echinoderms, crabs, etc. were found either dead or exhibiting abnormal behavior (limpets turned upside down and unable to attach to the substrate, crabs lethargic, polychaetes crawling out of rocks, etc.). A list of species found either dead or moribund on this date is given in Table 5. This interpretation is further reinforced by field and laboratory bioassay tests.

B-Comparison with Other Sites

Although the effect of mosto at the low intertidal zone at the test site is clear-cut and dramatic (Tables 3, 4A, 5), other considerations are warranted. First, the test site receives the maximum impingement of mosto so it is quite possible that this deleterious effect is highly localized. Second, the effect may be short lasting and the intertidal community may recover completely during those periods when discharge ceases. Third, do the "before" samples represent an unnatural or altered intertidal condition, and if so, is mosto or some other environmental variable responsible?

In an effort to evaluate these considerations, the samples taken from the test site were compared to those taken in other areas. In the first comparison, a cluster analysis using Orlici's (1967) standardized distance as a measure of similarity was used. Wet weight biomass was used to measure abundances of the species. Results for the samples taken from the break zone are shown in Figure 3. Communities from stations 3,8,4,7, and 2 show a high degree of similarity. Stations 6,1, and 5 (the test site) are highly dissimilar from other stations. The similarity between replicates taken at these stations indicate that these differences are real and not attributable to sampling variability. Station 6 is located about 2.5 km downstream (west) of the mosto outfall and station 1 is located about 400 m west of the mouth of the Manatí River.

TABLE 5. Some of the species observed in a fish and invertebrate kill in tidepools at the nearest rocky point downstream from the mosto discharge site, on June 2, 1978.

INVERTEBRATES

Class Polychaeta (marine worms)
- Family Amphinomidae
  - *Hermodice sp.*
- Family Eunicidae
  - 2 unidentified species
- Family Sabellidae
  - *Branchiomma sp.*

Class Gastropoda (snails)
- *Acmaea antillarum*
- *Fissurella nimbosa*
- *Fissurella angusta*
- *Fissurella barbadensis*
- *Littorina ziczac*
- *Nitidella laevigata*
- *Thais rustica*

Class Pelecypoda (bivalves)
- *Brachidontes exustus*

Class Crustacea (shrimps and crabs)
- *Panopeus occidentalis*
- *Portunus sp.*
- *Microphrys bicornutus*
- 1 unidentified caridean shrimp

Class Echinoidea (sea urchins)
- *Diadema antillarum*

FISH
- *Abudefduf saxatilis*
- *Abudefduf taurus*
- *Chlorinus sp.*
- *Paraclinus fasciatus*

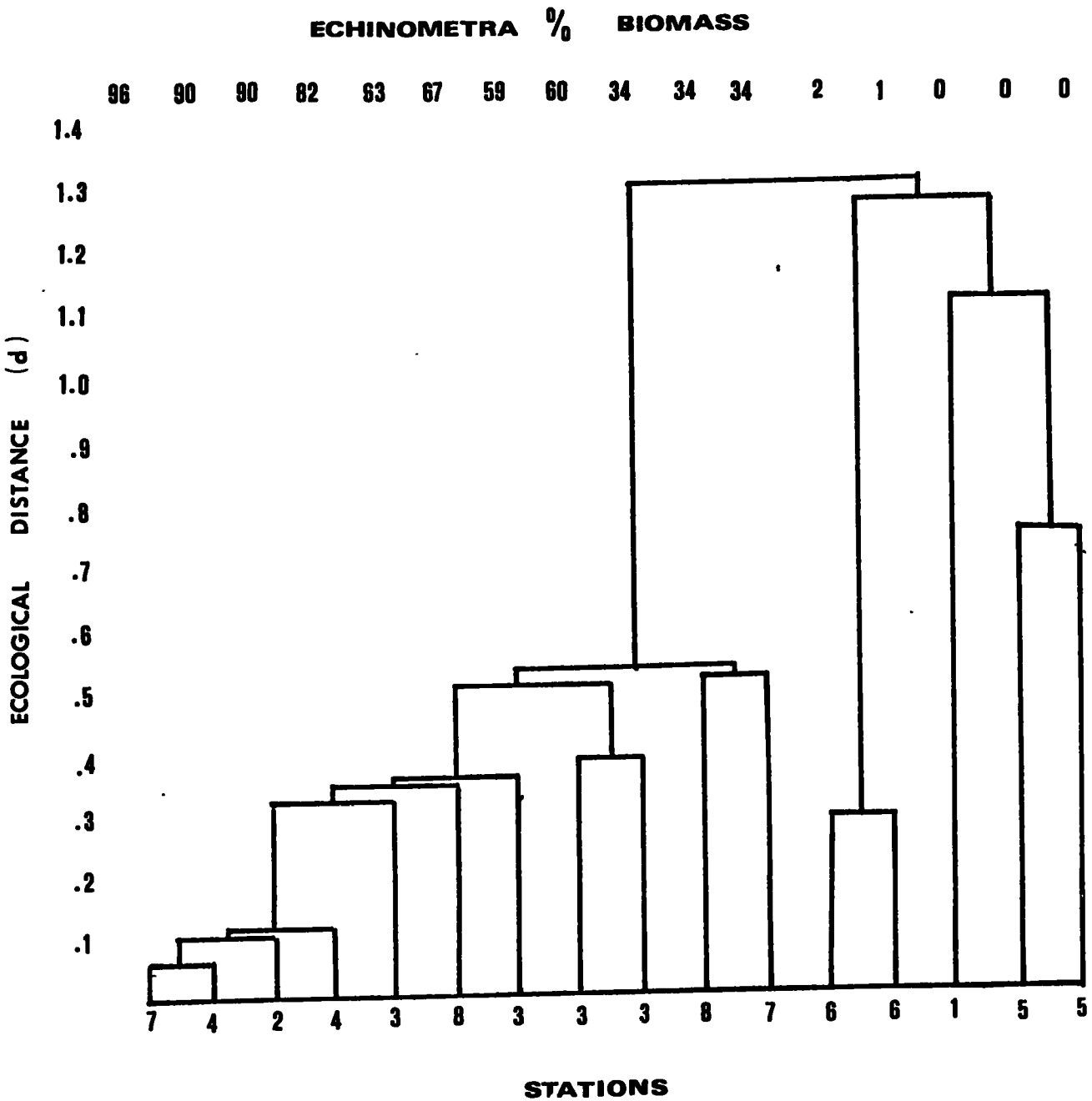


Figure 3. Cluster analysis of low intertidal samples using Orlici's (1967) standard distance as a measure of similarity. Percent of biomass accounted for by *Echinometra* are shown in the upper part of the diagram.

As can be seen in Figure 3, the station clusters closely parallel the relative abundance of the sea urchin *Echinometra lucunter* (stations 7,4,2,8, and 3 have high similarity and similarly high abundances of *Echinometra*). This is to be expected since the abundant species carry the most 'weight' in determining station similarity.

Stations with high *Echinometra* abundances probably represent what could be termed a well-developed, mature intertidal community. The biota at other stations probably indicate disturbed conditions. Station 1 is probably heavily influenced by the Manatí River. Station 2 only about 100 m west of station 1 has high *Echinometra* populations indicating that the riverine influence is highly localized. The small or nonexistent urchin populations at stations 5 and 6 (including areas in between which were inspected visually) cannot be attributable to a water borne factor (i.e., chemicals discharged by the Arecibo River) originating far upstream at station 5 since high urchin populations are found at station 4 located only about 700 m east.

The factor(s) limiting *Echinometra* along this intertidal zone probably originate(s) locally. Certainly mosto would be a logical possibility. In addition to mosto, periodic burial by sand is a possible cause. However, since these samples were taken when sand cover was at its seasonal maximum, and since the low intertidal zone was not covered by sand during this period, this possibility is somewhat minimized. Also, field and laboratory bioassays indicated that *Echinometra* is adversely affected by mosto.

The important role played by sea urchins in tropical as well as temperate environments is well documented. Paine and Vadas (1969) found decreased algal species diversity following the removal of *Strongylocentrotus*. Kitching and Ebling (1961) reported that algal cover increased from 1 to 100% following the removal of *Paracentrotus*. Finally, Ogden *et al.* (1973) attributed the barren 'halo' around West Indian patch reefs to intense grazing by *Diadema*. In addition, urchins may increase habitat heterogeneity by excavating cavities in the substrate (Ricketts and Calvin, 1969). This feature can be readily observed at many of the sites in the present study. Paine (1976) and Abele (1974) discuss cases where habitat diversity *per se* can increase species diversity. Thus, *Echinometra* may play an important structural and functional role in the intertidal community. The low abundance or absence of *Echinometra* from the study site and for a distance about 2.5 km westward, then, represents a significant change in the structure and probable organization of the rocky intertidal communities of the north coast of Puerto Rico.

Up-Downstream Mosto Intertidal Gradient

Low intertidal rocky locales within 1000 meters upstream (east) and downstream of the outfall were visually surveyed on August 29, 1978 to verify the results of earlier studies and to gain a more detailed description of the distribution of macroscopic intertidal organisms with respect to mosto discharges.

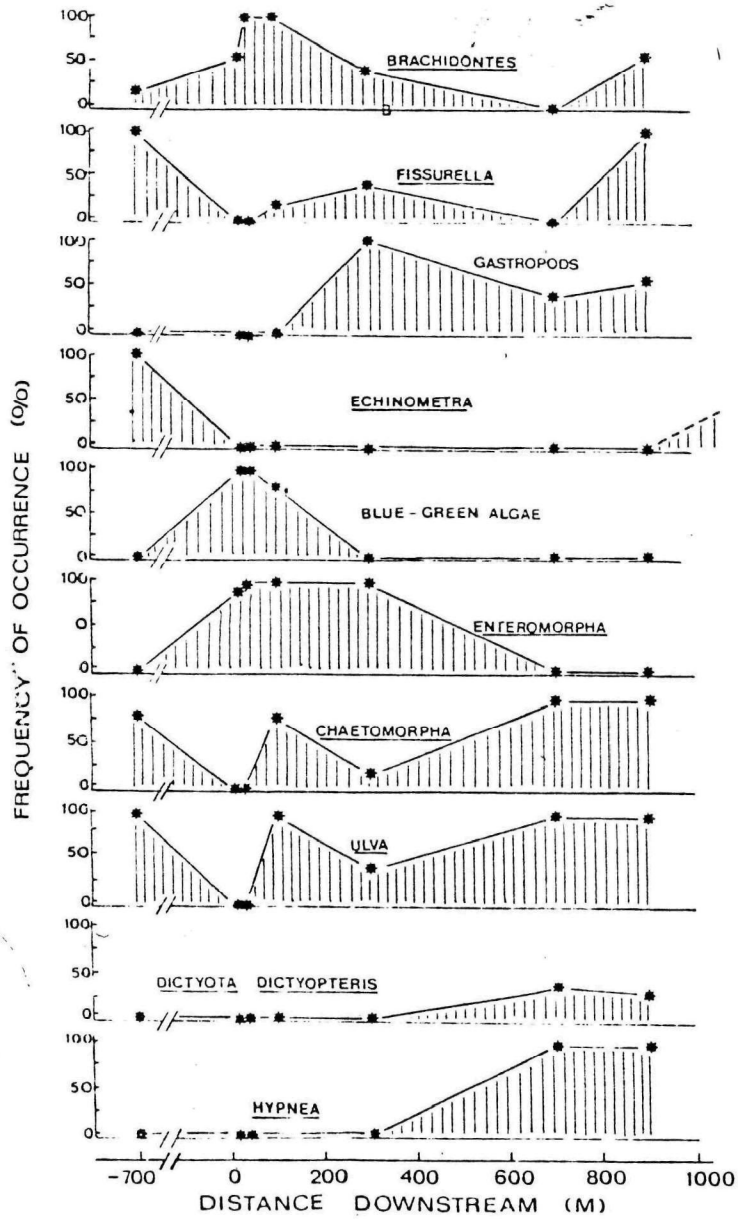
Results are shown in Table 6 and Figure 4. The lowest number of species identified occurred in the immediate area of the outfall and the highest in the stations further downstream and upstream, respectively. The number of

TABLE 6. Numbers of Species Identified in 5 Randomly Placed $1/16M^2$ Quadrats. Underlined Stations indicate no Significant Differences at the 0.05 Level.

	METERS DOWNSTREAM						
	Sta -700	Sta +20	Sta +30	Sta +100	Sta +300	Sta +700	Sta +900
Numbers of species per replicate	8	3	3	5	2	4	7
	10	1	3	5	6	4	6
	8	3	3	5	4	6	9
	8	2	3	4	3	5	6
	9	3	3	5	2	4	8
$\bar{X}$	8.6	2.4	3	4.8	3.4	4.6	7.2
Σ Species	12	3	3	6	6	7	10

Sta +20 Sta +30 Sta +300 Sta +100 Sta +900 Sta -700

Figure 4. Percent frequency of occurrence of selected taxonic categories.



species at these latter stations are significantly higher than at those near the outfall (Table 6, short-cut ANOVA, Tate and Clelland 1959).

The percent frequency of occurrence of selected taxonomic categories at these sites are shown in Figure 4. The occurrence of many species in this area is probably dependent upon the effects of the outfall. Variations in occurrence in other instances (i.e., *Fissurella* at station + 300) are probably due to differences in microhabitat.

The observations suggested that the most tolerant invertebrate is the mussel, *Brachidontes exustus*, and the most sensitive, *Echinometra*. (*Echinometra* does not occur until 2000 meters west of the outfall). These observations were confirmed by the bioassays.

The occurrence of *Enteromorpha* and blue green algae are highly suggestive of a stressed condition in the immediate area of the outfall. The only other alga occurring in this area is *Caulerpa*. Other algae begin appearing at various locales downstream of the outfall. *Ulva* and *Chaetomorpha* are apparently excluded by mosto only in the immediate area (100m) of the outfall. *Dictyota* and *Dictyopteris* do not appear for some 300 meters downstream.

Algal Assemblages

As previously discussed, the results of the cluster analysis using abundance (wet weight biomass) as a measuring criterion are largely determined by the most dominant organism, *Echinometra*. Secondary patterns may consequently be obscured. An alternative approach in the study of multispecies assemblages is an examination of patterns of presence/absence.

Presence/absence of algae in the low intertidal break and wash zones were analyzed by the Bray-Curtis (1957) polar ordination technique. Only algal species were considered since invertebrates were usually identified only to the phylum or class level. Also, algal genera rather than species were used because in some instances specimens in the samples were inadequate to permit species identifications.

The index of similarity used was

$$S.I. = \frac{C}{(N_a \; N_b)}$$

Where C = Number of species in common
N_a = Number of species in sample a
N_b = Number of species in sample b

Results are shown in Figure 5. The ordination of stations ranges from samples taken at the test site after discharge to station 3. The frequency of occurrence of selected algal species relative to this gradient is shown in Figure 6, and is strongly suggestive of a successional or developmental sequence. For instance, the algae present at station 5 during the discharge period are indicative of a highly disturbed condition at the initial stages

Figure 5. Bray-Curtis (1957) ordination of the low intertidal algal flora.
W = wash zone B = break zone

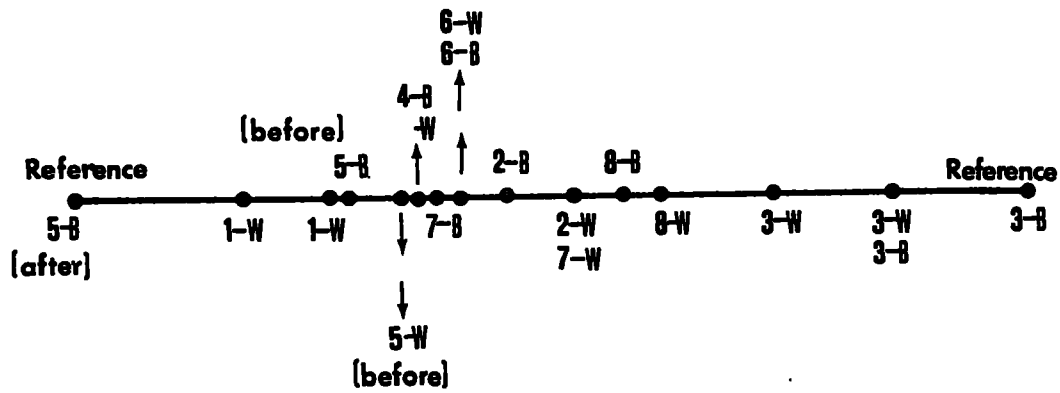
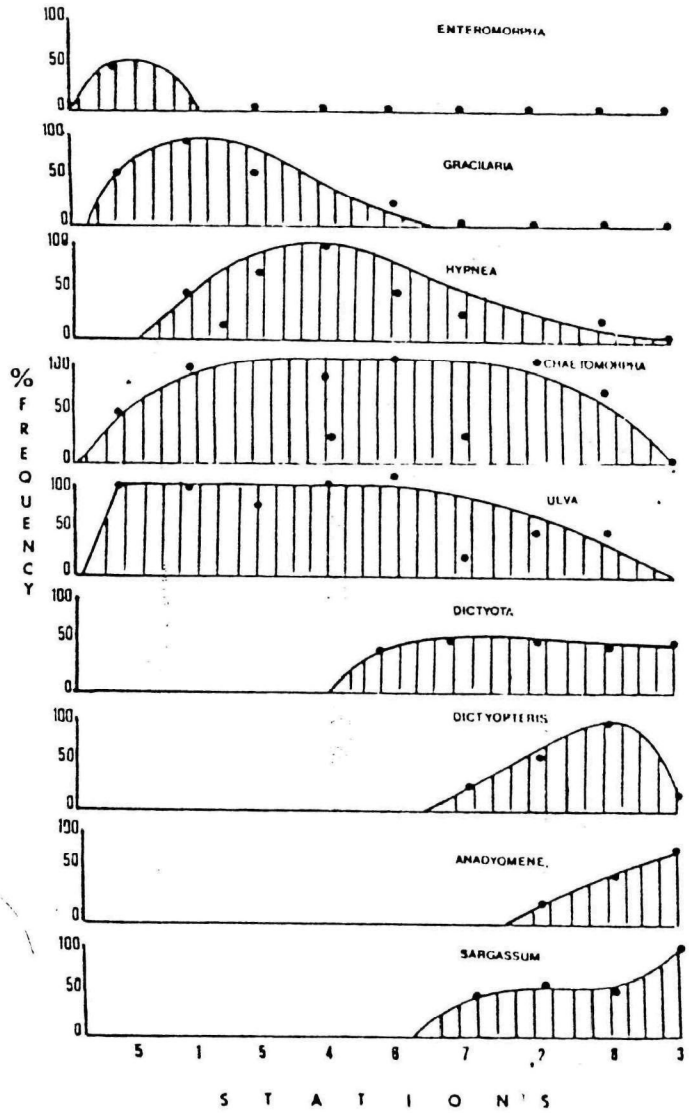


Figure 6. Frequency of occurrence of selected algal species. The sequence of stations was determined by the Bray-Curtis ordination technique (Fig. 5).



of colonization. The algae at station 1 would represent a community at a somewhat later stage of colonization and so on. Finally, the flora at station 3 would be representative of a mature community. The algae at station 5 before the discharge period would then represent an intermediate stage of community succession. These results would be in agreement with those based on the cluster analysis.

The Bray-Curtis method provides an additional insight into the ecological situation at the test site. Algal species found at the test site prior to the discharge period are probably characteristic of nutrient-rich conditions. The similarity with species found at station 4 which is located upstream of the mosto discharge suggests sources of pollution (probably domestic sewage) other than mosto. Unfortunately, nutrient levels were not monitored during this study.

In conclusion, the results of the Bray-Curtis ordination method suggest a highly disturbed algal community during the period of mosto discharge. This effect is relatively short-lived; the algal assemblage 1 1/2 months after discharge ceases is similar to those in sites in the vicinity that are not exposed to mosto. However, this 'background' algal assemblage is suggestive of other sources of pollution (nutrient enrichment).

SUMMARY

1. Mosto has an adverse effect on rocky low intertidal organisms in the immediate area of the discharge. This contention is supported by (1) observation of a mass mortality, and (2) comparison of samples taken before and after dumping.

2. Mosto appears to have an effect over a large area (2.5 km) due to its adverse effect on the sea urchin, *Echinometra lucunter*, an ecologically important species.

3. Algal distributions indicate that the study site is affected by sources of pollution other than mosto.

4. Mosto discharge apparently has no effect on sandy intertidal organisms at Arecibo, and an adverse effect at Palo Seco. However, the low natural abundances of organisms in this habitat make the detection of statistically significant differences difficult.

5. No adverse effect on subtidal fish life was observed at Arecibo although a fish kill was observed at the Palo Seco area.

6. Effects on rocky subtidal or high intertidal habitats, if any, could not be determined due to the effects of sand movement.

RECOMMENDATIONS

1. Due to lack of a previous data base, much of the present study has been devoted to gathering baseline data on the north coast intertidal zone. The effect of mosto on this habitat has been interpreted in this regard. At this stage, a longer term and more detailed study should be done in the outfall area and for a distance about 3 km west to verify the results of this study. In particular, distributional gradients of intertidal organisms downstream from the discharge site should be examined in regard to discharge and no-discharge periods. Also, the complicating effect of sand movement should be examined.

2. A separate study should be conducted in the Palo Seco area. The marine environments of the Arecibo and Palo Seco sites are quite dissimilar, thus the results from one area may not be applicable to the other.

APPENDIX A

Bray-Curtis Polar Ordination

The Bray-Curtis polar ordination technique is one of a fairly large number of multivariate techniques. Pielou (1977) and Poole (1974) provide reviews of the subject. Unfortunately, at present there is no general consensus as to which of these techniques is most appropriate for biological data. For instance, the results of the mathematically sophisticated Principal Component Analysis are often difficult to interpret biologically.

Perhaps the only valid criteria by which to judge the usefulness of a particular technique is by the biological insights it provides into the ecological system being examined. Whittaker and Gauch (in Tuxen, 1972) after comparing several ordination techniques recommend the use of the Bray-Curtis technique because of its biological interpretability.

Bray-Curtis (1957) devised their polar ordination technique to study the upland forest communities of Southern Wisconsin. This technique has consequently been widely applied by terrestrial plant ecologists. However, its application in marine ecological studies has been minimal.

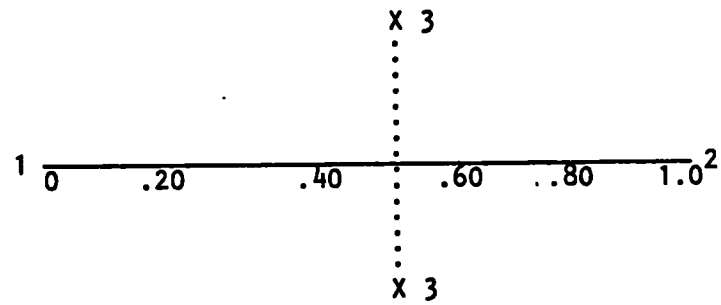
For a complete explanation of the Bray-Curtis polar ordination technique the reader is referred to Bray-Curtis (1957) or Poole (1974). Briefly, similarities are first calculated between all possible pairs of stations (samples). Relative abundance, presence/absence, or absolute abundance data can be used to calculate these indices. Values in these indices usually range between 0 (no similarity between two stations) to 1 (two stations are completely alike). A measure of dissimilarity is then defined as one minus the similarity index (1-S.I.). An example modified from Bray-Curtis is given below.

Station No.	1	2	3	4	5
1	...	.001	.30	.30	.30
2	.999	....	.30	.50	.50
3	.70	.70	...	.178	.796
4	.70	.50	.822	...	.352
5	.70	.50	.204	.648	...

The upper right hand portion of the table represents the similarity between the stations and the lower left the dissimilarity.

Following the reasoning of Bray-Curtis, the station pair having the greatest dissimilarity probably represents stations at the extremes of an environmental gradient. These are stations 1 and 2 in this example.

Stations 1 and 2 are then placed on an environmental gradient separated by a distance of .999 units. The positions of the remaining stations are then projected upon this gradient by the following method. Station 3 is .70 units from both stations 1 and 2. Circles with radii of .70 units and centers at stations 1 and 2 are then drawn. The intersections of these circles then represent the position of station 3 with respect to stations 1 and 2. A projection of the intersections of the circles onto the line joining stations 1 and 2 gives the position of station 3 with respect to this environmental gradient. The procedure is repeated for all stations. A graphical representation of the procedure described above for the location of the position of station 3 is given below.



The position of station 3 on the environmental gradient is then .50 units. By examining the order (ordination) of the entire set of stations (not drawn in the above figure) the nature of the environmental gradient is then inferred.

The procedure can be repeated to identify other important environmental factors. However, since no other factors were detected in the present case the exact procedure will not be discussed. If interested, the reader should refer to Bray-Curtis (1957).

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SECTION II

BIOASSAYS

INTRODUCTION

Field and laboratory bioassays of rum stillage (mosto in Spanish) were conducted using selected marine invertebrates as assay organisms. Test animals were chosen from the vicinity of the primary study site near Puerto Rico Distillers in Arecibo and a secondary site near Bacardi at Palo Seco in San Juan. Laboratory bioassays included a sea urchin, *Echinometra lucunter* (Linné, 1758) and intertidal mussel, *Brachidontes exustus* (Linné, 1758) and a chiton, *Chiton squamosus* (Linné, 1764) and the blue crab, *Callinectes sapidus*, Rathbun 1896. Field (*in situ*) bioassays were conducted using *Echinometra* at Arecibo and *Callinectes* at San Juan.

The Arecibo study covered several periods of mosto discharge. These were: a shut-down period before the initial flow began (May 9 through May 23), the initial discharge period (May 23 to June 6), a sustained discharge period (June 6 to July 3), a 10 day interruption in discharge (July 3 to July 13), and another period of discharge until the end of the study period in August.

Initial reconnaissance of the Arecibo site revealed that the effects of mosto effluent were more pronounced intertidally to the west from the discharge point. This circumstance presumably develops due to the relative position of the effluent pipe, the wave action acting to keep the mosto together as a coherent stream onshore, and a strong net drift westward along the shore (see Physical Oceanography section of this report). Due to the apparent greater impact onshore, emphasis was placed on work with benthic organisms in the intertidal zone, and bioassay organisms were chosen accordingly. Selections were from animals having apparent functional importance in the community which seemed to be, on first examination, sensitive to mosto.

Certain field observations suggested appropriate macroinvertebrates which could be sensitive to mosto. The urchin, *Echinometra lucunter*, was missing from rocky habitats downstream from the effluent pipe where it should normally occur. *Chiton squamosus* and *Brachidontes exustus* were present downstream, but in fewer numbers. Confirmation of these data can be seen by comparing organism densities from the impact site with the control sites (see the Benthic section of this report). *Chiton* and *Brachidontes* were also among mortalities observed shortly after flow resumed on May 29, 1978.

OBJECTIVES

1. Bioassay mosto using field and laboratory techniques.

2. Use assay organisms which have functional importance in the community.

3. Determine the effect of mosto on the rocky intertidal community.

Regarding functional importance, *Echinometra lucunter* typically dominates faunal biomass (see Benthic section) in well-developed north coast rocky intertidal communities. *Echinometra* bores holes into hard substrates, or at least enlarges depressions and crevices it occupies. Boring is a common habit among many echinoids (Reese, 1966). Although the precise mechanism for boring has not been established, McPherson (1969) and Khamala (1971) report that 11 and 14 percent of gut contents from *Echinometra* was substrate and sedimentary material, suggesting that boring may partly result during feeding activity. The holes occupied by *Echinometra* insure survival against strong wave action (McPherson, 1969) and provide protection against desiccation during low tides. As a result of boring by *Echinometra*, intertidal rocky surfaces are physically altered. Microcosms with pools, pinnacles and vertical surfaces are created to the advantage of other organisms where otherwise flat rock surfaces would exist.

Among other functionally important animals to the intertidal community were the molluscan grazers. Since these herbivores may feed preferentially, their effect is that of structuring and often increasing the diversity of an intertidal algal assemblage (Lubchenco, 1978). Among frequently found grazers upstream and downstream, but uncommon near the study site was *Chiton squamosus*.

Also important were individuals of the mussel *Brachidontes exustus* which often aggregated into dense mats, dominating space under certain conditions of continuing natural disturbance (e.g. sand movement over rock and heavy wave action against boulder surfaces) precluding occupation by other organisms. In certain cases, *Brachidontes* can act as an intermediate colonizer, simultaneously exploiting exposed surfaces and providing refuge for newly settled epifauna and infauna such as amphipods and polychaetes.

METHODS

Study Site

The effect of mosto discharge upon a rocky intertidal community was examined near Puerto Rico Distillers in Arecibo. Much of the field work was conducted at a rocky point, 150 meters west of the discharge pipe (Fig. 7). At this site, tidepools were selected (Fig. 8) to evaluate both the physical and biological effects of mosto effluent in the field.

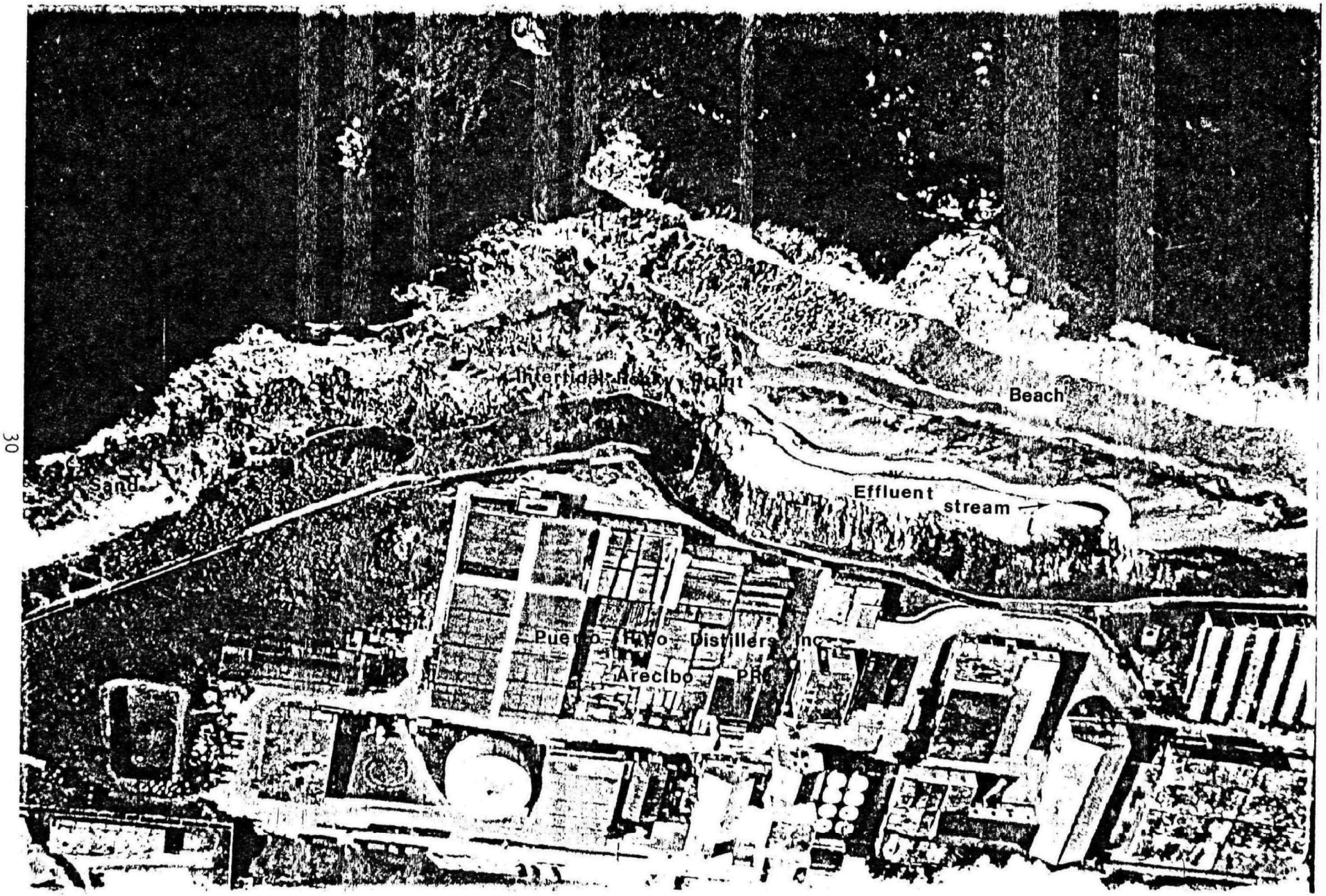


Figure 7. Site of Mosto effluent discharge for Puerto Rico Distillers, Inc. in Arecibo, P. R.

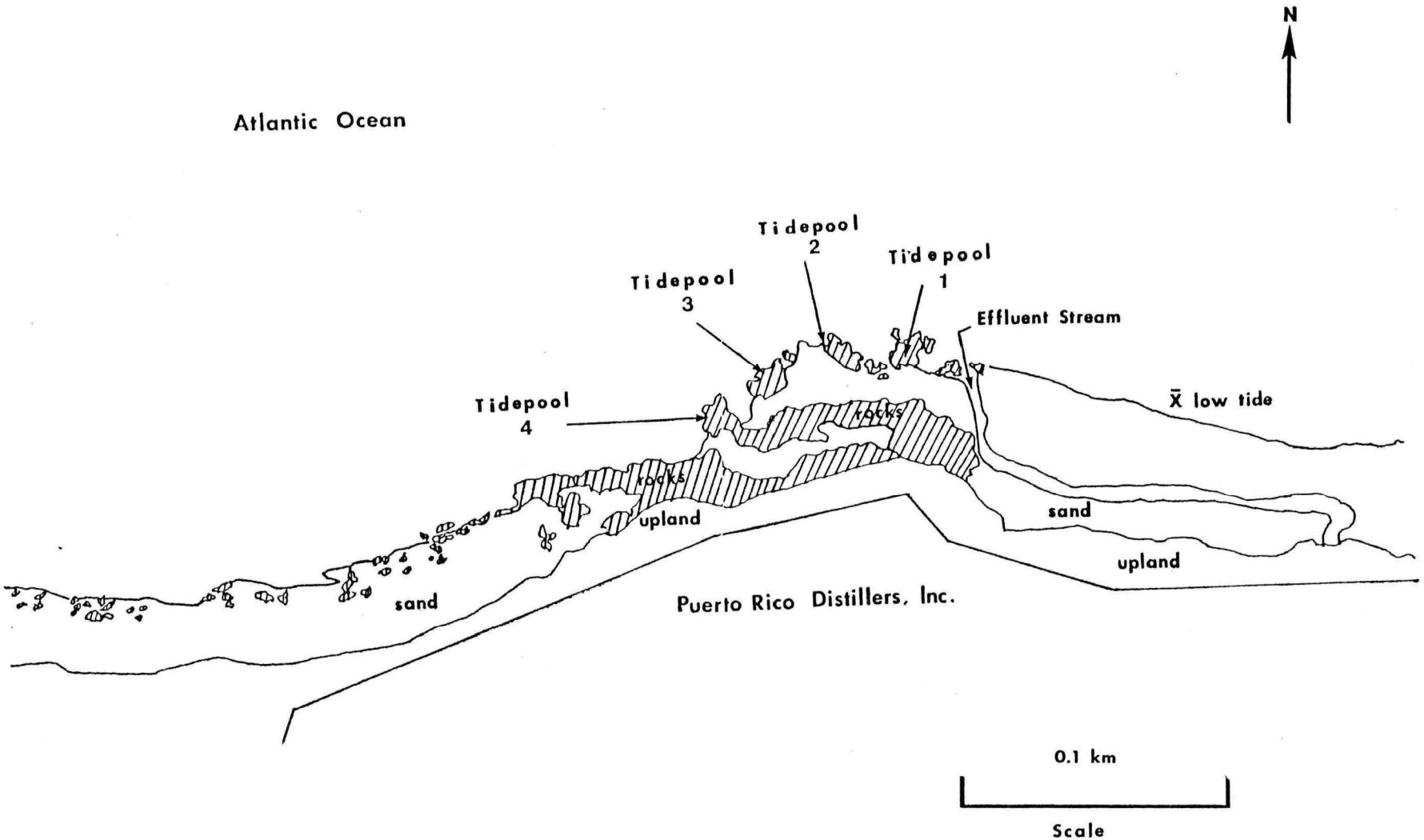


Figure 8. Tidepools selected at the primary study site in Arecibo.

Field work

In certain tidepools at Arecibo (Fig. 2) measurements of 1) temperature, 2) salinity and 3) oxygen were taken between May 9, 1978 and July 10, 1978 (Tables 1 and 2). When possible, mosto concentration was also determined. This was accomplished by removing water samples to the laboratory and comparing their optical density (Klett Colorimeter, using a 640 to 700 mμ filter) against a prepared standard dilution curve (Fig. 9).

Observations of both physical conditions and biological effects were obtained at the same time during periods of plant operation and non-operation with attendant discharge, 1) the first shut-down period (May 9 to May 23; a period of non-operation which preceded the beginning of the study, May 9, by approximately 6 weeks), 2) the initial discharge period (May 23 to June 6; a period during which plant discharge was intermittent), 3) sustained discharge (June 6 to July 3), and 4) a temporary interruption in discharge (July 3 to July 13; which was preceded and followed by sustained discharge). In order to establish normal background conditions, physical measurements were also taken at control sites in non-effected areas upstream (east) and downstream (west) of the study site.

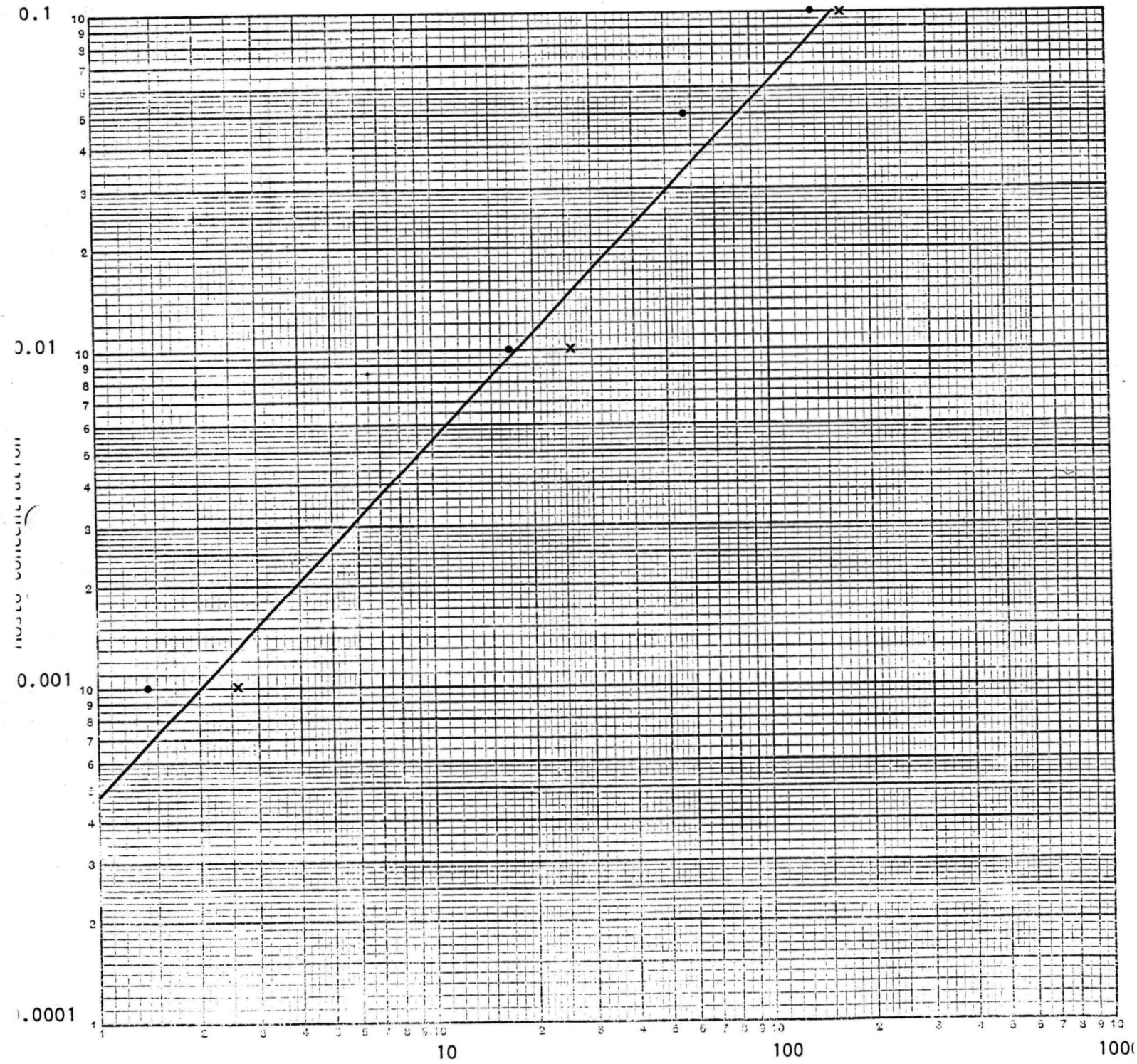
The sea urchin, *Echinometra lucunter*, (expected, but not present at the study site) was used as a field bioassay organism. A given number of urchins (usually 50 to 100) were transplanted into tidepools (Fig. 8) at the study site. These were counted at 1, 3, 7, 16 and 20 day intervals to determine the number of surviving urchins (Tables 3 & 4). The experiment was carried out during the period before resumption of discharge and repeated during the sustained discharge period and the July 3-13 shut-down period (called discharge interruption). The urchins used in field testing and laboratory bioassays were gathered from an unusually dense population of urchins upstream and beyond the influence of mosto discharge.

Laboratory Bioassays

A bioassay system was constructed (The Center for Energy and Environment Research at Guanajibo in Mayaguez) in a wet laboratory to handle bulk mosto and flowing seawater (Fig. 10). Bulk mosto was delivered in a 1,000 gallon stainless steel tank truck containing a single batch of mosto (not a composite sample) from the plant. At the wet lab, the distribution to test aquaria was accomplished through each of three mixing vats. Concentrations were regulated within each vat by adjusting mosto flow (peristalic pumps) and seawater flow (ball valves) simultaneously (Fig. 10). Each experimental concentration was maintained in a mixing vat and each was distributed to a separate system of 5 replicate aquaria (Fig. 10). Aside from these systems, a seawater control system was set up with 5 additional aquaria (Fig. 10). Each aquarium contained 40 liters of solution which was exchanged every 30 minutes and discharged into a drain equipped with a charcoal filter.

In most cases, bioassays were conducted for 96 hours, using test concentrations of 5% (1:20), 0.5% (1:200) and 0.05% (1:2000) mosto. Sixty individuals of a species were used for each test. In certain instances,

Figure 9. Standard Dilution Curve prepared with mosto in seawater.



Klett - Summerson Colorimetric Units

(°) = 660 mμ filter

(x) = 540 mμ filter

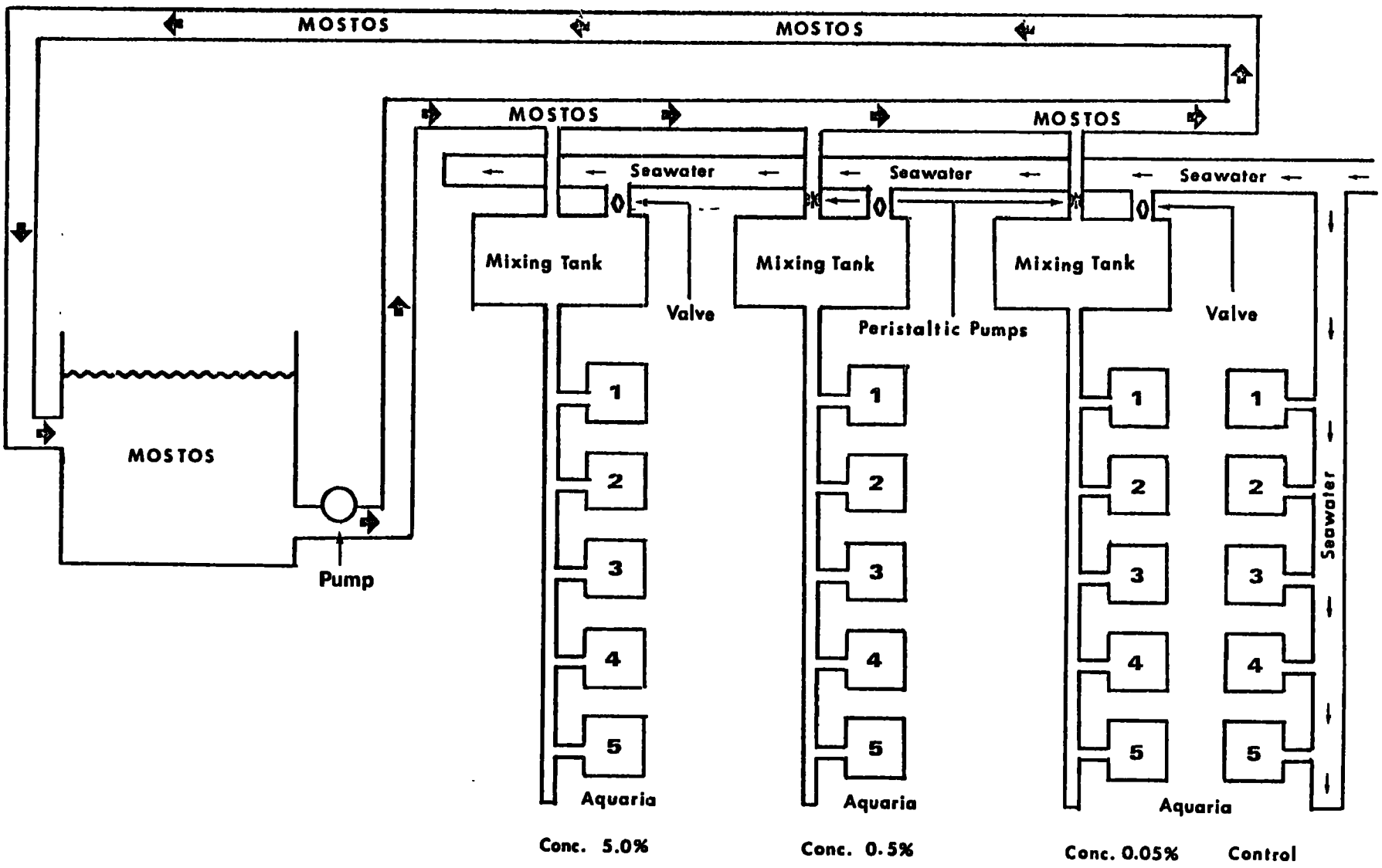


Figure 10. Laboratory Set up for Mosto Bioassays.

concentrations were decreased to 0.5% (1:200), 0.05% (1:2000) and 0.01% (1:10,000) mosto and conducted for 192 hours. Temperature, salinity and oxygen were monitored twice a day, morning and evening, and pH was taken at the end of each test run. Bioassay organisms were collected from upstream and downstream sites near the study area. Care was taken not to collect impoverished populations nor damage the habitat. Only those species easily collected and with characteristically large numbers of individuals were chosen for bioassays. In all cases, except with *Callinectes sapidus*, sexually mature individuals were used.

Lethal as well as sublethal effects of different mosto concentrations were observed. Survival was determined over each 24 hour period, providing lethality of concentrations (LC). Determination of effective mosto concentrations (EC) was provided by measuring an appropriate behavioral or physiological response, e.g. sea urchins = mean righting time, mussels = production rate of byssal threads, and chitons = ability to adhere to a substrate.

RESULTS

Physical Conditions with and without Mosto Discharge

Important differences between dissolved oxygen levels in tidepools with and without mosto were recorded (Table 7). Generally, the effect was to depress oxygen concentration so that during low tides, when pools may be stranded, levels approached zero. This condition was reversed from normal daytime low tide situations (Table 7), where photosynthetic production by algae supersaturated stranded pools with dissolved oxygen. This critical oxygen concentration difference at least partly contributed to mass mortalities of tidepool organisms observed during the first week after discharge began.

Field Dilutions of Mosto Measured by Colorimetry

Mosto effluent mixed into seawater was usually visible downstream for 2.5 kilometers (see aerial photographs, Appended), often exceeding that distance. Using a Klett Colorimeter, dilutions of 0.01 percent mosto were detected for 2 kilometers downstream, west of the discharge point on August 11, 1978. Mosto concentrations increased eastward approaching the discharge point (Fig. 11), being greatest at the first point of rocks, immediately west of the outfall (Fig. 8). In Table 8 the range of mosto concentrations measured in tidepools at this location reflects day-to-day variations, as well as differences due to tidal influence. It was apparent that the temporal range of dilutions for any one location was large and that much of the downstream effect occurred at concentrations less than 0.1 percent (1,000:1).

TABLE 7. Effects of Mosto on Dissolved Oxygen Levels in a Tidepool at the Arecibo Site.

Event/date	Mosto Conc. (%)	TIDEPOOL #1 Temp. (°C)	TIDEPOOL #1 O_2 (ppm)	CONTROL TIDEPOOLS Temp. (°C)	CONTROL TIDEPOOLS O_2 (ppm)
1st Shutdown					
5/9/78	0	28.0	11.2	-	-
5/19/78	0	29.5	10.8	-	-
5/23/78	0	29.0	6.2	-	-
Initial Discharge					
5/29/78	0.1	29.0	4.5	-	-
6/6/78	-	31.0	2.5	-	-
Sustained Discharge					
without wave exchange					
6/12/78	0.68	32.0	0.3	31.5	12.5
6/20/78	0.12	32.5	1.8	32.5	7.0
6/27/78	0.42	29.0	0.4	30.5	7.2
with wave exchange					
6/21/78	0.01	28.0	5.2	28.0	6.3
6/23/78	0.25	28.3	5.3	28.2	6.8
Discharge Interrupted					
7/3/78	0	33.5	8.5	-	-
7/4/78	0	31.5	6.8	28.8	6.0
7/10/78	0	28.5	6.3	28.5	5.9

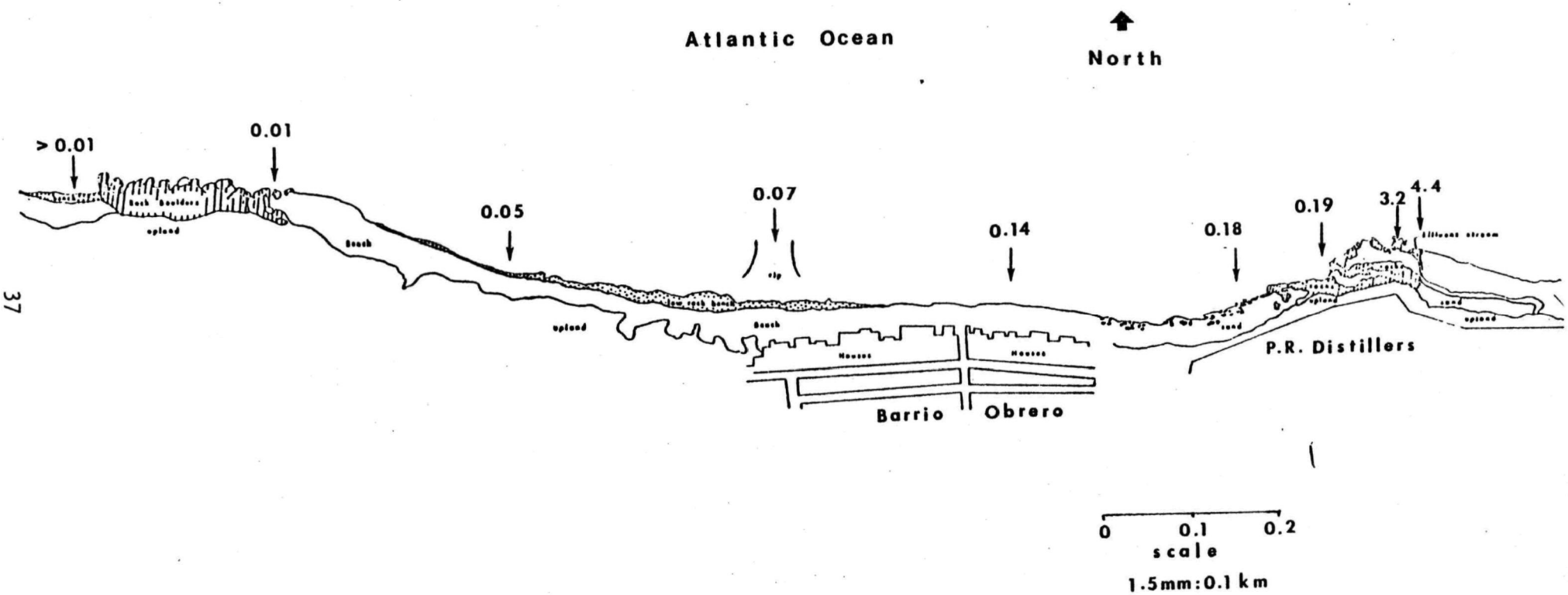


Figure 11 Percent Mosto Concentration in Seawater from Intertidal Habitats Downstream from the Discharge Point on August 11, 1978.

TABLE 8. Mosto Concentrations* at the Rocky Point Nearest and West of the Effluent Outfall.

Site	Distance from the pipe	Percent Mosto						
		29 May	3 Jun	12 Jun	20 Jun	21 Jun	23 Jun	27 Jun
Upstream	100m east	0	-	0	0	0	0	>0.01
Ocean Entry	125m west	6.5	5.4	3.8	1.6	3.8	2.8	-
Tidepool 1	150m west	0.1	-	0.68	0.12	>0.01	0.25	0.42
Tidepool 2	175m west	0.09	0.55	1.8	>0.01	>0.01	0.18	0.36
Tidepool 3	200m west	-	-	0.17	>0.01	>0.01	0.06	0.21
Tidepool 4	225m west	-	-	0.15	-	>0.01	0.01	0.27

*Klett Colorimeter

Transplanted Urchins: Survival Before and During Mosto Effluent Discharge

The sea urchin, *Echinometra lucunter*, was not present beginning at the first point of rocks west of the discharge pipe, nor was it found on shore rocks for 2.5 kilometers beyond. When urchins from upstream tidepools were transferred to tidepools at the study site before discharge began, survival after 20 days was 70 percent (Table 9). Typically, the largest loss (<11%) occurred during the first 24 hours of acclimation.

When mosto was being discharged, *Echinometra* did not survive beyond one week (Table 10). Survival increased in tidepools located successively downstream from the outfall (Fig. 12; also see Fig. 8 for tidepool locations). Between July 3 to July 13, when effluent discharge was temporarily discontinued, urchin survival rate was higher than during sustained mosto discharge (Table 11), but not as high as before discharge began. Without discharge, after one week, survival of transplanted urchins was 40 percent despite hostile weather, high tides, and storm waves. The tidepools at this time were barren of algal growth, normally available as food and protective cover for invertebrates. Mosto residue appeared to linger on rock surfaces. The environment had been altered so that survival of transplanted urchins was effectively lessened, even in the absence of discharge.

The Effect of Mosto on *Echinometra lucunter*

In laboratory bioassays, mosto diluted with seawater visibly and measurably affected the urchin, *Echinometra lucunter*, (Table 12). In 96 hour tests of 5.0% and 0.5% mosto, urchins reacted as though under stress by locking their normally movable spines and becoming inactive to the point of torpor. This behavioral response began immediately in 5.0% mosto. A similar response was observed in all animals placed in 0.5% mosto after 24 to 48 hours. Field observations revealed similar behavior during stress by desiccation and heat caused when tidepools were stranded during mid-day low tides. Importantly, Glynn (1968) reported that *Echinometra lucunter* has a high degree of tolerance to exposure and high temperatures, suggesting a certain degree of ability to accomodate environmental stress. It would appear that laboratory responses observed were a generalized reaction to stress. The stress induced by mosto initiated death in 5.0% and 0.5% concentrations, as shown by survival curves in Figure 13. Survival in the control was 100% (0% mortality).

In nature, urchins that are dislodged and turned over must be able to return to their normal position quickly, since an unattached urchin can be washed from its habitat by advancing and retreating waves. This critical ability to right themselves was found to be affected by mosto (Table 13). Mean righting time was lessened in response to greater mosto concentration (Fig. 14). In 5% mosto, urchins could not right after 2.5 hours, spine movement ceased or was uncoordinated and tube feet would not remain attached to substrate surfaces. A similar condition developed in urchins placed in 0.5% mosto after 48 to 72 hours. In 0.05% mosto, righting time was slower than the control, but the ability to right remained. Test animals subjected to 2.5 hours of 5.0% mosto and gradually returned to control seawater did not

TABLE 9. Survival of transplanted *Echinometra lucunter* in tidepools during the first shutdown period.

Date	Cumulative # of Days	Tidepool 1 # of Individuals	Tidepool 2 # of Individuals	Tidepool 3 # of Individuals	Tidepool 4 # of Individuals	Tidepool 5 # of Individuals	$\bar{X}$ Survival
5/3/78	0	100	50	100	100	100	-
5/4/78	1	88	50	86	79	92	89%
5/19/78	16	89*	49	90*	74	69	84%
5/23/78**	20	-	46	84	72	46	70%

*Counts higher than previous ones were due to exceptional water clarity resulting in improved counting efficiency.

** Effluent discharge in progress.

TABLE 10. Survival of *Echinometra lucunter* Transplanted in Tidepools During Mosto Discharge.

Date	Cumulative # of Days	Increasing Distance from Outfall: Tidepool 1 # Individuals	Tidepool 2 # Individuals	Tidepool 3 # Individuals	Tidepool 4 # Individuals	$\bar{X}$ Survival
6/20/78	0	50	50	100	50	-
6/21/78	1	7	12	38	27	33%
6/23/78	3	1	7	16	20	18%
6/27/78	7	0	0	0	0	0

TABLE 11. Survival of *Echinometra lucunter* Transplanted in Tidepool During a Period of NO Mosto Discharge (i.e. Interruption).

Date	Cumulative # of Days	Tidepool 1 # Individuals	Tidepool 2 # Individuals	Tidepool 3 # Individuals	Tidepool 4 # Individuals	$\bar{X}$ Survival
7/3/78	0	50	50	30	46	-
7/4/78	1	39	30	22	32	70%
7/6/78	3	31	30	*	24	58%
7/10/78	7	19	18	-	21	40%

*Mortality due to sand movement and urchin burial.

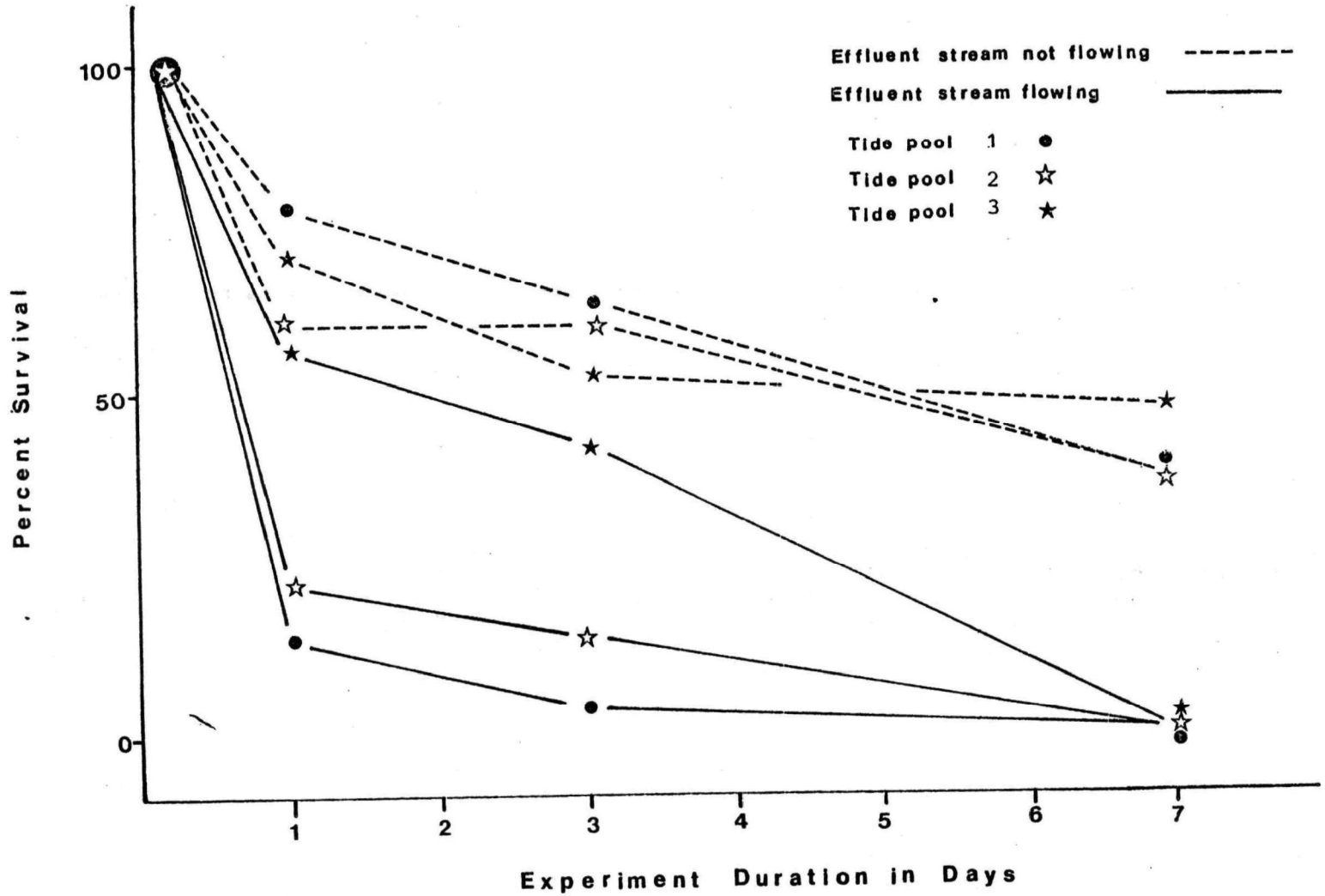


Figure 12. Survival of Transplanted *Echinometra lucunter* with and without Mosto Effluent Discharge.

TABLE 12 A 96 Hour Bioassay of Dilutions of Rum Distillation Waste in Seawater using the urchin, *Echinometra lucunter*.

A. Cumulative Mortality

Hour	Percent Dead (n=60/test)			
	0.05 Mosto	0.005 Mosto	0.0005 Mosto	Control
24	1.6	0	0	0
48	70.9	8.2	0	0
72	100	60.6	18.6	0
96	-	100	37.3	0

B. Effect on Righting Behavior

Hour	Righting Time in Seconds Mean, Std. Dev., (Range)			
	0.05 Mosto	0.005 Mosto	0.0005 Mosto	Control
24	0	77 ± 54 (12 - 199)	63 ± 52 (7 - 268)	46 ± 36 (9 - 214)
48	0	0	58 ± 48 (11 - 206)	41 ± 32 (8 - 156)
72	-	0	67 ± 52 (24 - 218)	.62 ± 41 (15 - 213)
96	-	-	58 ± 36 (19 - 161)	48 ± 38 (8 - 212)

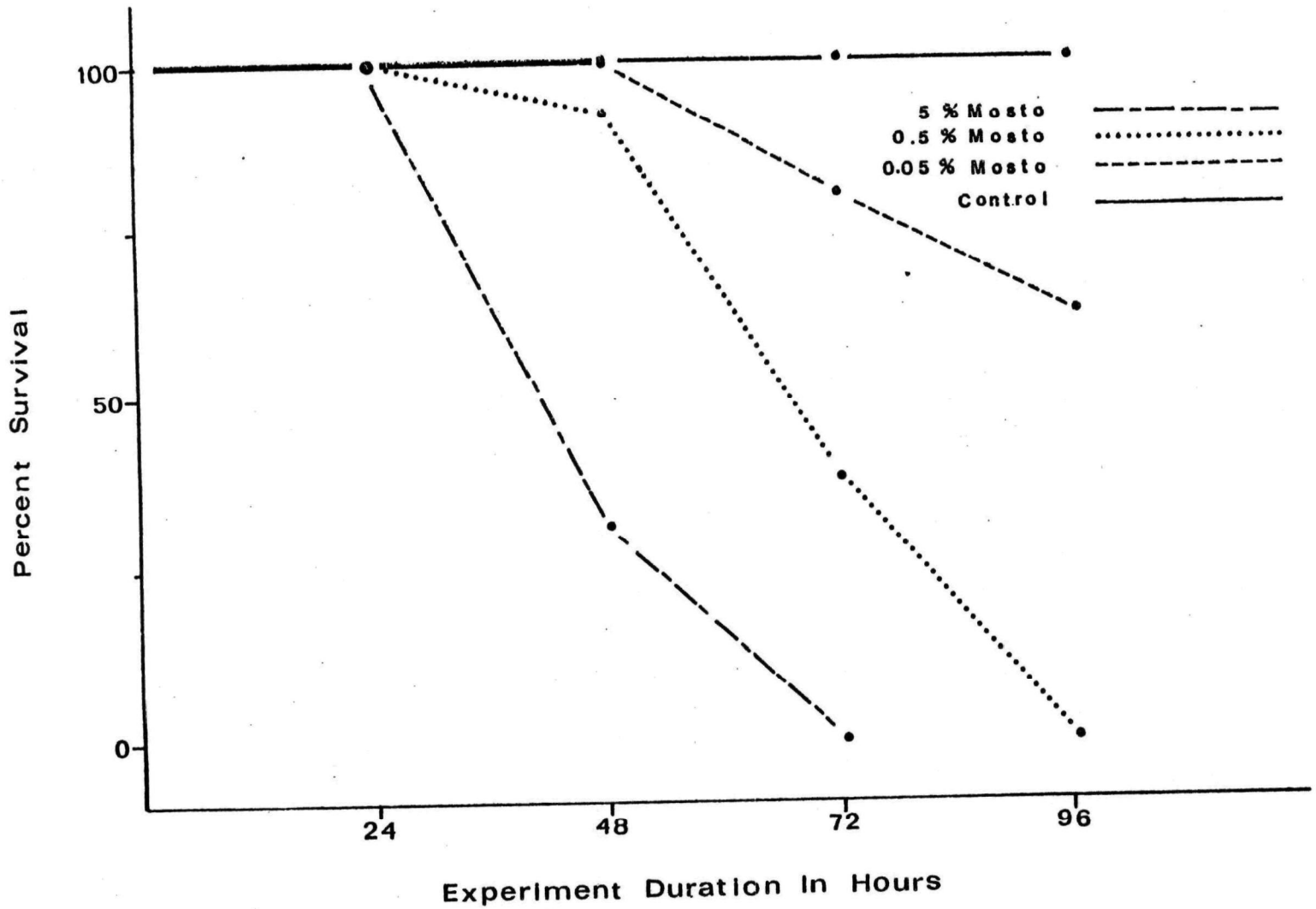


Figure 13. Bioassay of Rum Distillery Waste Seawater: Survival of Urchin, *Echinometra lucunter*, (n = 60 individuals per dilution).

TABLE 13. Recovery of *Echinometra lucunter* (Mean Righting Time) after 2.5 Hours in 5 Percent Mosto.

	Righting Time in Seconds* Mean, Std. Dev., (Range)	
Time	0.05 Mosto	Control
2.5 hours	0	31.1 ± 19.1 (6 - 100)
24 hours	65.1 ± 36.9 (13 - 174)	37.2 ± 31.0 (7 - 218)
48 hours	84.6 ± 57.4 (24 - 245)	34.9 ± 20.5 (7 - 88)

*n = 60 individuals/group.

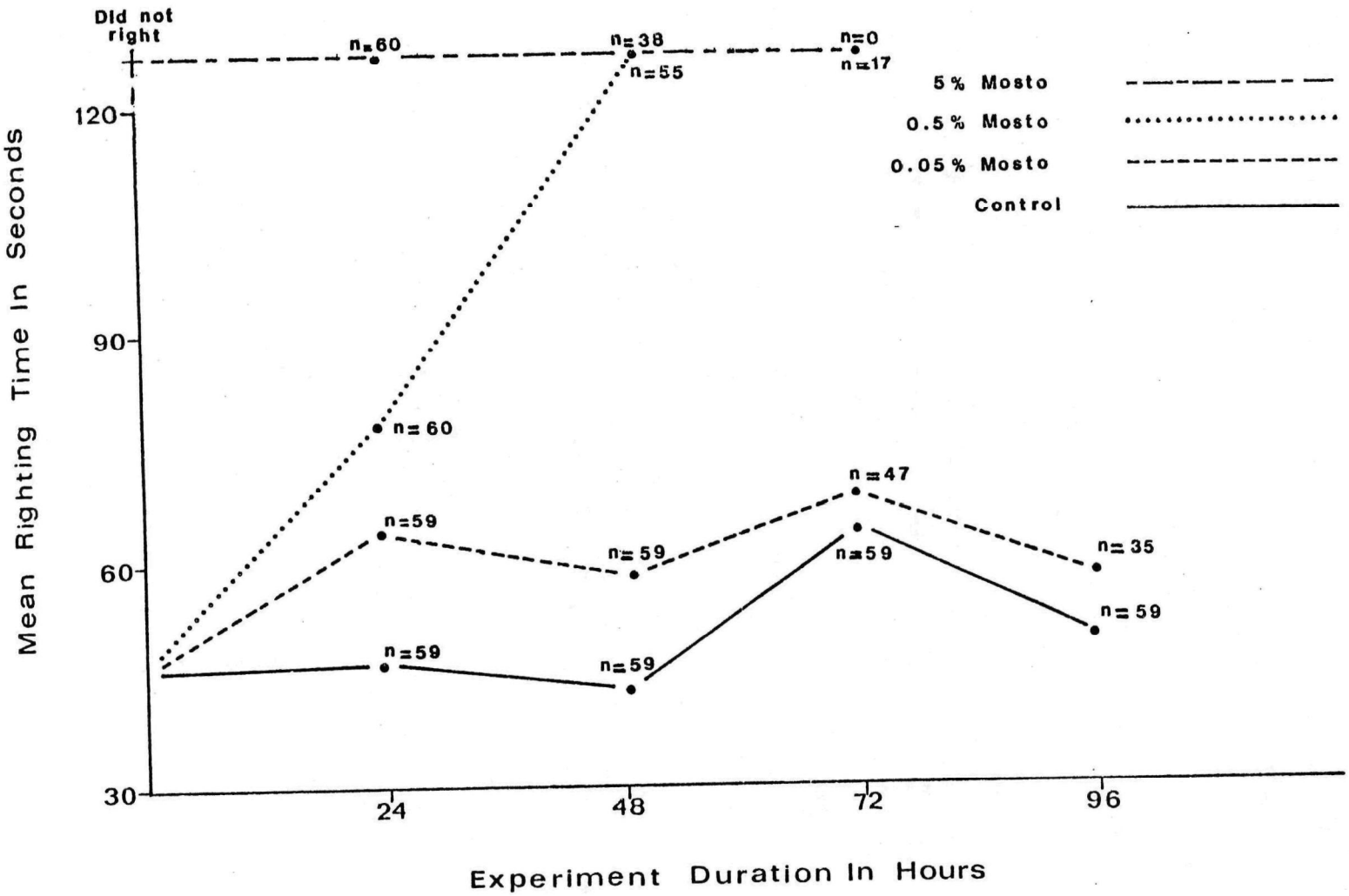


Figure 14. Bioassay of Rum Distillery Waste in Seawater: Effect on Righting Behavior of *Echinometra lucunter*.

recover righting ability completely. After 24 to 48 hours, righting time was slower than for controls (Table 13). There appeared to be a latent effect worsening after 24 hours.

The Effect of Mosto on *Brachidontes exustus*

In 96 hour bioassays of mosto in seawater, 5.0% mosto was lethal to the mussel *Brachidontes exustus* and concentrations of 0.5% and 0.05% were not (Table 14 and Fig. 15). However, production of byssal threads, by which *Brachidontes* attaches itself to substrates, was affected in 0.5% and 0.05% mosto (Table 14 and Fig. 16). In 0.5% mosto, byssal thread production was less than that of control production. In 0.05% mosto, byssal thread production was more than control production. In the mussels, *Modiolus demissus* and *Mytilus edulis*, Van Winkle (1970) found that physical disturbances (i.e. environmental stress) can cause deviation in mussel byssal thread production. This manifestation may be in the form of higher production as effected by exposure to air (Van Winkle, 1970) and elevated temperatures (Van Winkle, 1970 and Allen *et al.*, 1976), or it may be lower production as elicited by mechanical agitation (Van Winkle, 1970), and lower salinities (Allen *et al.* 1976). Van Winkle (1970) also observed that calcium and magnesium ions must be readily available for proper byssal thread formation. The absence of byssal thread production by *Brachidontes* in 5.0% mosto may be due to such an ionic imbalance. Martin *et al.* (1975) suggest a similar finding, reporting decreased byssus production for *Mytilus edulis* on exposure to high levels of the toxic metals cadmium, copper, chromium and lead.

The Effect of Mosto on *Chiton squamosus*

After 96 hours in 0.5% and 0.05% mosto, the herbivorous mollusc, *Chiton squamosus*, was detrimentally affected (Table 15 and Fig. 17). One hundred percent mortality occurred in 0.05% mosto by 72 hours and 38% mortality in 0.05% mosto after 96 hours. The trend was upheld so that after 192 hours mortality was 76% in 0.05% mosto. At 0.01% mosto concentration, *Chiton* survival was nearer to, but less than, controls (Table 15 and Fig. 17). After 192 hours in 0.01% mosto, mortality was 24%. Mortality among controls was 12%, of which at least one-half could be attributed to damage inflicted after 120 hours in returning escaped *Chitons* to aquaria.

A particular effect of mosto on *Chiton squamosus* may be impairment of foot function and resulting loss in ability to adhere to substrates. Comparison of *Chiton* in 0.05% and 0.01% mosto with controls up to 144 hours, indicates fewer attached animals in aquaria containing mosto (Table 15 and Fig. 18). After 192 hours the percentage attached among individuals remaining returned to near control levels. These latter results imply temporal accommodation or that a portion of the *Chiton* population may be more resistant to mosto. These data have been supported by observations in the field where a few (abnormally few, see Field Studies section) *Chitons* were found on heavily impacted rocks. In general, the *Chiton* population appears sensitive to mosto at 0.01% concentration or less.

TABLE 14. A 96 Hour Bioassay of Dilutions of Rum Distillation Waste (Mosto) in Seawater using the Intertidal Mussel, *Brachidontes exustus*.

A. Cumulative Mortality

Hour	Percent Dead (n=60/test)			
	0.05 Mosto	0.005 Mosto	0.0005 Mosto	Control
24	5	0	0	0
48	60	2	2	3
72	86	3	2	6
96	96	5	3	6

B. Effect on Byssus Fiber Production

Hour	Number Fibers Produced per Day Mean, Std. Dev. (Range)			
	0.05 Mosto	0.005 Mosto	0.0005 Mosto	Control
24	0	1 ± 2.6 (0 - 16)	2.8 ± 3.2 (0 - 15)	2.2 ± 3.8 (0 - 17)
48	0	2.7 ± 4.3 (0 - 20)	6.8 ± 6.9 (0 - 28)	6.6 ± 6.2 (0 - 25)
72	0	1.9 ± 3.6 (0 - 15)	15.1 ± 16.6 (0 - 75)	5.5 ± 6.6 (0 - 26)
96	-	2.5 ± 4.3 (0 - 26)	17.0 ± 15.5 (0 - 51)	9.4 ± 10.6 (0 - 36)

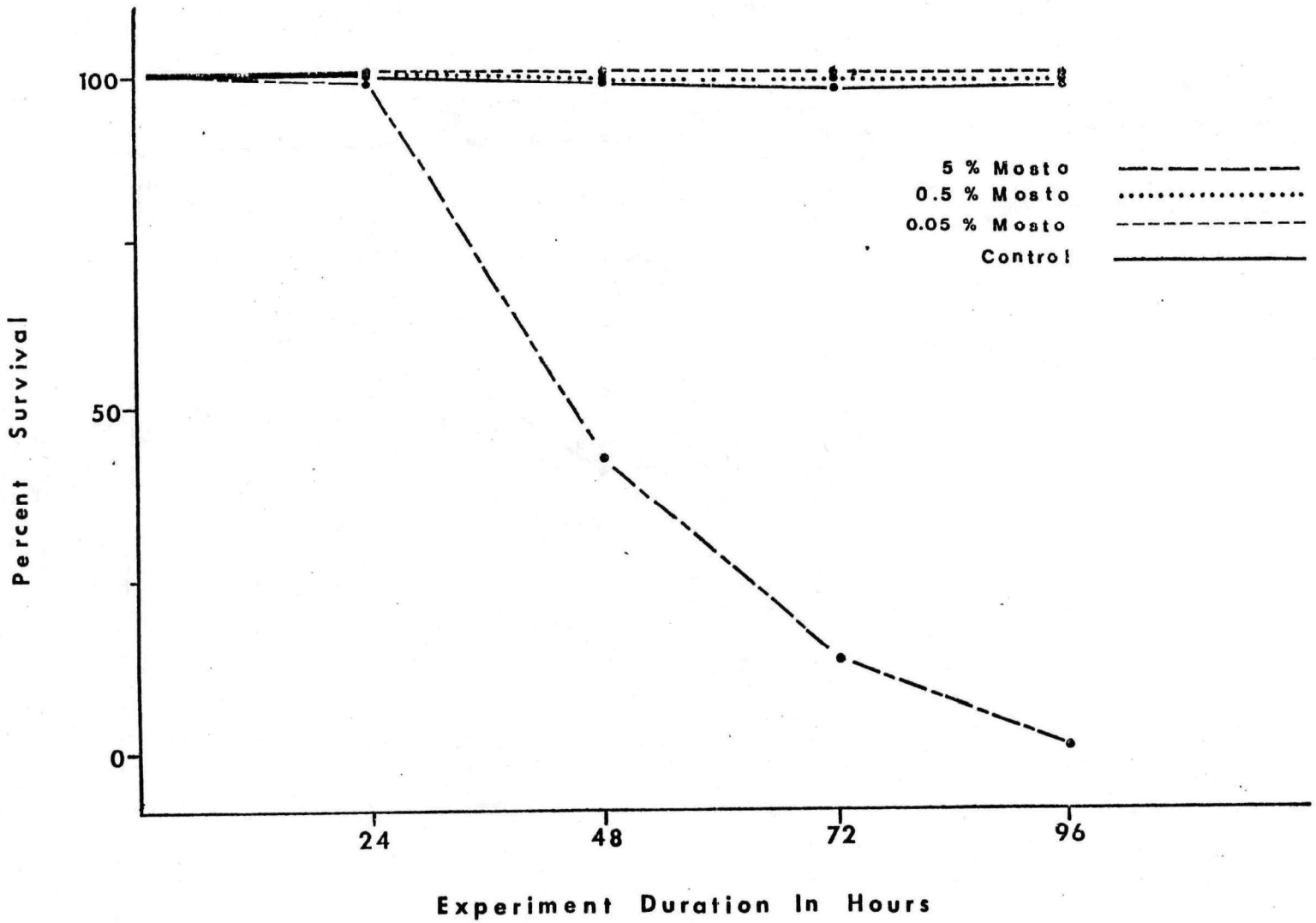


Figure 15. Bioassay of Rum Distillery Waste in Seawater: Survival of Mussel, *Brachidontes exustus* (n = 60 individuals per dilution).

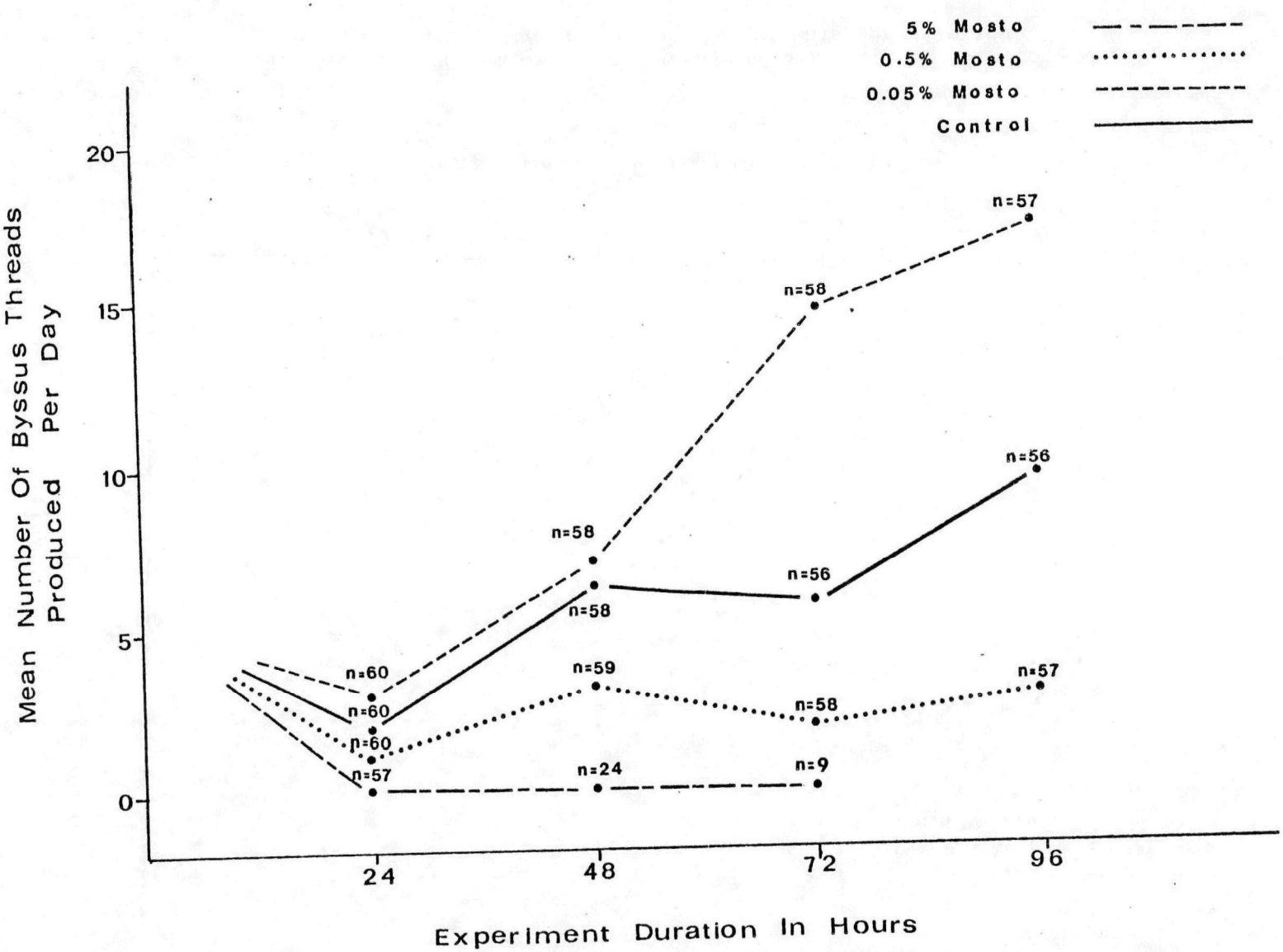


Figure 16. Bioassay of Rum Distillation Waste in Seawater: Effects of Byssus Thread Production by the Mussel, *Brachidontes exustus*.

TABLE 15. A 192 Hour Bioassay of Dilutions of Rum Distillery Waste (Mosto) in Seawater using the Intertidal Coat-of-Mail Shell, *Chiton squamosus*.

A. Cumulative Mortality

Hour	Percent Dead (n=60/test)			
	0.005 Mosto	0.0005 Mosto	0.0001 Mosto	Control
24	5	3	3	2
48	89	3	3	2
72	100	5	5	2
96	-	38	10	2
120	-	47	12	2
144	-	65	22	6
168	-	76	22	12
192	-	76	24	12

B. Effect on Ability to Remain Adhered

Hour	Percent Adhering to Aquaria (individuals remaining)			
	0.005 Mosto	0.0005 Mosto	0.0001 Mosto	Control
24	65(57)	95(58)	90(58)	95(58)
48	0	91(58)	98(58)	100(56)
72	-	74(55)	91(55)	100(54)
96	-	57(35)	86(50)	98(52)
120	-	60(30)	77(47)	94(50)
144	-	35(23)	79(40)	92(46)
168	-	69(18)	100(38)	91(41)
192	-	100(16)	97(38)	97(39)

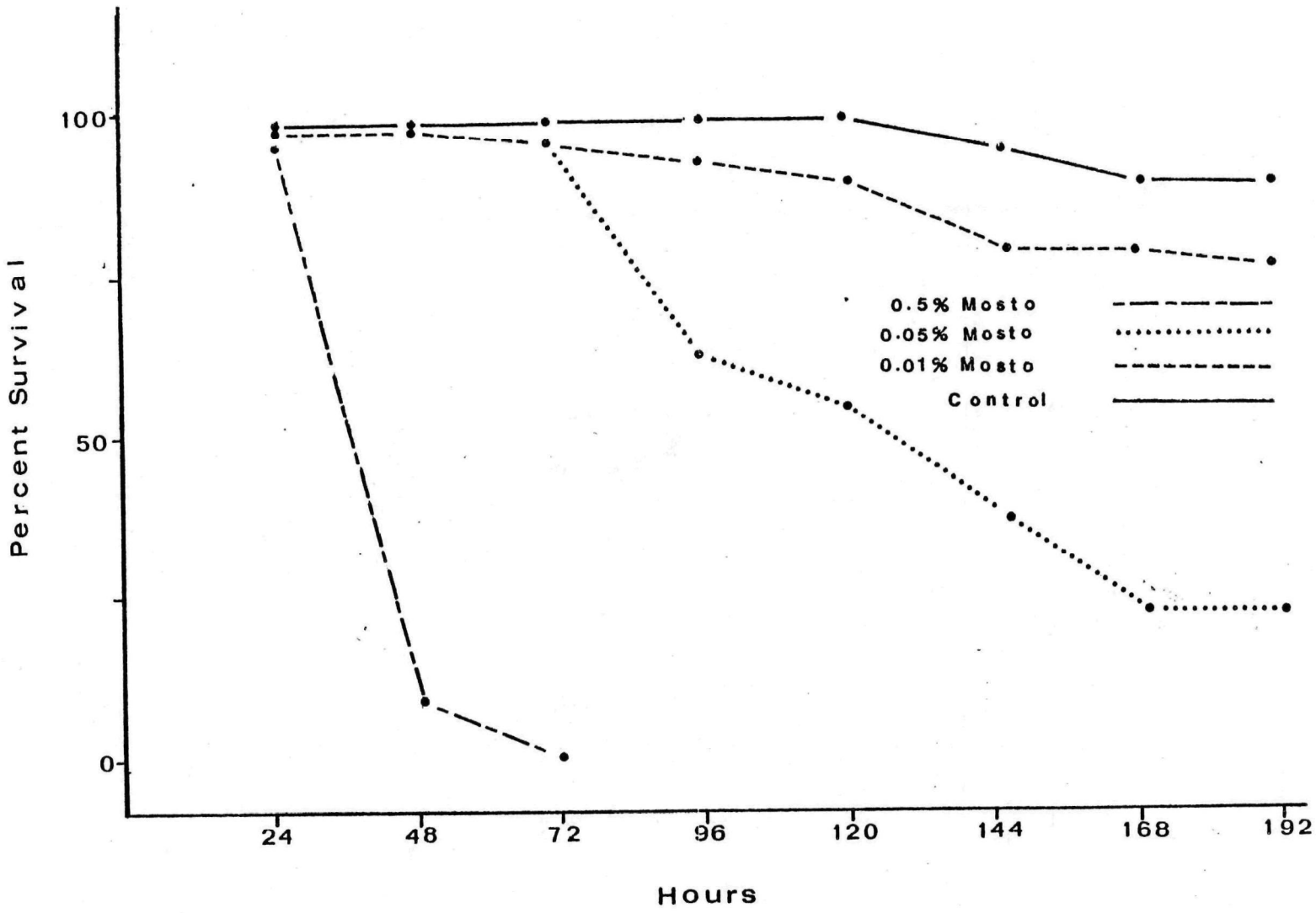


Figure 17. Bioassay of Rum Distillery Waste in Seawater: Survival of *Chiton squamosus* (n = 60 individuals per dilution).

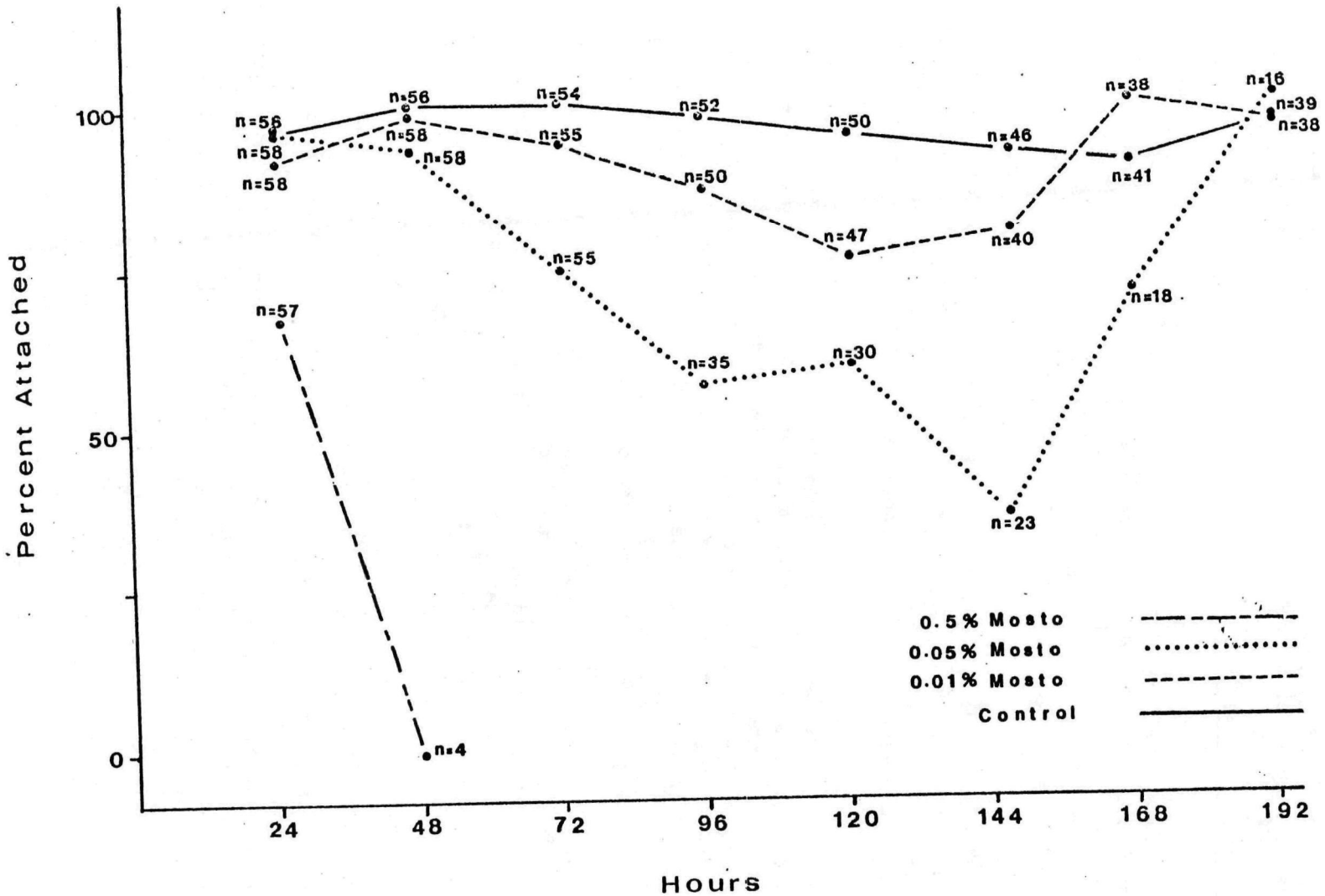


Figure 18. Bioassay of Rum Distillation Waste in Seawater: Effect on Ability of *Chiton squamosus* to Adhere to Substrate.

Bacardi Survey

At the Bacardi discharge site near Palo Seco (Fig. 19); several short-term field experiments were conducted to test potential effects of rum effluent. On July 25, 1978, two wire cages (hardware cloth, 1/4 inch square mesh) with 12 *Callinectes sapidus* each were placed in the effluent plume downcurrent as delineated by characteristic mosto discoloration of seawater. Two additional cages were placed in clear water upcurrent and in the bay near the new mouth of the Bayamon River, almost 2 kilometers downstream. All *Callinectes* were obtained by trawling in the mouth of the Bayamón River.

Results of Bacardi Survey

After six hours, four *Callinectes* (n=12) were dead at the site nearest the discharge. At the second site, offshore of the Palo Seco Power Plant intake channel, all 12 *Callinectes* were in a narcotized (inactive) behavioral state. In effect, they were immobilized, but not dead. The distinctive odor of hydrogen sulfide was evident in the effluent plume area. At the two remaining sites, upcurrent and downcurrent, all *Callinectes* remained alive.

After 21 hours (overnight), all *Callinectes* were dead at the cage site nearest the discharge. Four *Callinectes* were dead (n=12) at the power plant site, and all *Callinectes* were dead in the cage downcurrent and west near the mouth of the Bayamón River. Upcurrent and east, the *Callinectes* (n=12) remained alive.

After 30 hours, seven *Callinectes* (n=12) remained alive at the power plant site and 12 *Callinectes* (n=12) upcurrent. After 45 hours, seven *Callinectes* (n=12) continued to survive at the power plant site. At this time, however, (8:00A.M., July 27) the current had changed and the effluent discharge covered the upstream eastern control, leaving four *Callinectes* dead and six in an immobile (inactive) state. Only two *Callinectes* were capable of swimming. Dissolved oxygen at this site was measured to be less than 0.1 ppm in eight feet of water from surface to bottom.

Laboratory bioassays of *Callinectes sapidus* indicated them to be highly resistant to the effects of mosto (Table 16 and Fig. 20). Mortalities of *Callinectes* caused in the field were unmistakably associated with the effluent plume, but were not directly due to mosto. These preliminary findings indicate an indirect effect possibly due to low oxygen levels and toxic concentrations of dissolved hydrogen sulfide in seawater.

SUMMARY AND INTERPRETATION

Invertebrates used in bioassays of rum distillery effluent responded differently, indicating that some invertebrates are highly sensitive to mosto (*per se*) and others are resistant. The sea urchin *Echinometra lucunter* and the Coat-of-Mail Shell *Chiton squamosus* were most sensitive to mosto as indicated by mortality and altered behavior at the lowest concentrations

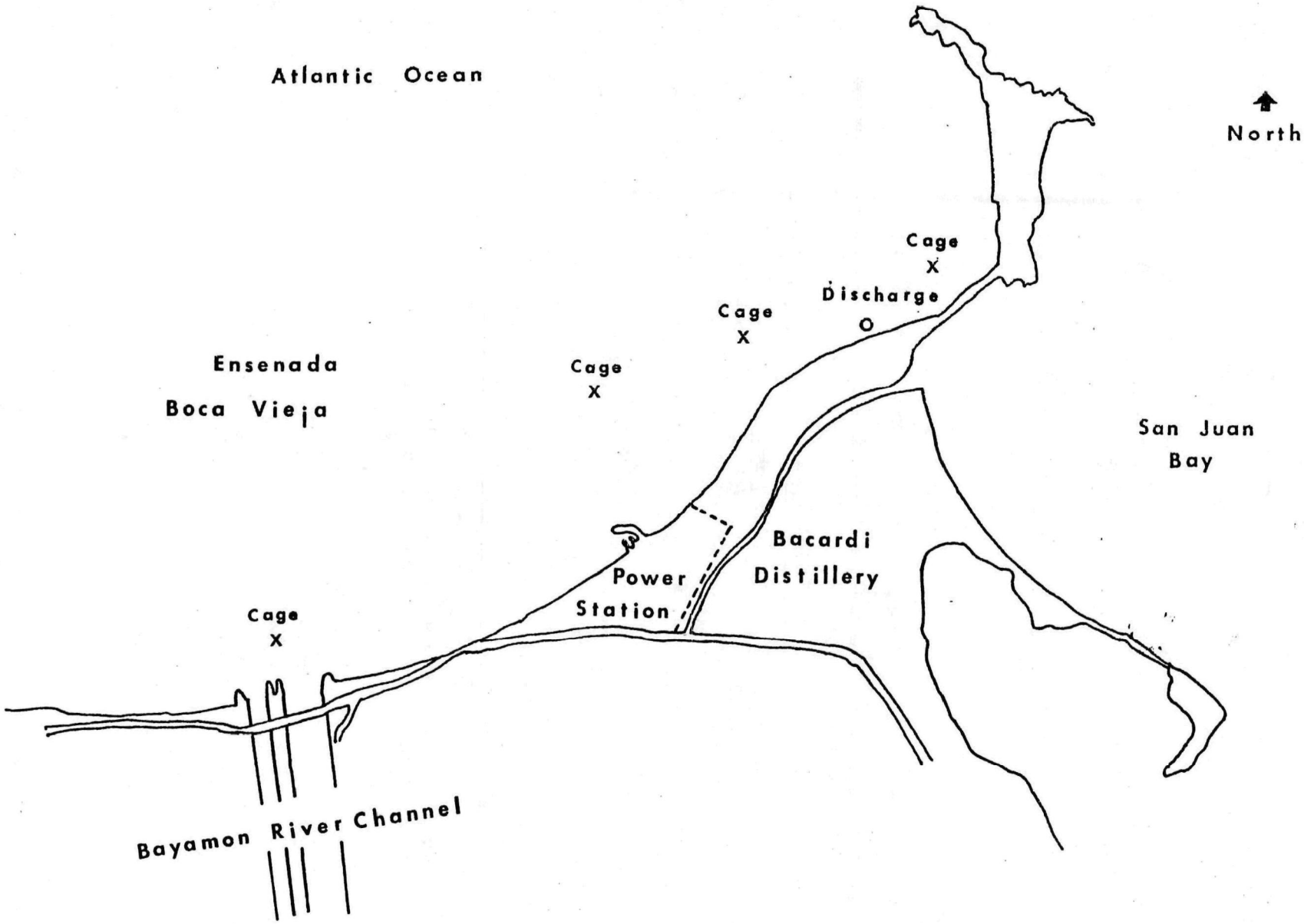


Figure 19. Cage Placement with *Callinectes sapidus* in Area of Bacardi Mosto Discharge.

TABLE 16 A 96 Hour Bioassay of Rum Distillery Waste in Seawater using the Blue Crab, *Callinectes sapidus*.

Hour	Cumulative Mortality Percent Dead			
	0.005 Mosto (n = 30)	0.0005 Mosto (n = 30)	0.0001 Mosto (n = 30)	Control (n = 28)
24	0	0	0	0
48	0	0	0	0
72	0	3	13	0
96	3	9	13	4

Note: Mortality (not entered into the above table) was often observed when newly molted individuals were cannibalized. Molting frequency was higher in aquaria containing mosto than that of control aquaria.

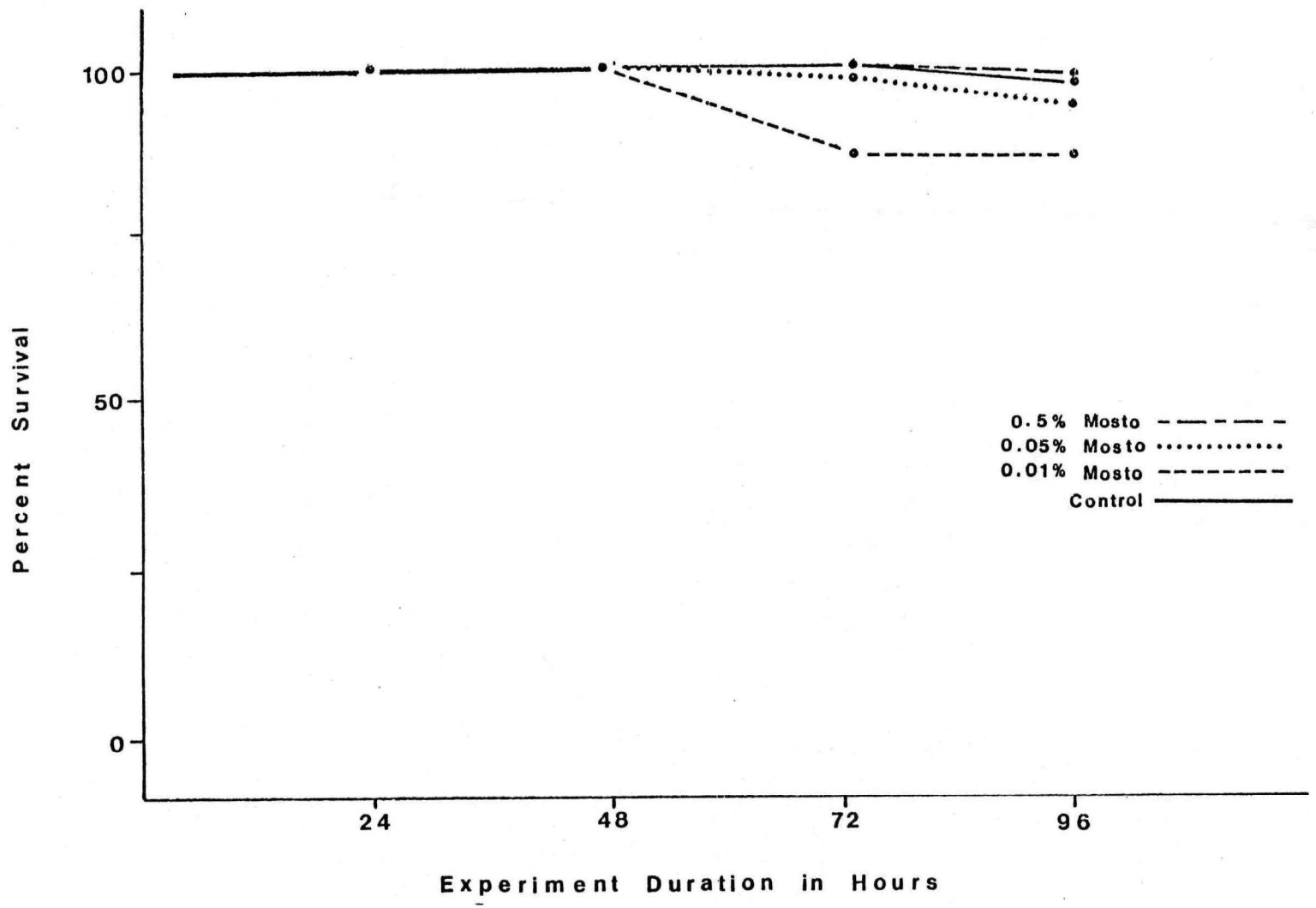


Figure 20. Bioassay of Rum Distillery Waste in Seawater: Survival of the Blue Crab, *Callinectes sapidus* (n = 30 individuals per dilution).

tested 2,000:1 and 10,000:1). These observations were borne out in field data, where both organisms were absent or rare in impacted areas. The mussel, *Brachidontes exustus* and the blue crab, *Callinectes sapidus*, were somewhat more resistant to the rum waste. These organisms survived in seawater containing 0.5% mosto (200:1). *Brachidontes* was observed present on the lowest intertidal rocks in a heavily impacted area. Sublethal effects (physiological stresses) were observed for example, in laboratory production or byssus threads. That such sublethal effects critically affect survival under certain field conditions was evidenced by mortalities during the first weeks of effluent discharge, and disappearance of *Brachidontes* from upper intertidal rocks. *Callinectes sapidus* was highly resistant to mosto in the laboratory, but did not survive in the field (Bacardi). Secondary effects measured by very low dissolved oxygen levels and the presence of hydrogen sulfide dissolved in seawater may have precluded the survival of *Callinectes*.

The differential effect of mosto on organisms has the overall result of artificially restructuring communities. Highly sensitive organisms which may have important functions in the community, such as *Echinometra* and *Chiton*, may be eliminated. Since *Echinometra* dominates mature rocky intertidal communities by its physical alteration of habitat (e.g. through maintaining and enlarging depressions, holes and crevices in intertidal rocks, this species creates more heterogenous surface areas and small tidepools which retain water during low tides thus increasing the variety of habitat for other organisms), its elimination changes the community. The elimination of important grazers of marine algae such as *Chiton* may have a similar effect. Due to their preferences for certain algae over others, these herbivores contribute to determination of algal species assemblage structure. Their grazing activities also continually open new space for settlement of new algal species. In effect, rum effluent has become the dominant predator of a variety of species and the conditions created by rum effluent have determined the existing community of species, however unnatural that may be.

The following points are provided in the summary:

1. *Echinometra lucunter* in the field was essentially absent from usual habitats for at least 2.5 kilometers downstream. Before effluent discharge began, transplanted urchins survived for 20 days. After discharge survival was less than one week. Mortalities occurred in all laboratory-96 hours-bioassays of mosto using this species where none occurred in the controls. In the presence of mosto, the ability of *Echinometra* to right once upended was impaired. Results suggest that *Echinometra* is highly sensitive to mosto.

2. *Chiton squamosus* was uncommonly rare in the field under conditions of mosto impact. In laboratory bioassays with this species, mortalities were greater than controls in concentrations of mosto as low as 0.01%. Mosto may affect the ability of *Chiton* to adhere to substrates. This species was deemed highly sensitive to mosto.

3. The mussel, *Brachidontes exustus*, was observed on low intertidal rocks impacted by mosto, but absent from normal habitat higher in the intertidal. Laboratory-96 hour-bioassays confirmed the resistance of *Brachidontes* to mosto. In concentrations as high as 0.05% mosto, mortalities were not different than those of controls. Stress was indicated, however, to concentrations as low as 0.005% mosto in seawater by abnormal byssal thread *Brachidontes* was deemed moderately tolerant to mosto discharge.

4. *Callinectes sapidus* did not survive field conditions in mosto discharge (Bacardi site only) despite a high degree of resistance shown by laboratory bioassays. In 96 hours bioassays *Callinectes* tolerated 0.05% mosto (discounting canibalism). Field mortalities were apparently a result of secondary effects due to low oxygen and hydrogen sulfide. Of the organisms used in bioassays, *Callinectes* was highly resistant to direct effects of mosto.

5. The overall effect of mosto at levels observed was that of restructuring the natural community. The dominant structuring element in the artificial community created was mosto itself, or that of secondary physical and hydrological effects due to the waste indirectly.

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APPENDICES ON BIOASSAY RESULTS

TABLE 17. Differences at the 1% Risk Level (99% C.I.) between test replicates using Link and Wallace's shortcut ANOVA (Tate and Clelland 1957, pp. 119-121 with tables on 147-148).

From Figure 7 (*Echinometra* survival: mosto in seawater)

Hours	Concentrations 5.0	0.5	0.05	Control
24	Same			Different
48	Different	Same		Different
72		Same		
96		Same		

From Figure 9 (*Brachidontes* survival: mosto in seawater)

Hours	Concentrations 5.0	0.5	0.05	Control
24	Same			
48	Different	Same		
72	Different	Same		
96	Different	Same		

From Figure 11 (*Chiton* survival: mosto in seawater)

Hours	Concentrations 0.5	0.05	0.01	Control
24	Same			
48	Different	Same		
72	Different	Same		
96		Different	Same	
120		Different	Same	
144		Different	Same	
168		Different	Same	

From Figure 14 (*Callinectes* survival: mosto in seawater)

Hours	Concentrations 0.5	0.05	0.01	Control
24	Same			
48	Same			
72	Same			
96	Same			
120	Same			
144	Same			
168	Different	Same		
192		Same		

APPENDIX II

THE DIFFERENCE BETWEEN MOSTO OBTAINED FROM BACARDI AND PUERTO RICO DISTILLERS

Objective

To determine whether mosto from Bacardi and mosto from P.R. Distillers have significantly different bioassay properties.

Methods

Standard 96-hour bioassays were conducted simultaneously with Bacardi mosto, P.R. Distillers mosto and a control without mosto using the same apparatus previously described. *Echinometra lucunter* was selected as a sensitive organism for the bioassays. Survival among 50 individuals after 96 hours was determined for each of four separate replicate experiments.

Results were compared for differences using Link and Wallace's short-cut Analysis of Variance. This analysis was chosen since it is a non-parametric and conservative statistical test (reference = Tate and Clelland, 1957).

Results and Discussion

Table 18, Part A reports the survival among urchins subjected to 0.5% mosto from Bacardi and 0.05% mosto from P.R. Distillers as well as controls without mosto. Potential survival (100%) in the four experiments for each treatment (column sums) was 200 individuals. In the controls, 190 survived: in P.R. Distillers mosto, 131 survived: and in Bacardi mosto, 77 survived.

Using Link and Wallace's short-cut ANOVA at the 1% risk level (99% probability of making the correct decision) highly significant differences exist between Bacardi and the control experiments (Table 18, Part B). Puerto Rico Distillers overlaps with both Bacardi and the control. At the 5% risk level (95% probability of making the correct decision) significant differences exist between Bacardi, P.R. Distillers and the controls (Table 18, Part B). Since the ANOVA test which was used is a conservative one, we can safely assume that differences exist between the properties of mosto from Bacardi and P.R. Distillers.

The obvious conclusion is that mosto from one rum distillery is not the same as mosto from another distillery. These differences in mosto may be inherent within the respective plant processes. They could be due to mosto concentration variability, or they could be due to more complex and presently unknown chemical factors. An examination of specific gravity of mosto from both plants, collected on the same days, indicates little difference in concentration (Table 19). The bioassay differences must then be due to other physical/chemical mechanisms.

In consideration of toxicity to the sea urchin *Echinometra lucunter*, Bacardi mosto is more toxic and P.R. Distillers is less toxic. Mosto from both plants is significantly more toxic as compared to controls.

TABLE 18. A Bioassay of the Differences between Bacardi and Puerto Rico Distillers Mosto (96 hour test with 0.05% mosto in seawater using 50 *Echinometra lucunter* per test).

	Number of Surviving Urchins after 96 Hours		
Test	Bacardi	P.R. Distillers	Control
1 (Nov. 13)	37	43	49
2 (Nov. 15)	12	24	49
3 (Dec. 11)	14	32	49
4 (Dec. 20)	14	32	43
TOTAL	77	131	190
RANGE	25	19	6=50

Using Link and Wallace's Short-cut Analysis of Variance at 1% (68.0= allowance) and 5% (47=allowance) risk levels.

	Bacardi	P.R. Distillers	Control
1% (99% C.I.)	Same	Same	
	Same		

	Bacardi	P.R. Distillers	Control
5% (95% C.I.)	Different	Different	Different

TABLE 19. Specific gravity of *mosto* from Bacardi and Puerto Rico Distillers.

	Specific Gravity	
Date Collected	Bacardi	P.R. Distillers
Oct. 18, 1978	1.050	1.034
Oct. 27, 1978	1.042	1.043
Nov. 9, 1978	1.045	1.034
Dec. 6, 1978	1.048	1.046
$\bar{x}$	1.046	1.039
Range	0.008	0.012

Not significantly different using Link and Wallace's nonparametric ANOVA.

APPENDIX III

THE EFFECT OF DEPRESSED OXYGEN LEVELS ON *ECHINOMETRA LUCUNTER*

Objective

To evaluate the effect of low oxygen concentrations on the urchin *Echinometra lucunter* in seawater and in seawater with mosto.

Methods

A bioassay procedure and apparatus as previously described for *Echinometra lucunter* were employed. Two treatments, one with 0.05% mosto in seawater and one with seawater alone were allowed to deplete to low levels of oxygen content by diverting a flow-through seawater exchange. After an effect was observed upon the urchins in the mosto treatment (in this case, the inability to move spines), flow-through exchange was resumed and oxygen levels returned to ambient. Control urchins, replicating the treatments, remained at the ambient oxygen conditions with flow-through exchange for the entire period of the experiment.

Results and Discussion

The results are plotted in Figure 21. In the 0.05% mosto treatment, oxygen depletion to less than one ppm occurred after 10 hours (27°C). In seawater without mosto, depletion to the same level occurred after 20 hours. Oxygen levels were restored to normal after 26 hours and continued to 50 hours. Thus, the urchins in the mosto treatment were subjected to low oxygen for 16 hours and urchins in the seawater treatment were subjected to low oxygen for six hours. This level of exposure in the mosto treatment caused total mortality (as determined after 50 hours). In the seawater treatment recovery began when oxygen was restored and survival after 50 hours was 75 percent. All control urchins in the ambient flow-through setup survived.

Two conclusions are evident:

1) that mosto in seawater depletes of oxygen more rapidly than seawater alone,

2) that a period of oxygen deprivation between six and 16 hours will cause total mortality in an *Echinometra* population. For shorter periods, less than six hours, *Echinometra* has the potential to withstand and recover from a low level of dissolved oxygen in its environment.

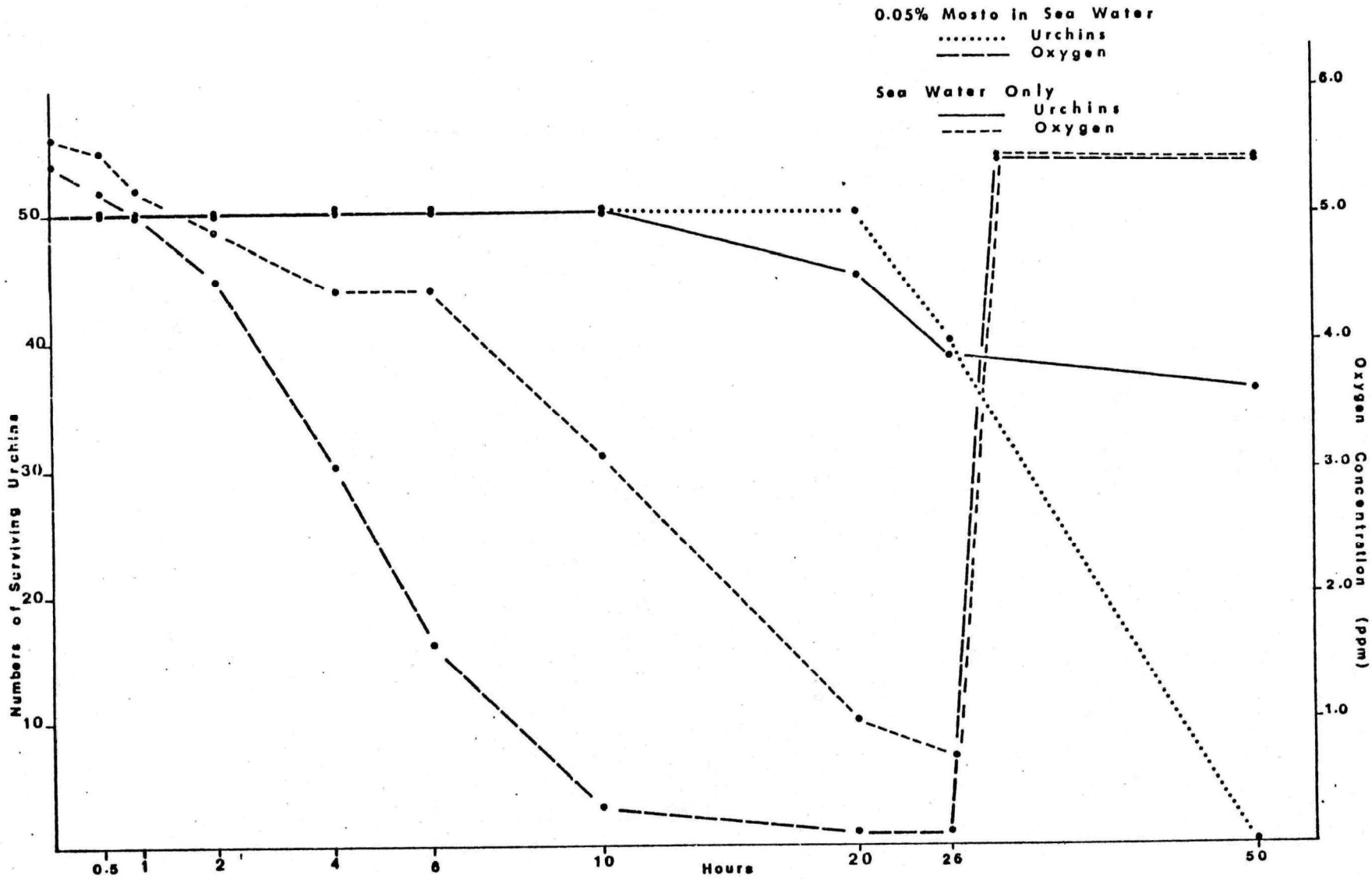


Figure 21. The effect of oxygen depletion on the sea urchin, *Echinometra lucunter*.

APPENDIX IV

THE ORIGIN OF SLIME PRODUCED IN SEAWATER WITH MOSTO

Objective

To determine whether the slime-like substance produced when mosto is mixed with seawater has physical-chemical or biological origin.

Methods

A technique was employed using combinations of autoclaved (sterilized) and non-autoclaved (unsterilized) mosto and seawater. By observing whether or not certain combinations resulted in the formation of the slime, a preliminary evaluation could be made on its living or non-living nature. Previous visual examinations with a microscope were unsatisfactory since the slime, when formed, quickly becomes contaminated with micro-organisms. The slime discussed has been observed forming both in the laboratory (bio-assays) and in the field (St. Croix Distillers and Puerto Rico Distillers).

Four sterile and non-sterile combinations were mixed accordingly: 1) non-sterile mosto in sterile seawater, 2) sterile mosto in non-sterile seawater, 3) sterile mosto in sterile seawater, and 4) non-sterile mosto in non-sterile seawater. Each flask containing 200 milliliters of solution was stoppered with sterile cotton and all flasks were incubated for 48 hours under an enclosed hood. Two concentrations, one with 0.5% and another with 0.05% mosto were examined.

Results and Discussion

The results, (Fig. 22), demonstrate that the slime-like substance does not form in sterile mosto mixed into sterile seawater, nor in non-sterile mosto in sterile seawater. These data preclude physical-chemical activity or biological activity in the mosto as the slime source. The slime did form however in sterile mosto mixed with non-sterile seawater, and in non-sterile mosto in non-sterile seawater (Fig. 22). These latter data suggest that the slime-like substance, as observed in seawater containing mosto, is the result of a micro-biological agent in seawater. Since the organism is not a blue-green algae (it develops in the absence of light), it is probable that it is caused by a fungal or bacterial agent.

The conclusion is further supported by results of Tosteson *et al.*, 1973, who determined that mosto promotes the growth of marine bacteria (crude mosto concentration between 0.1 and 2.0 gms/liter) while inhibiting the growth of micro-algal cells (*Chlorella*).

Reference

Tosteson, T.R., B.R. Zaidi, D.Hale and K. Verner. 1973. The effect of the mosto on the growth of marine micro-organisms. Rum Pilot Plant Report PPR:1-73, October 1973. Published by the Agricultural Experiment Station College of Agriculture Sci., Mayaguez Campus, U.P.R.,Mayaguez, P.R.00708.

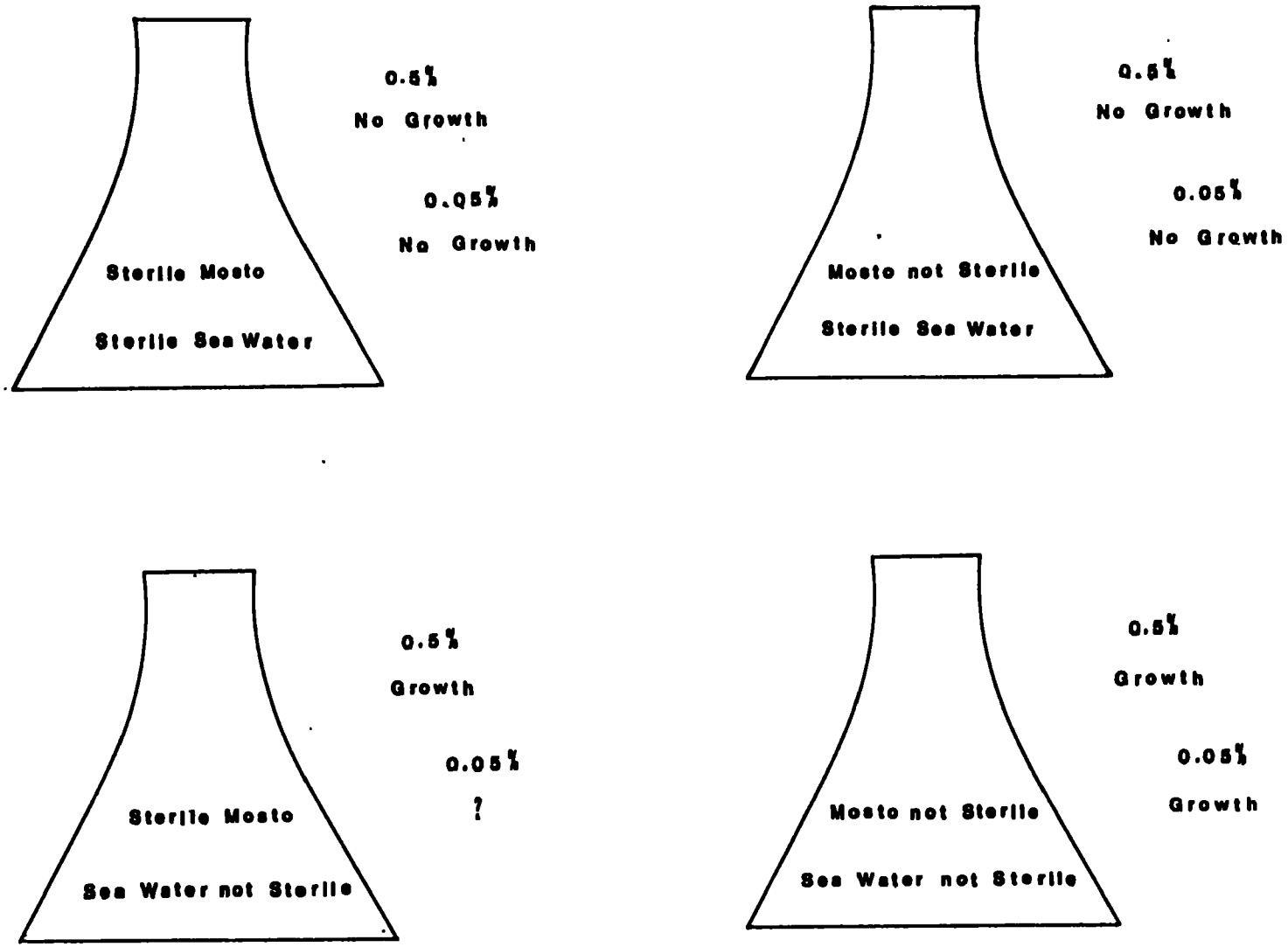


Figure 22. The formation of slime in sterile (autoclaved) and non-sterile (non-autoclaved) mosto and seawater.

APPENDIX V

A BIOASSAY OF MOSTO USING MARINE BENTHIC ALGAE

Objective

To provide a preliminary examination of positive or detrimental effects of mosto diluted with seawater to growth of several marine algae.

Methods

A standard 96 hour bioassay as previously described was employed. Three marine algae, *Ulva lactuca*, *Hypnea musiformis* and *Gracilaria sp.*, were tested in 0.05% mosto in seawater. Except for attenuation of light due to the color in mosto, conditions for treatments and controls were equivalent. Change in biomass was measured by volume displacement.

Results and Discussion

The results show a positive increase in biomass (mean differences, Table 20) for *Ulva* and *Gracilaria* and a slight decrease for *Hypnea* after 72 hours. However, statistical evaluation (Student's t test) indicates no significant differences between the means.

These preliminary data, although not confirming a positive effect on growth, appear to discount the possibility of large scale detrimental effects of mosto to the growth of marine algae at dilutions greater than 0.05%. Since mosto at least has the potential of stimulating growth in marine algae further research in this area is in order.

In certain areas downstream of Puerto Rico Distillers outfall and proximal to the Bacardi outfall where dilution occurs algae have been observed to be unusually abundant. If the phenomenon is due to the presence of mosto, it could be either through the elimination of normally important grazers or enrichment directly affecting algal growth.

TABLE 20. Effect of 0.05% Mosto on Algal Biomass after 72 hours measured by volume displacement in milliliters.

Ulva lactuca

Control 0 hrs	72 hrs	Difference	Treatment 0 hrs	72 hrs	Difference
565	560	- 5	610	560	- 50
570	560	-10	540	580	40
555	555	0	570	610	40
570	563	- 7	575	568	- 7
573	560	-13	540	553	13
	$\bar{x}$ =	- 7		$\bar{x}$ =	7

Means not significantly different.

Hypnea musciformis

Control 0 hrs	72 hrs	Difference	Treatment 0 hrs	72 hrs	Difference
53	56	3	57	56	- 1
54	58	4	54	54	0
60	60	0	55	58	3
58	64	6	58	66	8
56	57	3	57	62	5
	$\bar{x}$ =	3.2		$\bar{x}$ =	3

Means not significantly different.

Gracilaria

Control 0 hrs	72 hrs	Difference	Treatment 0 hrs	72 hrs	Difference
207	212	5	212	220	8
213	210	- 3	206	208	2
210	210	0	211	210	- 1
207	208	1	212	212	0
208	208	0	210	214	4
	$\bar{x}$ =	0.6		$\bar{x}$ =	2.6

Means not significantly different.

SECTION III

CHEMICAL MEASUREMENTS IN THE ARECIBO RUM DISTILLERY MARINE WASTE DISCHARGE STUDY

INTRODUCTION

This section discusses some of the chemical and physical aspects of a study of the influence of the Puerto Rico Distillers Co., wastewater discharge on the marine environment of the coast of Arecibo. The effluent discharge is composed of rum distillery slops (mosto) and process water. The resulting wastewater stream is relatively hot (approximately 40°C), diluted mosto of a tea-like color. A complete chemical characterization of this wastewater has been conducted by the U.S. Environmental Protection Agency Laboratory at Athens, Georgia.

The discharge outfall is positioned in such a fashion as to dump the effluent directly on the beach, a short distance below the cliff where the distillery is located. The waste flows on the beach for 75 meters as a meandering stream and meets the surf near a massive rocky outcrop on the water's edge. Some of the biological observations discussed in other chapters focused on this rocky intertidal environment. As the waste enters the ocean, it mixes, diffuses and disperses, forming a visible plume which can be seen usually moving westward and hugging the shore for several miles. Details of the plume's behavior are discussed in a separate chapter (see the Physical Oceanography section). The discoloration due to the distillery effluent can be seen to remain close to the coast and to come ashore on the beaches and rocky areas along the coast. In this study we measured the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of these waters as an indirect estimate of the organic matter loading resulting from the distillery waste. The results give an estimate of distribution of the waste along the coast of Arecibo. Observations were made at intervals within 8.5 km east and 8.0 km west of Puerto Rico Distillers Co. Other measurements made included turbidity, temperature, dissolved oxygen and salinity. We also measured the trace heavy element content of beach sediments.

METHODS

Water and sediment sampling stations were established at accessible points on the shore from Islote, 8.5 km east of the distillery's outfall, to 8.0 km west of this outfall. Station locations are shown in Figures 23 and 24. We decided to sample the surf waters instead of sampling offshore, since the waste plume appeared to remain adjacent to the coast and to come ashore

Figure 23. Arecibo shoreline showing station locations.

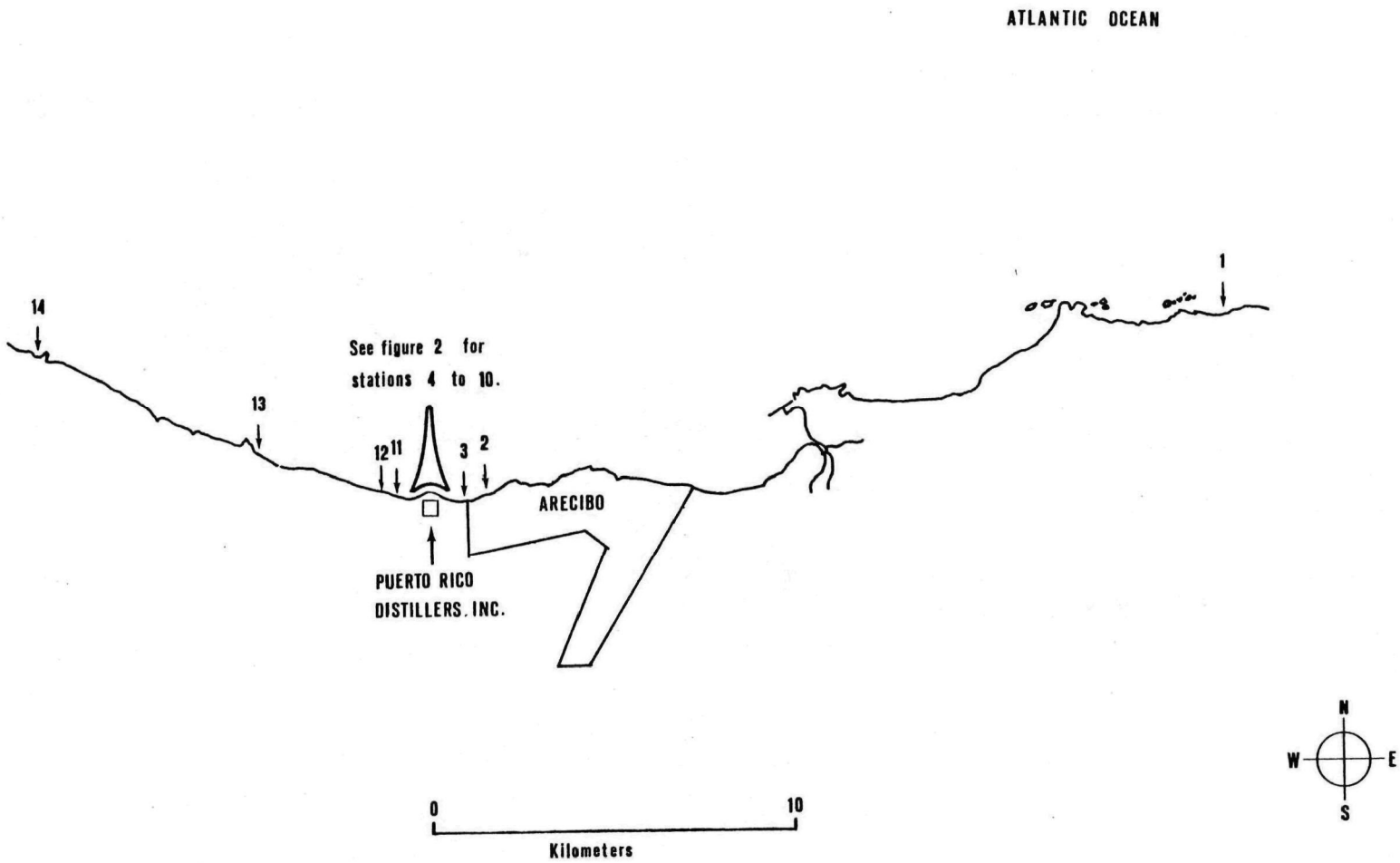
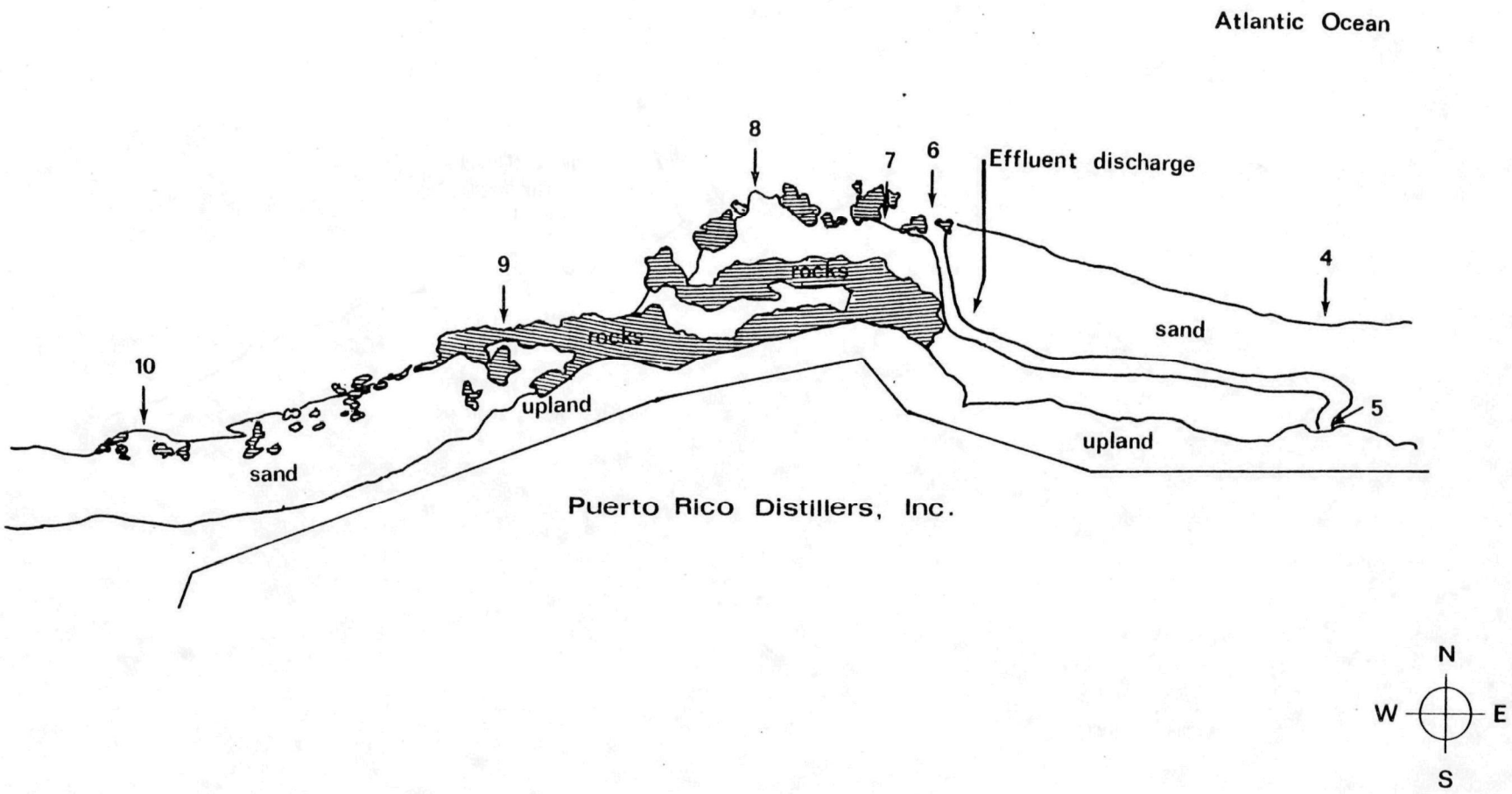


Figure 24. Sampling stations in the vicinity of Puerto Rico Distillers, Inc. effluent discharge.



continuously. Also, due to the prevailing rough seas and the numerous submerged rock outcroppings near the shore, it was not possible to operate a boat safely within most of the area affected by the plume.

Water samples were obtained by wading into the sea and dipping the appropriate containers after rinsing them thoroughly in this water. Samples for BOD were collected in pre-washed, 1 liter polyethylene cubitainers, stored over ice, in the dark, and transported to the laboratory where they were analyzed within six hours of collection. Samples for COD were collected in pre-washed 500 ml glass bottles and were preserved by adding 1 ml of concentrated H_2SO_4 on site. A piece of aluminum foil liner was used to cover the mouth of the bottles to prevent contact of the sample with the bottle cap. Water samplings were conducted on various dates through July and August. Our sampling included both periods of mosto discharge and periods when the waste stream was clear and contained no mosto.

Sediment samples for trace heavy element analysis were obtained from the area of the beach bathed by the waves at the same location where water was sampled. No sediment could be collected at the Islote site (Station 1) because the shoreline there is solid rock. The sediment samples were placed in plastic containers and kept refrigerated at 4°C until analysis.

Biochemical Oxygen Demand

Five-day biochemical oxygen demand (BOD_5) was determined on water samples following the method prescribed by U.S. Environmental Protection Agency (1973) and APHA, *et al.* (1976). Determinations were performed in duplicate, incubating in the dark for five days at 20°C and using a YSI, BOD oxygen sensing probe with a YSI 57 dissolved oxygen meter for the initial and final dissolved oxygen measurements. The appropriate corrections for the effect of salinity on oxygen solubility were made directly on the meter for each sample. The meter was calibrated daily. Dilutions were made where appropriate. Distilled, deionized water used for dilution was kept in the incubator at 20°C. An enclosed, air-conditioned room was kept at this temperature and a special thermostatic water bath was built to accommodate a large number of BOD bottles at 20°C. Dissolved oxygen readings were conducted under strictly controlled temperature conditions resulting in excellent agreement between replicates. Results are presented as the average value of duplicates in mg-O_2/l.

Chemical Oxygen Demand

Chemical oxygen demand (COD) was conducted on water samples as outlined by U.S. Environmental Protection Agency (1973) for high level saline wastes. A correction for chloride interference was applied as recommended. Chloride concentrations were estimated from salinity values. In this method, an aliquot of the sample is treated with an excess of $K_2Cr_2O_7$ and digested for 2 hours under reflux with H_2SO_4, Ag_2SO_4 (as catalyst) and $HgSO_4$ to eliminate chloride interference. The excess of dichromate, after digestion, is determined by titration with standard $Fe(NH_4)_2(SO_4)_2$. Duplicate determinations were performed and results are presented as the average values mg-O_2/l.

Turbidity

Turbidity was determined in the laboratory on portions of the water samples used for the BOD determinations. We used a Model DRT-200 turbidity meter. Results appear in nephelometric turbidity units (NTU).

Dissolved Oxygen and Temperature

To measure dissolved oxygen and temperature in the field, we used a Model 57 YSI oxygen meter and sensing probes. The oxygen probe was calibrated daily. The instrument provided for correction of the effect of salinity on oxygen solubility. Results are offered in mg-O_2/l and temperature is reported in degrees Celsius.

Salinity

We measured salinity by direct reading on an American Optical hand-held refractometer of a precision of ± 0.5 parts per thousand (ppt). Readings are reported in ppt or g/kg.

Trace Heavy Element Analysis of Sediments

Beach sediments were wet-digested and the digestates analyzed for Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn by flame atomic absorption spectrophotometry (AAS). Sediments were oven-dried overnight at 60°C and ground to a powder with a porcelain mortar and pestle. Two-gram triplicate portions were weighed into acid-washed pyrex beakers. To each sample 25 ml of a 3:1 mixture of HNO_3:HCl was added and refluxed in the beaker covered with a watch glass at 90-95°C until 1 ml remained. After cooling, 30 ml of H_2O_2 30% solution was slowly added and refluxed until 1 ml remained. This was repeated three times, and a final reflux with 6 ml of 2N HCl was stopped when 3 ml remained. The material was transferred quantitatively to plastic centrifuge tubes and after centrifugation at 1700 rpm for 20 minutes, the supernatant was decanted carefully and brought to volume in a 10 ml volumetric flask with distilled, deionized water. Trace heavy element determinations were performed by direct aspiration of this digestate into a Perkin-Elmer 303 AAS using D_2-Arc background correction. Results are reported in µg/mg or mg/gm.

RESULTS AND DISCUSSION

Biochemical Oxygen Demand

Distribution of BOD_5 along the coast of Arecibo for various dates are summarized in Table 21. The highest BOD_5 values correspond to sampling at station 5, which is the end of the outfall pipe. This represents the full-strength effluent before it reaches the marine environment. Values ranged from 1100 to 1680 mg/l at the effluent outfall. A 24-hour composite sample of mosto from the distillery, provided by US Environmental Protection Agency, showed a BOD_5 value of 23,000 mg/l or approximately 14 times the BOD_5 levels

TABLE 21. Distribution of BOD_5 ($mg\text{-}O_2/l$) at Selected Stations on the Coast of Arecibo on various Dates in 1978.

Station	BOD_5 ($mg\text{-}O_2/l$)					
	July 7	July 12	July 14	July 21	August 8	August 10
1	1.05	0.35	0.95	0.35	0.70	-
2	1.55	0.65	1.95	0.75	1.00	1.75
3	1.15	0.90	1.20	0.70	1.40	1.00
4	6.40	0.00	1.95	0.25	10.00	3.25
5	1500	1660	1100	1680	1590	1660
6	180	5.95	5.05	770	670	950
7	0.65	1.15	3.35	530	280	270
8	0.65	0.65	4.10	70.00	50	100
9	0.95	0.10	2.60	250	15.00	47.50
10	0.30	0.15	3.20	220	12.50	77.50
11	0.90	0.00	2.15	210	15.00	52.50
12	0.55	0.00	1.20	6.00	0.00	16.00
13	0.70	0.00	0.70	1.65	0.30	5.85
14	0.55	0.00	0.60	0.20	0.05	0.85
15	-	-	-	-	0.10	-

Dash (-) indicates that no measurement was made.

measured at the outfall. Substantial dilution of mosto occurs in the distillery's waste prior to discharge in the environment. On July 7, 12, and 14 the effluent wastewater from the outfall was clear and colorless. However, relatively high BOD_5 was observed for these waters. The waste had a very strong smell of alcohol, a substance likely responsible for the high BOD_5 values observed. During these dates, total waste flow was small (approximately 2 m^3/min or less).

Station 6, which represents the area of waste mixing with seawater, varied widely in BOD_5 content (from 5.05 to 950 mg-O_2/1). The lowest values at station 6 were observed during July 7, 12, and 14 when no mosto was being discharged. During mosto discharge, waste dilution at station 6 was approximately by a factor of two when compared to the outfall (Station 5). The waste plume moved largely westward against the beach with the prevailing currents. It usually had components moving offshore and moving eastward on some occasions. This is reflected in the BOD_5 data where those stations westward of station 6 showed progressive dilution of BOD_5 as a function of distance from station 6, the entry point. Data for station 4 during mosto discharge times give some evidence of a small component of the waste stream moving eastward.

Stations 1, 2, and 3 represent reference areas which are located east of the outfall in areas relatively unaffected by mosto discharge. At station 1 in Islote, the farthest away (8.5 km) from the outfall point, BOD_5 values are relatively low, as they are at stations 14 and 15 to the west. These values are normal background or ambient values for shore waters in the area. Occasional sewer outfalls occur along the coast of Arecibo, which probably contribute locally to BOD_5 loading of these waters. A major influence in this respect may be the Río Grande de Arecibo that flows into the embayment formed by the Arecibo Harbor.

The BOD_5 data appear to indicate a return to ambient levels in the shore waters within 3 km west of the outfall (station 15). On August 10, traces of the waste (as indicated by BOD_5) could be found at station 13 or 4 km away from the entry point. By contrast, on August 8 the water coming ashore on station 12, 0.5 km away from station 6, appeared devoid of an excess of BOD_5 showing a return to ambient level within that distance. On this occasion, the waste plume followed an unusual pattern flowing northeasterly and away from shore.

Figures 25 and 26 show graphically the distribution of BOD_5 in the shore waters of Arecibo showing the contrast dates when the distillery's effluent did and did not include mosto. This is shown as a function of distance east and west of station 6, which is plotted as the origin in these graphs. The figures show a small inflection in the curve near the outfall area during the time of no mosto discharge. Although relatively low, this inflection represents a BOD_5 addition above ambient by the Puerto Rico Distillers Co.'s outfall. The curve during a mosto discharge day (Fig. 25) shows a very sharp rise in BOD_5 at the origin in front of the distillery and a relatively sharp decline in these values moving away from the origin. The area under the curve represents the mass of BOD_5 as

Figure 25. Variation in BOD_5 in shore waters of Arecibo as related to distance from Puerto Rico Distillers, Inc. on July 14, 1978.

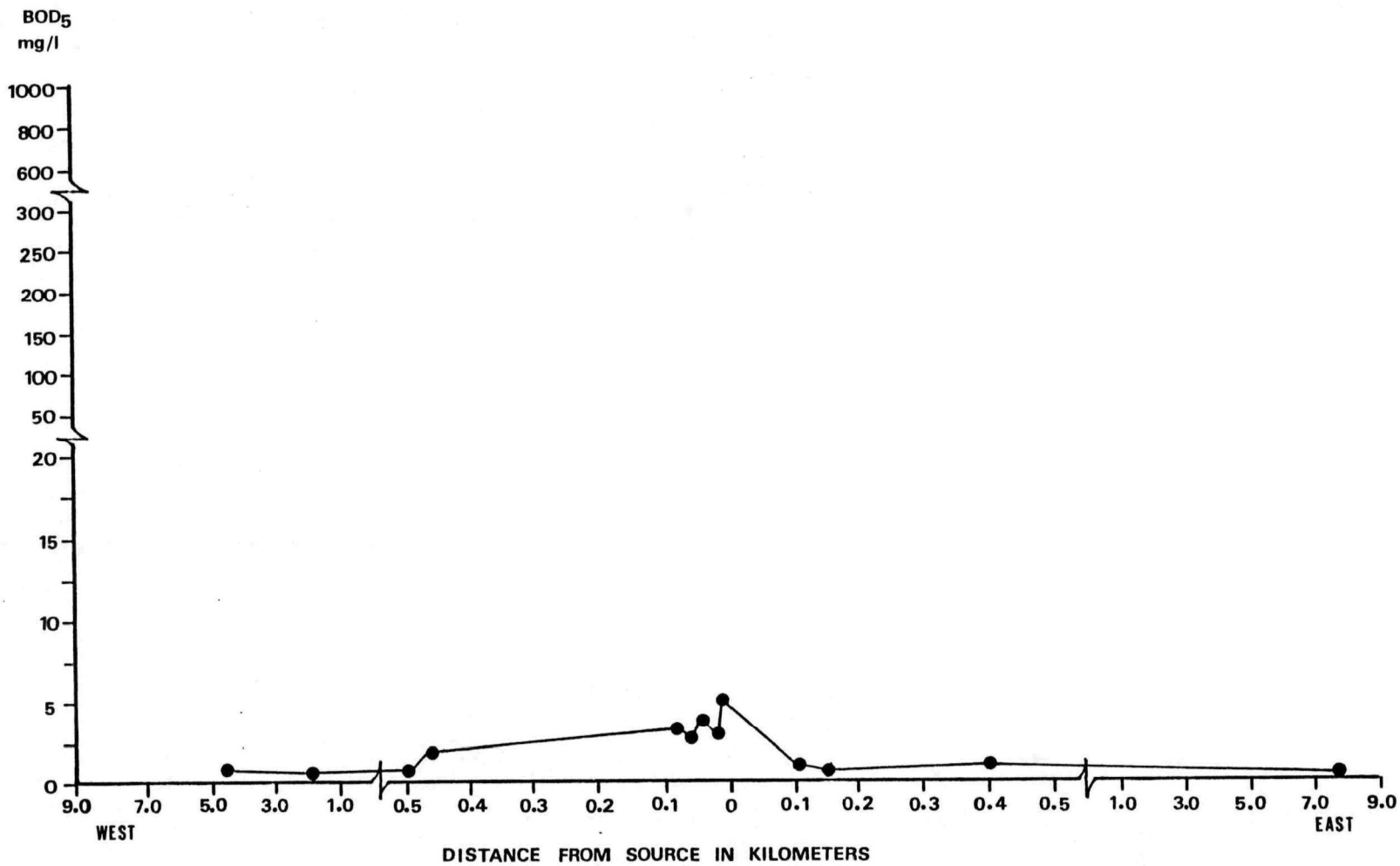
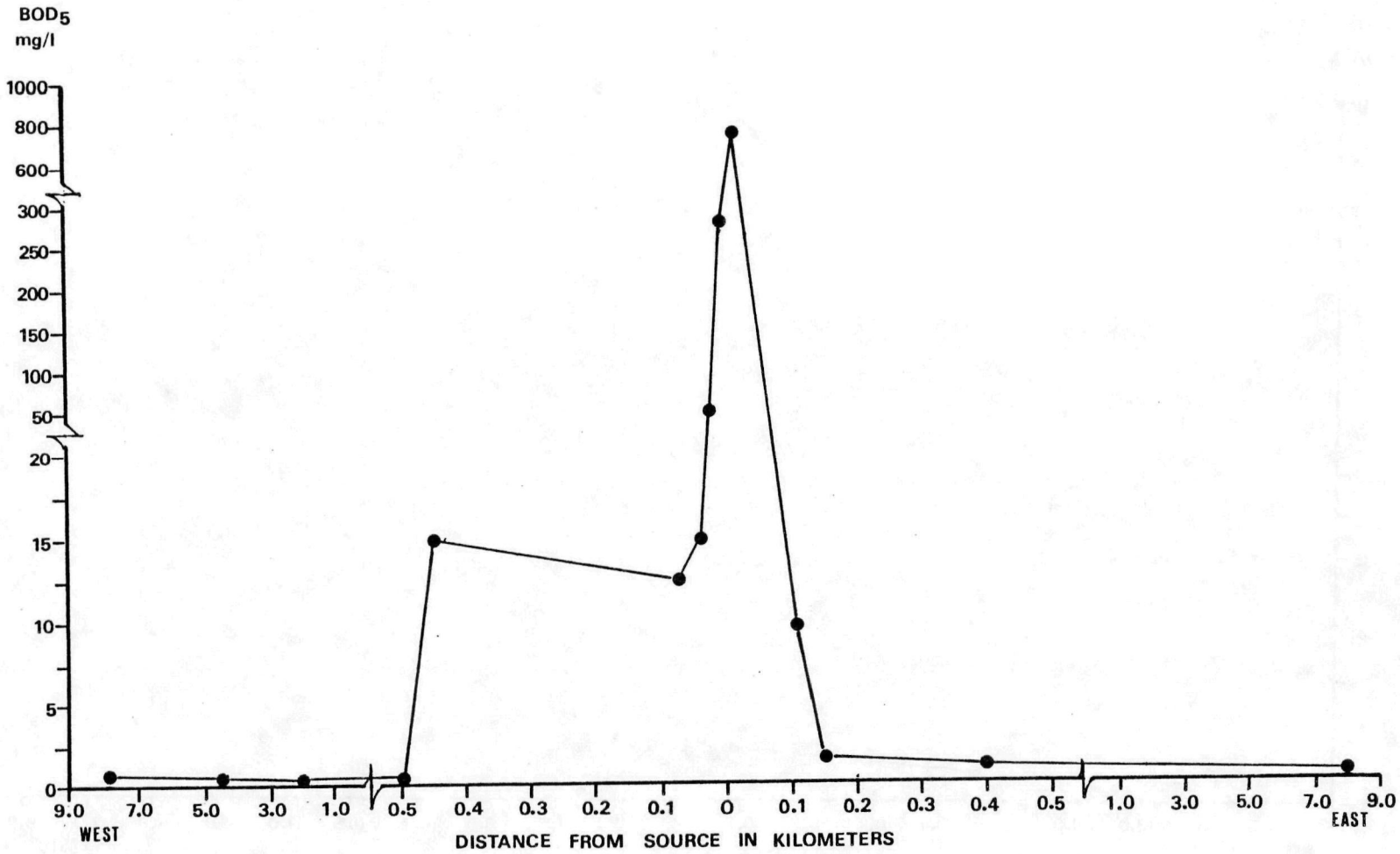


Figure 26 Variation in BOD_5 in shore waters of Arecibo as related to distance from Puerto Rico Distillers, Inc. on August 8, 1978



distributed against the shore. The shape of the curve indicates a substantial waste mass to the west of station 6. This is further evidence of the visually observed westward transport of the colored waste along the shore.

Chemical Oxygen Demand

Values of COD in the shore waters followed closely with the distribution of BOD_5 values discussed above. Table 22 lists COD data by station for various dates. The outfall values of COD ranged from 8448 to 24000 mg-O_2/1. Dilution of the waste's COD is apparent from Table 22 following patterns similar to BOD_5. These data also support the westward transport model of the waste plume described above. COD is not a very satisfactory parameter to describe oxygen demand of organic waste in seawater owing to problems of chloride interference in high salinity waters. Provisions in the methodology to correct for these errors are highly empirical and subject to inaccuracies.

Turbidity

Additional information to characterize the shore waters of Arecibo is offered in Table 23 in the form of turbidity measurements. During mosto discharge periods, turbidity of the waste at the outfall ranged from 70 to 302 NTU. Turbidity decreased sharply as the waste stream travelled over the beach to its mixing place with the sea (station 6) and then continued to decrease slowly westward along the shore. Again, the extreme stations represent background or ambient turbidity in the range of 0.06 to 1.85 NTU. Variations in turbidity along the coast of Arecibo are probably related to local conditions near sewer outfalls, the river and areas of land runoff. However, the turbidity values observed at and near Puerto Rico Distillers Co. discharge are well above this background variability and represent the influence of the mosto waste mass as it diffuses in the area waters. Figures 27 and 28 demonstrate this graphically showing turbidity distribution in the shore waters as a function of distance from the waste origin on days of discharge and no discharge of mosto. These curves are analogous to those for BOD_5 where a general trend of westward transport of the waste along the shore is documented.

Salinity, Temperature, and Dissolved Oxygen

Salinities of the Arecibo waters are listed in Table 24 for various dates. The salinity values are indicative of a well-mixed ocean with relatively uniform distribution in the area. These values were usually from 34.0 to 36.0 ppt in unaffected areas with a small depression in salinity at the place of mixing of the waste with the ocean, where dilution of the seawater occurred locally. Salinity values returned to ambient levels a short distance away from this mixing area. For the purpose of tracing the path of the waste plume, salinity alone would be inadequate, as only at the mixing locality are differences observed. Table 25 details salinity, temperature and dissolved oxygen at stations 1 through 14 on August 24. Salinity of the waste at the outfall was 2.0 ppt diluting the seawater to 20.0 ppt at the mixing place (station 6). Back-to-ambient values were found in areas immediately adjacent and elsewhere as well. Ambient temperature of the shore waters

TABLE 22 Chemical Oxygen Demand in Waters from Selected Stations on the Coast of Arecibo on Various Dates in 1978.

	COD, $mg\text{-}O_2/l$				
Station	July 14	July 21	August 4	August 10	August 24
1	96.60	67.80	63.00	-16.08	34.61
2	103.80	72.60	121.51	15.00	9.26
3	96.60	53.40	39.60	92.40	30.00
4	99.00	68.76	-	5.40	10.97
5	-	24000.00	-	8448.00	11155.20
6	-	2000.00	-	3456.00	-
7	94.20	900.00	-	672.00	126.17
8	114.00	1400.00	-	270.00	98.52
9	97.20	240.00	-	171.60	103.13
10	110.16	174.00	164.40	130.78	146.90
11	104.40	141.00	97.20	103.13	98.52
12	96.60	75.00	61.20	34.20	96.27
13	53.40	70.20	89.40	75.00	134.23
14	-	84.60	101.40	53.40	168.79
15	-	-	32.40	-	-

Dash (-) indicates that measurement was not made.

TABLE 23. Distribution of Turbidity (NTU) at Selected stations on the Coast of Arecibo on Various Dates in 1978.

Station	Turbidity, NTU					
	June 21	July 14*	August 4	August 8	August 10	August 24
1	0.06	0.38	4.10	1.15	0.39	1.40
2	2.05	0.42	7.00	7.20	2.40	4.50
3	0.46	0.34	0.28	0.64	0.34	4.40
4	0.72	0.30	0.26	2.05	1.10	2.60
5	70.20	2.15	302.00	200.00	200.50	102.50
6	7.00	2.80	60.40	30.5	10.30	50.60
7	17.00	0.55	20.60	10.29	10.15	40.20
8	1.00	0.36	1.05	4.80	0.71	30.50
9	0.78	0.56	1.05	2.40	1.50	3.30
10	0.54	0.42	1.10	2.50	0.56	10.15
11	0.74	0.30	0.44	2.00	0.95	4.10
12	0.41	0.25	0.30	1.20	0.34	3.70
13	1.15	4.60	0.325	4.00	0.48	1.10
14	0.20	0.24	0.29	1.15	0.32	2.15
15	-	-	0.22	1.85	-	-

Dash (-) indicates that no measurement was made.
(*) Indicates no mosto discharge.

Figure 27. Variation in Turbidity in shore waters of Arecibo as related to distance from Puerto Rico Distillers, Inc. on July 14, 1978.

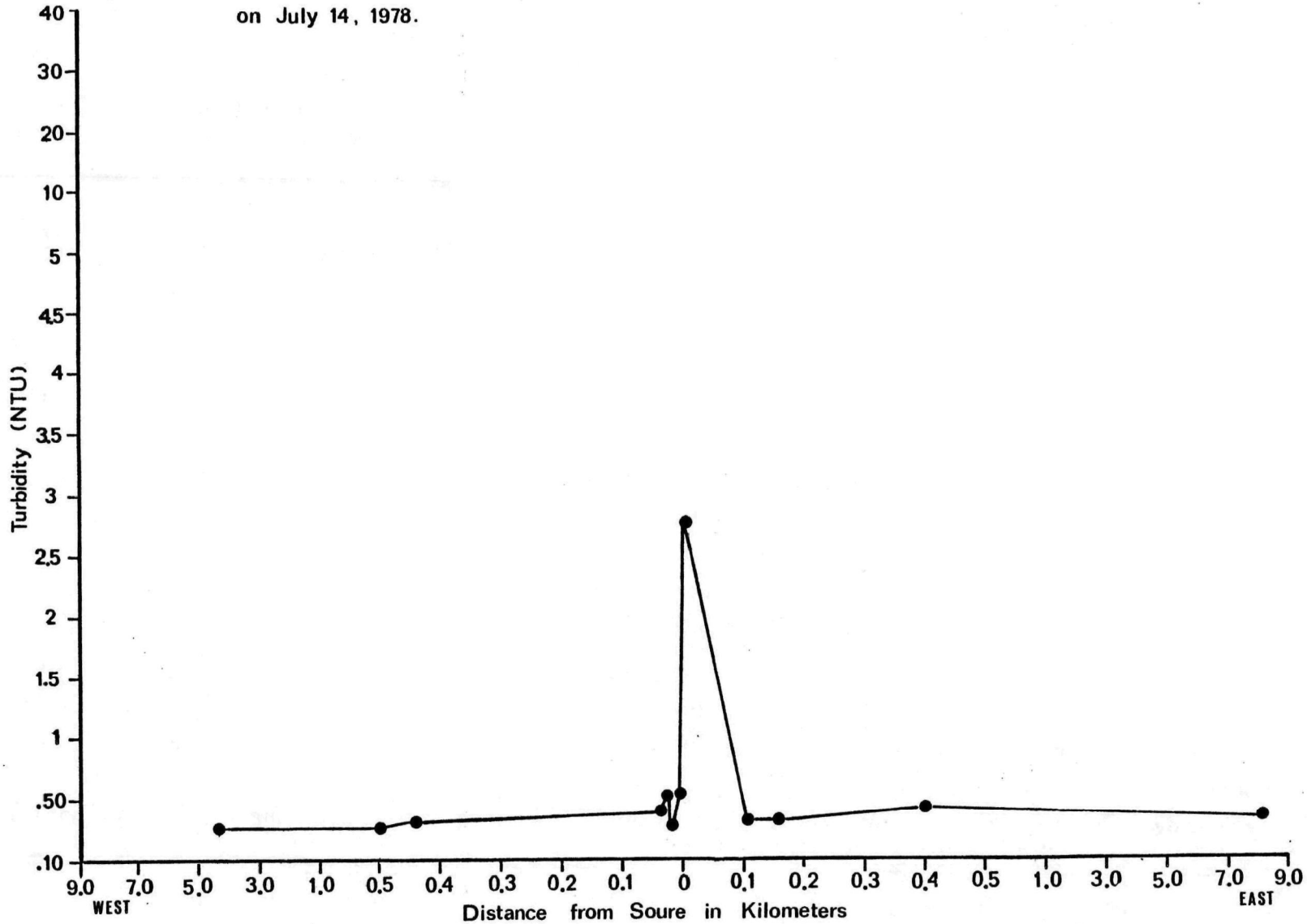


Figure 28 Variation in Turbidity in shore waters of Arecibo as related to distance from Puerto Rico Distillers, Inc. on August 8, 1978.

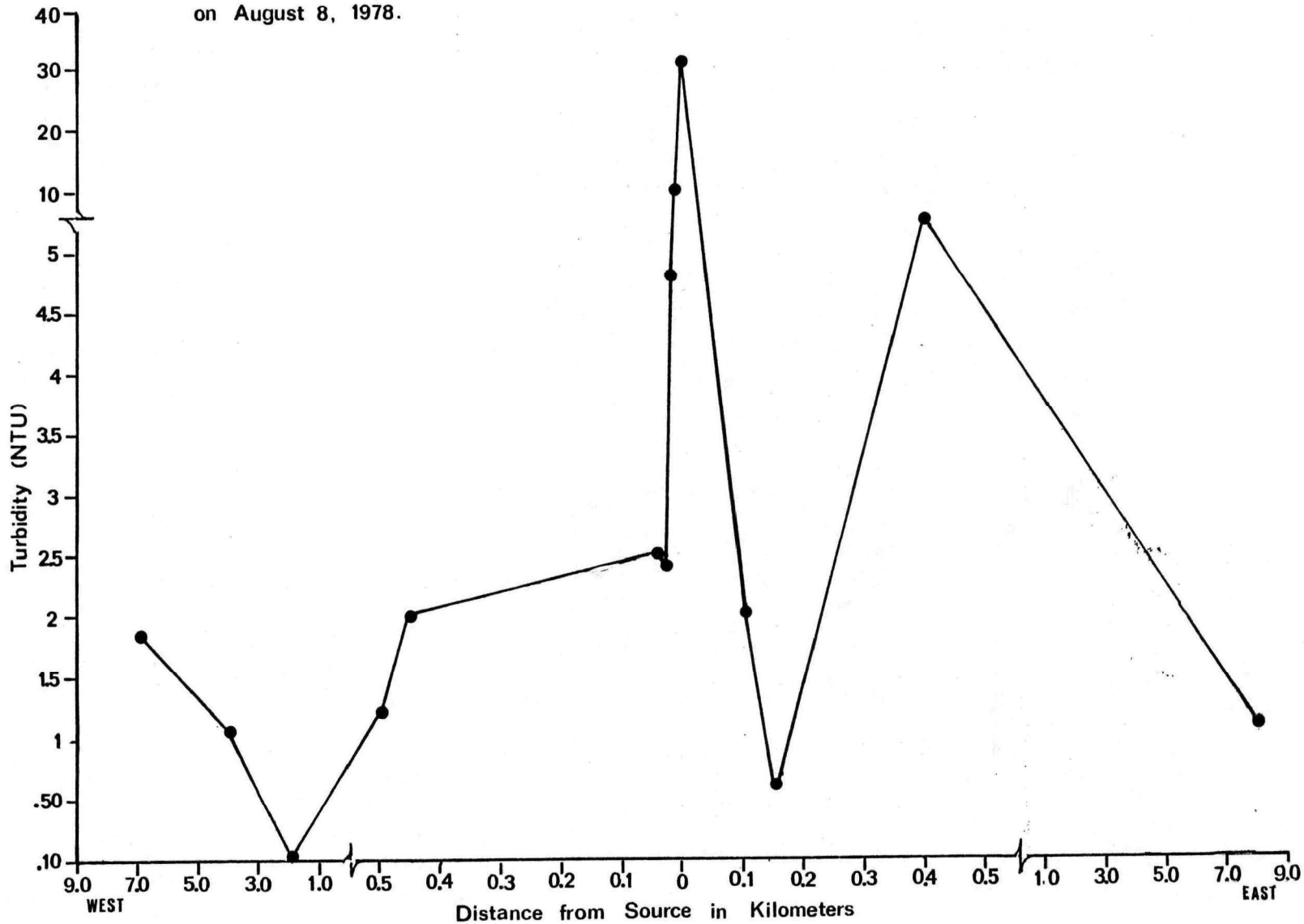


TABLE 24. Distribution of Salinity (ppt) at Selected Stations on the Coast of Arecibo for Various Dates in 1978.

	Salinity, ppt				
Station	July 21	Aug 4	Aug 8	Aug 10	Aug 24
1	35.0	35.0	34.0	35.0	34.0
2	35.0	31.0	35.0	35.0	34.0
3	35.0	34.0	35.0	34.0	34.0
4	35.0	34.0	35.0	35.0	36.0
5	0.0	4.0	1.0	2.0	2.0
6	20.0	12.0	25.0	20.0	20.0
7	25.0	28.0	30.0	32.0	35.0
8	34.0	33.0	34.0	34.0	35.0
9	34.0	33.0	34.0	34.0	35.0
10	34.0	34.0	35.0	35.0	35.0
11	35.0	34.0	36.0	35.0	35.0
12	35.0	34.0	35.0	-	35.0
13	35.0	35.0	35.0	35.0	35.0
14	35.0	35.0	35.0	-	35.0
15	-	35.0	-	-	-

Dash (-) indicates that no measurement was made.

TABLE 25. Salinity, Temperature and Dissolved Oxygen Distribution at Selected Stations on the Coast of Arecibo on August 24, 1978.

Station	Salinity (ppt)	Temperature (°C)	Dissolved Oxygen (mg/l)
1	34.0	28.0	6.5
2	34.0	28.0	5.8
3	34.0	28.5	6.0
4	36.0	28.0	6.0
5	2.0	39.0	4.2
6	20.0	35.0	4.2
7	35.0	28.5	5.6
8	35.0	28.5	5.5
9	35.0	28.5	5.7
10	35.0	28.5	5.2
11	35.0	28.5	5.7
12	35.0	29.0	6.0
13	35.0	29.0	6.0
14	35.0	28.0	5.8

varied from 28.0°C to 29.0°C from Islote to MasterMix (station 14). The waste at the outfall registered 39.0°C and was 35.0°C at the mixing locale. Immediately adjacent areas were 28.5°C or ambient values. Dissolved oxygen values were at or near saturation in the shore waters of Arecibo. Values ranged from 5.8 to 6.5 mg/l in areas far away from the waste origin. There appeared to be a depression in dissolved oxygen at the mixing area and the immediate vicinity. Dissolved oxygen concentration was 4.2 mg/l at the outfall and at the mixing point. Some depletion was also apparent westward of this location, supporting our earlier conclusions from data presented above. This influence was apparent as far west as station 12, 0.5 km away from the source.

Trace Heavy Elements in Beach Sediment

We present results of trace heavy element determination on Arecibo beach sediments in Table 26. The material on the beach was generally coarse sand. Relatively low amounts of trace heavy elements were found in the area sediments. Cadmium occurred in the lowest concentrations of all elements measured, showing less than 0.25 µg/gm at all stations. Iron occurred in the highest concentrations ranging from 10 to 133 mg/gm followed by manganese at from 123 to 295 µg/gm. Lead, copper and chromium were less than 20 µg/gm and nickel was less than 10 µg/gm at all stations. The zinc concentration ranged from 10 to 43 µg/gm. Chromium, iron and lead appear to be slightly higher in the beach area adjacent to Puerto Rico Distillers Co. outfall (stations 3, 4, 6 and 7). The values observed here are not significantly different from values observed along the coastline of Arecibo. The various sewer outfalls and other effluents into this area can be responsible for localized variability in the area sediments trace heavy element content. There is no readily apparent trend in these data to suggest that the distribution of said elements in the sediments is influenced by mosto discharge. The amounts of these elements found in the sediments are probably of little or no adverse environmental significance. This can only be ascertained through further study of the sediments and their potential influence (toxicity enhancement) on aquatic life.

TABLE 26. Trace Heavy Element Content of Sediments from Selected Stations on the Coast of Arecibo

Station	Cd ug/gm	Cr ug/gm	Cu ug/gm	Fe mg/gm	Mn ug/gm	Ni ug/gm	Pb ug/gm	Zn ug/gm
2	<0.25	7.6	14.1	60.2	286.9	7.0	11.8	43.1
3		6.7	13.2	44.9	238.8	5.9	12.4	34.4
4		15.5	10.0	133.5	241.5	6.3	10.0	32.1
5		5.0	11.4	31.3	188.2	5.4	6.0	20.0
6		5.0	16.2	34.5	218.8	5.5	19.3	22.3
7		10.8	15.5	73.2	250.2	6.5	10.2	24.7
8		2.8	12.0	10.6	123.7	<1.8	<6.0	11.5
9		4.9	11.6	10.0	126.5	1.8	<6.0	25.2
10		6.5	12.1	24.1	176.0	3.1	7.7	30.7
11		4.6	10.1	10.3	225.1	<1.8	<6.0	9.6
12		8.3	18.6	71.3	295.0	4.6	10.5	22.0
13		8.3	15.0	34.5	273.1	3.1	6.8	19.7
14	<0.25	6.0	17.8	11.2	194.2	1.8	<6.0	12.8

REFERENCES

APHA, AWWA and WPCF. 1976. Standard methods for the examination of water and wastewater. 14 ed. Washington, D.C.

Lopéz, J.M. 1976. Evaluation of the elutriate test for heavy metals released during the aquatic disposal of dredged sediments. Ph.D. dissertation, The University of Texas at Dallas.

US Environmental Protection Agency. 1973. Manual of methods for chemical analysis of water and wastes. Office of Technology Transfer, Washington, D.C.

SECTION IV

SUSPENDED MATTER AND PRIMARY PRODUCTIVITY

Suspended matter resulting from the discharges of various industrial activities is known to affect severely coral reefs and shallow intertidal ecosystems. Large concentrations of suspended particles increase the turbidity of the water, thus decreasing light penetration which in turn may affect primary productivity. Furthermore, the unpleasant smell and unappealing look of the content of the effluents and plumes impose threats to the aesthetics of the area. For several weeks a study of these aspects of the discharge canal of the Puerto Rico Distillers in Arecibo, Puerto Rico was undertaken.

The areas under study are those in front of the Puerto Rico Distillers effluent at Arecibo, which include waters containing rum slops, and an area off Islote, which was used as a reference site. The rum waste discharge site may be affected by the suspended matter discharged by the riverine system in Arecibo Bay. However, the Islote area, being east of Arecibo, is not affected by the rum slops.

In all instances the suspended matter in the rum waste discharge area was 15.5% higher than that of the reference area (see Table 27). Station DS1 depicts the amount of suspended matter from the Arecibo Bay System only. Values obtained from stations DS2 on represent waters from the Arecibo Bay System as well as waters containing mosto from the effluent of the Puerto Rico Distillers. Co.

When mosto was being discharged, no productivity measurements were obtained because readings of the dissolved oxygen at the end of the experiment were zero in both the dark and light bottles. The oxygen demand of the mosto inside the bottles was so high that it was depleted from the samples in a short time. This may not happen in the natural environment under normal conditions because wind and wave action incorporate oxygen on the near-shore and surface waters more quickly.

The use of YSI-D.O. probes for the BOD bottles proved unsuitable for field use, therefore, YSI probes and Winkler were used.

Productivity measurements were not registered at the discharge area and along the mosto plume while mosto was being discharged. However, during the period of June 30, 1978 to July 10, 1978, no mosto was discharged from the Puerto Rico Distillers. Data are shown in Table 28.

TABLE 27. Data from Rum Slops Project for Suspended Matter.

Date: 5/31/78

Dumping Site	Suspended Matter gm/l	Mean of all Stations
DS1	0.013	
DS2	0.016	
DS3	NO	
DS4	0.058	
DS5	0.052	0.0317 gm/l
DS6	0.019	
DS7	0.037	
DS8	0.023	
DS9	0.030	
DS10	0.036	
Control Area		
CO1	0.011	
CO2	0.015	
CO3	0.010	
CO4	0.011	
CO5	0.010	0.013 gm/l
CO6	0.010	
CO7	0.012	
CO8	0.012	
CO9	0.012	
CO10	0.018	

Date: 6/1/78

Dumping Site		
DS1	0.778	
DS2	0.015	
DS3	0.101	
DS4	NO	
DS5	0.040	0.134 gm/l
DS6	0.044	
DS7	0.087	
DS8	0.045	
DS9	0.038	
DS10	0.060	
Control Area		
CO1	0.014	
CO2	0.014	
CO3	0.012	
CO4	0.013	
CO5	0.013	0.013 gm/l
CO6	0.014	
CO7	0.013	
CO8	0.013	
CO9	0.014	
CO10	0.013	

TABLE 27 (continued)

Date: 6/6/78		
Dumping Site	Suspended Matter gm/l	Mean of all Stations
DS1	0.071	
DS2	0.169	
DS3	0.061	0.199 gm/l
DS4	0.561	
DS5	0.135	
Control Area		
CO1	0.012	
CO2	0.013	
CO3	0.012	0.012 gm/l
CO4	0.013	
CO5	0.011	
Date: 5/15/78		
Dumping Site		
DS1	0.041	
DS2	0.102	
DS3	0.082	0.085 gm/l
DS4	0.127	
DS5	0.073	
Control Area		
CO1	0.036	
CO2	0.011	
CO3	0.017	0.019 gm/l
CO4	0.014	
CO5	0.017	
Date: 6/22/78		
Dumping Site		
DS1	0.052	
DS2	0.069	0.083 gm/l
DS3	0.100	
DS4	0.117	
DS5	0.077	
Control Area		
CO1	0.015	
CO2	0.014	
CO3	0.014	0.014 gm/l
CO4	0.014	
CO5	0.014	

TABLE 27 (continued)

Date: 6/29/78

Dumping Site	Suspended matter gm/l	Mean of all Stations
DS1	0.028	
DS2	0.018	
DS3	0.049	0.036 gm/l
DS4	0.032	
DS5	0.055	
Control Area		
CO1	0.019	
CO2	0.033	
CO3	0.002	0.015 gm/l
CO4	0.017	
CO5	0.003	

TABLE 28. Data From Rum Slops - Primary Productivity

Date	Control Area	(YSI D.O. Probe)
June 22, 1978	Dark Bottle 7.6 ppm O_2	Light Bottle 7.69 ppm O_2

Light - Dark = 0.9 mg O_2/l

Net carbon fixation = 33.75 mg C/m^3/4 hrs

		(YSI D.O. Probe)
June 29, 1978	Dark Bottle 5.9 ppm O_2	Light Bottle 6.16 ppm O_2

Light - Dark = 0.26 mg O_2/l

Net carbon fixation = 97.5 mg C/m^3/4 hrs

		(YSI D.O. Probe)
July 5, 1978	Dark Bottle 5.8 mg O_2/l	Light Bottle 6.13 mg O_2/l

Light - Dark = 0.33 mg O_2/l

Net carbon fixation = 124 mg C/m^3/4 hrs

		(Winkler)
	Dark Bottle 4.27 ml O_2/l	Light Bottle 4.45 ml O_2/l

Light - Dark = 0.18 ml O_2/l

Net carbon fixation = 97.5 mg C/m^3/ 4 hrs

	Dumping Site*	(YSI D.O. Probe)
July 6, 1978	Dark Bottle 7.46 ppm O_2	Light Bottle 7.6 ppm O_2

Light - Dark = 0.14 mg O_2/l

Net carbon fixation = 52.6 mg C/m^3/4 hrs

*No mosto being dumped.

TABLE 28 (continued)

(Winkler)

	Dark Bottle	Light Bottle
July 6, 1978	2.75 ml Tio	2.85 ml Tio

Light - Dark = 0.15 ml O_2/1

Net carbon fixation = 86.25 mg C/m^3/4 hrs

Dumping Site

(YSI D.O. Probe)

	Dark Bottle	Light Bottle
June 8, 1978	0.19 ppm O_2	0.32 ppm O_2

Light - Dark = 0.13 mg O_2/1

Net carbon fixation = 48.75 mg C/m^3/4 hrs

Control Site

(YSI D.O. Probe)

	Dark Bottle	Light Bottle
June 15, 1978	6.25 ppm O_2	6.38 ppm O_2

Light - Dark = 0.13 mg O_2/1

Net carbon fixation = 48.75 mg C/m^3/4 hrs

PRIMARY PRODUCTIVITY SUMMARY

No Mosto Dumping	Site	Date	mg C/m^3/4 hrs	Winkler	YSI Probe
	Discharge	6/8/78	48.75		X
	Control	6/15/78	48.75		X
	Control	6/22/78	33.75		X
	Control	6/29/78	97.50		X
	Control	7/5/78	97.50	X	
	Control	7/5/78	124.0		X
X	Discharge	7/6/78	86.25	X	
X	Discharge	7/6/78	52.60		X

Primary productivity values in the waters of the reference area (Islote) were low (see Table 28). This is not unique for this area as the waters of the north shore of Arecibo are mainly oceanic which, in this area, are known to have low values.

SECTION V

SEDIMENT STUDIES IN ARECIBO AND PALO SECO (BACARDI SITE)

METHODS

Sediment sample analysis was carried out in accordance with the methods described by Folk (1968). A portion of each sample was divided into sand and fine fraction by wet sieving, using a 230-mesh screen. The sand fraction in the sieve was dried at 100°C in an oven and weighed. Then it was passed through a set of sieves ranging from -2.0 phi to 4.0 phi, at half-phi intervals. The sample was poured into the top sieve, and the set was placed on the magnetic shaker for 15 minutes. Each sieve fraction was weighed. Sediment collected in the pan was weighed and added to the fine fraction in the cylinder.

After wet sieving, the fine fraction that remained in the pan was transferred to a 1000 ml calibrated cylinder, and allowed to settle for 48 hours. The supernatant was decanted and Calgon, a detergent, was added as a dispersant, in concentrations of 5 g/l. After vigorous stirring, 20 ml aliquots were extracted following the standard procedures according to Folk (1968). Aliquots were placed in pre-weighed 50 ml beakers, and their weights recorded after being oven dried. A correction factor was added due to the presence of Calgon.

Standard analysis of the data includes graphic representation of the cumulative percentages of each phi class. Parameters of size distribution included in the analysis are the mean grain size, sorting, and skewness.

Sediment samples were analyzed for percent of total organic matter (% TOM). The percent of organic matter was determined by the titration method described by Royse (1970). This method determined all oxidizable matter in a sediment sample as oxidized by chromic acid in the presence of sulfuric acid. After the reaction, the excess dichromate was titrated with a solution of ferrous ammonium sulfate. The sample was first ground to a fineness of 200 mesh, dried to a constant weight of one gram, and then used in the analysis.

RESULTS AND DISCUSSION

Frequently, an inverse relationship exists between grain size and organic matter content. Sediments usually become coarser with an increase in energy,

such as wave action. All the sediment samples at the Arecibo site are sandy sands with mean grain sizes ranging from 0.3 to 1.5 phi. Nearly all stations (Fig. 29) showed moderately sorted sands, with the exception of station 4 with poorly sorted sands. Stations 1, 2, and 6 are nearly symmetrical curves, approaching a normal distribution; station 5 and station 4 showed a tendency toward the finer sands, and station 3 to the coarser sands. Percent TOM was relatively low, with values ranging from 0.12% to 0.66% (on station 8). (See also Table 29).

The sediment samples from Bacardi (Fig. 30) are also sands, with mean grain size ranging from 0.27 to 1.33 phi; and moderately sorted sands, except station C, which is poorly sorted. There is an apparent pattern followed by the distribution of the percentages of TOM. The direction of overall sediment transport in the northern coast of Puerto Rico is from east to west. It is precisely 100 m immediately to the west of the rum pipe that the highest value of % TOM appears (0.86%), decreasing to 0.41% and then to 0.12% TOM, approximately 1 mile west of the pipe, this being the lowest value. To the east of the rum pipe (100 m), TOM is 0.40%. (Refer to Table 30).

In unprotected areas there is, generally, a greater amount of coarse sediments in the samples than the amount of fine. The environment, being more dynamic, with faster moving waters in the form of breaking waves, sea currents, and tides (refer to Physical Oceanography section) creates turbulence which removes the fine sediments. In situation like this, light material is removed from the sediments, and becomes suspended in the water column, as it can be in the case of organic matter.

Figure 29. Benthic stations (no station 2).

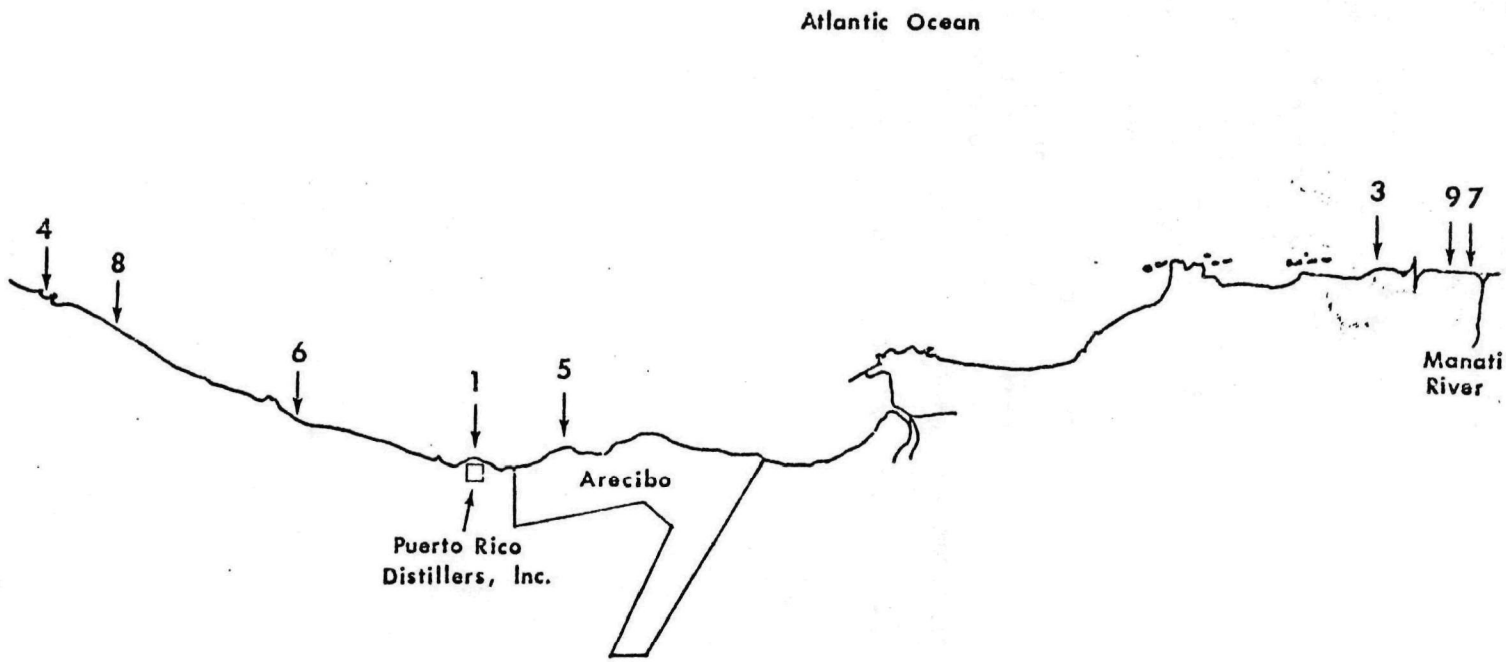


TABLE 29. Percent of Total Oxidizable Matter(TOM) (Arecibo)

STATION

1 Control (Taken east of the effluent during a no dumping period.)

	% TOM	=	25	(1-47.5/51.3)	(0.23)	=	0.40
2	% TOM	=	25	(1-49.9/51.3)	(0.23)	=	0.17
3	% TOM	=	25	(1-50.7/51.3)	(0.23)	=	0.06
4	% TOM	=	25	(1-51.7/52.85)	(0.23)	=	0.12
5	% TOM	=	25	(1-51.6/52.85)	(0.23)	=	0.12
6	% TOM	=	25	(1-50.35/52.85)	(0.23)	=	0.29

STATION

1 Upstream (Control; east of dumping site.)

	% TOM	=	25	(1-46.7/49.5)	(0.23)	=	0.33

1 Shore (at dumping site)

	% TOM	=	25	(1-45.9/49.5)	(0.23)	=	0.42
8	% TOM	=	25	(1-43.8/49.5)	(0.23)	=	0.66

Figure 30. Bacardi core stations.

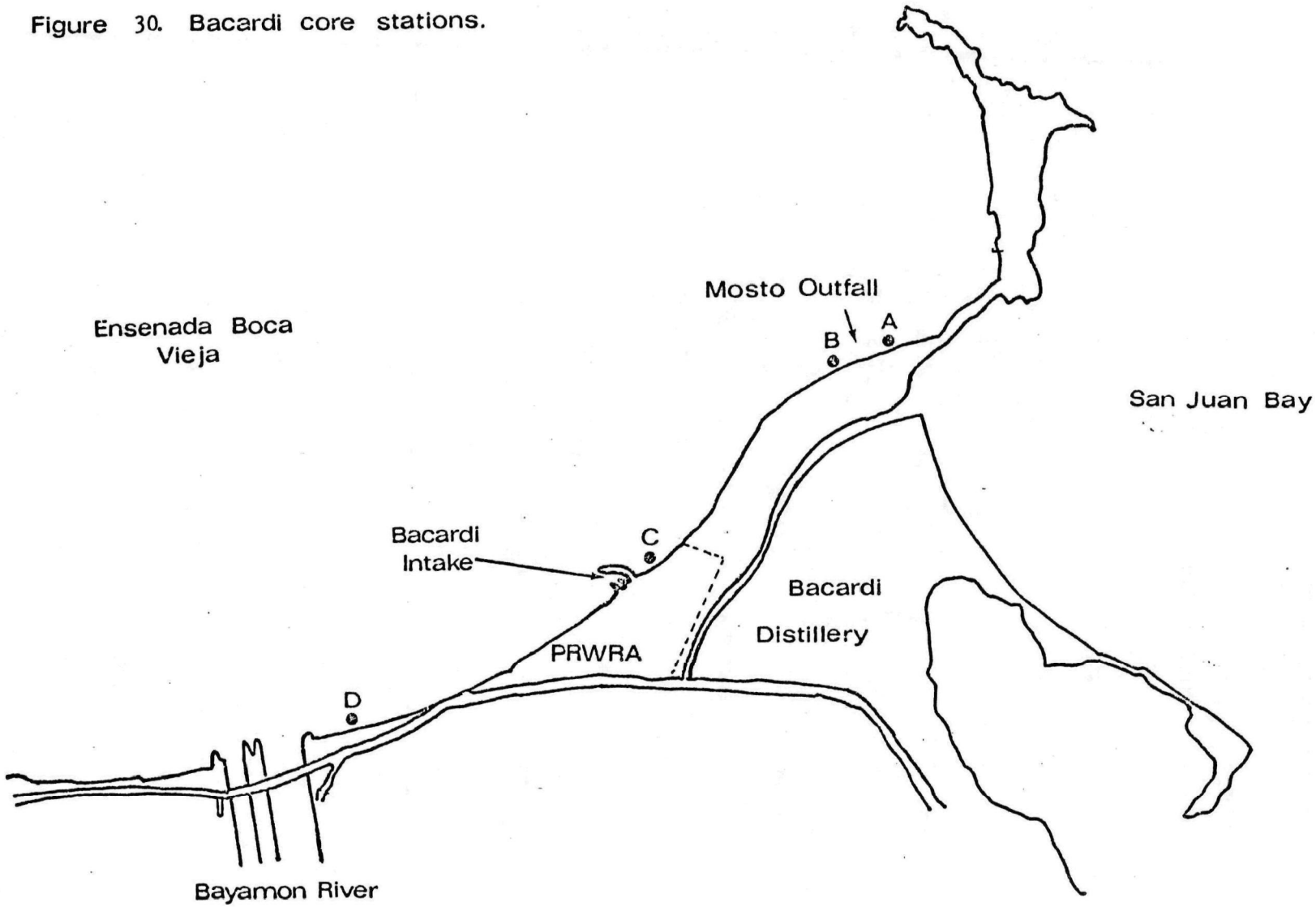


TABLE 30. Percent of Total Oxidizable Matter (TOM) (Bacardi)

SAMPLE A

% TOM = 25 (1-44.0/47.2) (0.23) = 0.40

SAMPLE B

% TOM = 25 (1-40.2/47.2) (0.23) = 0.86

SAMPLE C

% TOM = 25 (1-43.8/47.2) (0.23) = 0.41

SAMPLE D

% TOM = 25 (1-46.2/47.2) (0.23) = 0.12

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SECTION VI

PHYSICAL OCEANOGRAPHY STUDY

The physical oceanography study was conducted to determine and characterize the general nearshore circulation and water properties in the coastal sector of the rum distillery. Field investigations consisted of monitoring circulation patterns employing three *in situ* current meters, daylight tracking of five drifting drogues at different depths, a wave regime analysis which included wave refraction-wave power distribution patterns (in order to determine wave-induced mass transport and wave-induced currents), tidal-circulation correlations, and temperature-salinity (thus density) distribution throughout the water column. A surface dye-dispersion study was also undertaken to determine the rate of diffusion.

Results from previous field investigations, and those obtained in this study, indicate that the dominant current components in the Arecibo coastal sector appear to be the wind-induced surface circulation and the tidal forcing below 5 meters depth levels on the offshore areas. The wave-induced components and the effect of submarine morphology are dominant in the nearshore zones.

Tidal currents, waves and wind regimes, and advective currents will affect the mixing and spreading of a pollutant. Thus, the influence of these dynamic forces has to be taken into consideration. The periodic oscillation of tidal currents will generate macroturbulence which aids in mixing the pollutant with water beneath. Waves, particularly breaking ones, will also expedite the dispersion in the surface layers. Wind stress can spread the layer of pollutant downwind and in this sense can cause pollution in zones prior to its adequate mixing. Even small horizontal currents can have a significant effect on the diluting mechanism. All of these process variables are significant in the Arecibo area.

The wind and wave climate of the area constitutes a relatively unidirectional system displaying very little seasonal variability. The basic character of this system is the result of the constant energy input from the northeast trade winds. Secondary influence on the wave climate would be the addition of North Atlantic swells during the winter months. Because of the relatively straight and uniformly spaced bathymetric contours and narrowness of the shelf, wave attenuation is minimized. In conjunction with the high levels of energy input at the shelf edge this means that shoreline energy levels can be expected to be high. However, the absolute value of the shoreline energy for a given wave height is a function of wave direction of approach, decreasing as this angle approaches 90°(east). Therefore, the

combination of the wave processes described give rise to a unidirectional longshore current and transport system directed toward the west. Only short-term reversals will occur.

It is known from studies of other coastal areas with similar wave conditions that nearshore circulation is controlled by the dominant effects of a strong longshore current system. Commonly the longshore drift system in these settings is periodically interrupted by the offshore movement of water and sediment in the form of rip currents. These small-scale circulation cells induce a set of unique response features in the nearshore and beach environments, beach cusps and a variety of alongshore bar configurations. Associated with these coasts which have strong longshore currents, large volumes of sedimentary materials are transported alongshore as well as waste in suspension.

A quantitative evaluation of the magnitude of wave-induced processes discussed above can be accomplished by applying the results of the wave refraction/power analysis. For example, littoral currents are generated in the surf zone as a result of the wave breaking process and generally move parallel to the shoreline. The strength of the littoral current increase with a corresponding increase in breaker angle and/or breaker height. At the study site a typical breaker (height 1 meter, 5° angle and beach slope of 5°) will generate a littoral current of approximately 49 cm/sec. This velocity is strong enough to transport coarse sand.

The results of this study can also be used to determine the dispersion characteristics of water and/or pollutants in the surf zone. In this way the movement of possible beach pollutants may be estimated for the study site from a knowledge of beach geometry and the wave conditions given in this report. The dispersion of water within the surf zone is a function of two important mixing mechanisms each having a distinctive length and time scale. The first is associated with turbulence and shear of the breaking wave and its bore which produces rapid mixing in an on-offshore direction in the surf zone. The second mechanism is associated with the longshore and rip current systems in the nearshore circulation cell.

The waste from the rum distillery in Arecibo comes out of a pipe sticking out from the small cliff bordering the beach. From here it falls to the beach and streams out to the shoreline where it meets the full force of breaking waves and surf. Littoral currents are particularly strong in this area. These dynamic environmental conditions imply extreme turbulent mixing conditions.

A dye experiment was conducted on July 18 at the same location of outfall, where one-gallon of Rhodamine B dye was injected at about 1300 hours. The trace and dispersion of the dye plume created was photographed from the air and visually observed for the next 4 hours. The path of the dye dispersed in a western direction, hugging the shoreline. At the beach, on the west side of the point in front of the distillery, the patch of dye delineated a rip current system which is represented in Fig. 31 of the text. Some dye flowed east for a distance of about 100 meters as an effect of diffusion.

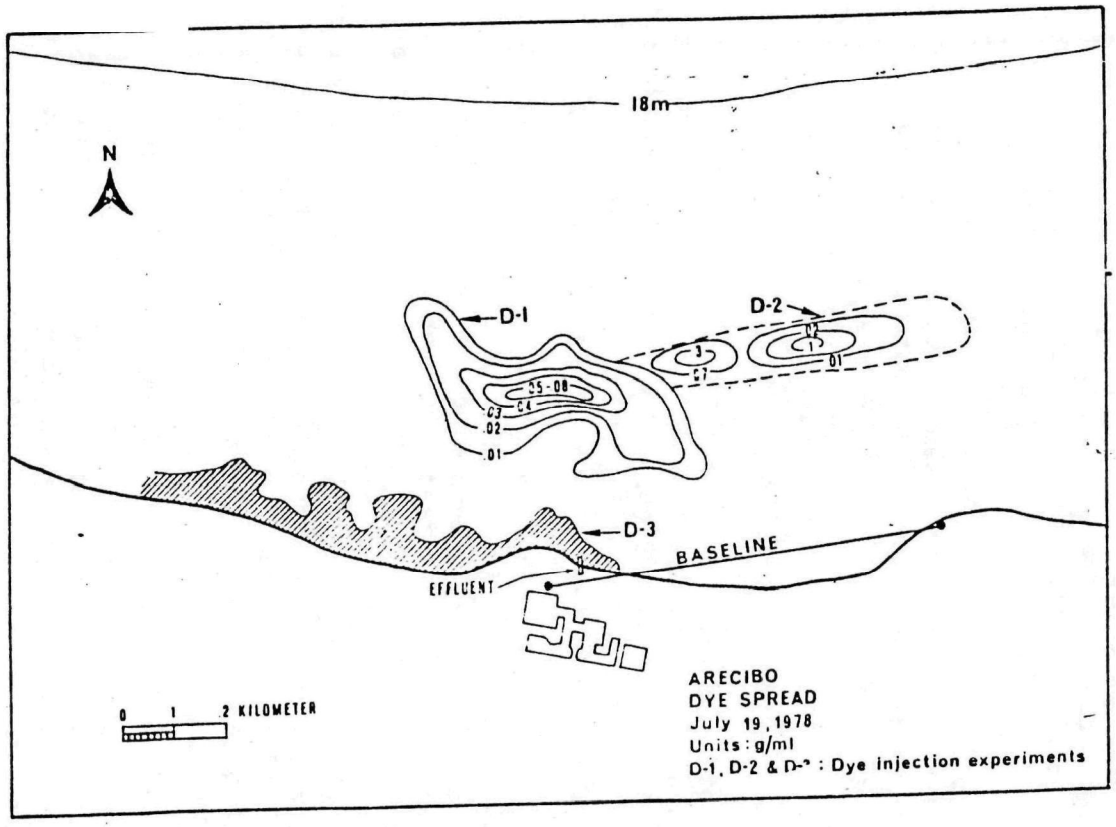

Figure 31. Dye injection experiments in Arecibo on July 19, 1978.

The density of the mosto or sewage that spills out into the surf zone from the distillery was calculated; it is denser than the seawater where it spills (1.032). This means that some of it, before being diluted and mixed in the surf zone, will sink and drift offshore with the tides or hydraulic back flows which brings it into the influence of coastal currents. Rip current systems (cells) will also carry sewage in solution offshore, as observed in the dye experiments. Coastal circulation patterns will influence the dispersion and spreading of the remaining waste in solution according to the dynamic conditions acting at the time when it reaches the area of their influence. As it has been observed, these conditions vary throughout the day as a function of the differential contributing forces of the dynamic parameters. It should be remembered that the dispersion coefficient and dilution factors depend on the concentrations, mass of the pollutant and the acting forces, such as current velocities, wind stresses and tidal stage, and density of the medium in which it is discharged.

Figure 31 of the text also shows the dye concentration averaged distribution pattern according to the samples taken. Dye spread number D-2 separated into two maximum concentration patches and was not continuous. This was ascribed to wind effects. Concentrations (averaged) ranged from .01 to .08 mg/ℓ in D-1, reaching a value of about 0.3 mg/ℓ in patch D-2.

The general conclusions of this study are as follows:

1. The most prominent characteristic of nearshore/offshore circulation on the coast of Arecibo is its temporal and spatial variability. These conditions influence the path of pollutants in a similar manner: highly variable rates of transport and spreading directions.

2. The dominant current components are the wind-induced surface movements and the tidal forcing below 5 meters depth levels on the offshore areas depending on the wind stress. Waste at the surface will spread according to the wind direction; waste below 5 meters depth will be driven by the tidal variations.

3. The wave-induced, wind-driven current components, and the effect of submarine morphology are dominant in the nearshore zones (from the 60 meters depth contour shoreward). Waste in this sector will be transported alongshore by the littoral currents.

4. According to #2 and #3 above, there seems to be two distinct zones in which conditions vary according to the intensity of the dynamic forcing factors involved: the offshore (beyond the 120 meters depth contour) and the nearshore areas from the 60 meters depth contour to the shoreline.

5. Eddy circulation cells are commonly developed in this area. The general circulation pattern appears to be (derived from the available data) an eddying flow eastward during early

morning hours, and a reversing flow westward during the afternoon, especially below the 4 meters depth level.

6. There is evidence that a three to five days periodic variation in current direction is present. This could imply an inertial current component.

7. North-northwestern winds generate eastward longshore currents which will transport wastes in this direction.

8. Most frequent (70%) longshore currents are in a westward direction with speeds ranging from approximately 15 to 40 cm/sec (1.44 km/hour, maximum measured).

9. Inverse current speed gradients (faster flow as a function of depth) are commonly encountered beyond the 60 meters depth contour. Opposite eastern current flow with depth is also frequent as shown in #5 above.

10. Current speed at the surface is a function of wind stresses, varying from about 5 to 46 centimeters per second (.18 to 1.7 km/hour) depending on the direction of tidal flows (ebb or flood stages) which oppose or aid surface circulation. Most frequent (70%) flow direction is westward and toward shore. Waste will follow the coastline to the west except at the rip currents cells locations.

11. Flow below the 5 to 8 meters depth levels is a function of tidal flow stage in a southeastern (flood) or northwestern (ebb) dominant direction with speeds ranging between 1 to 30 centimeters per second (.36 to 1 km/hour).

12. The effluent of the distillery is being discharged in a highly turbulent medium which augments the mixing processes. Turbulent forces at the shoreline oppose the dispersion of waste at the surface and prevent it from flowing offshore except where rip currents are dominant. This material, already in solution, will drift with the dominant nearshore currents in a westward direction along the shoreline and at intervals the flow will be offshore. Beyond the 60 meters depth contours the waste will flow toward the east depending on the eddying patterns and the differential spatial and temporal variations of the current forcing factors. Possibly longer periodic cycles (inertial components) which have not been fully determined are acting in this sector. A vertical current structure of variable speed with depth is frequently observed: onshore components exist in the near-surface and near-bottom layers, and a seaward-directed component is present in the middle levels of the water column.

13. Current stability (β), as shown by the calculations made with the *in situ* current meters, range from 70.7 to 100 percent. This indicates the range of directional variations. The most frequent current stability value is 93.3 percent.

14. Density gradients, as a factor of current generation processes, are negligible in the Arecibo nearshore areas. The salinity-temperature-density measurements indicate that the waters are well mixed and homogeneous. Vertical mixing due to turbulent processes such as waves, breakers, and wind stresses are dominant in the area. The degree of turbulence will maintain the waste in suspension for longer periods of time.

15. Averaged dispersion coefficient was calculated to be 43.3 cm^2/min, or .72 cm^2/min (.08 to .36 m^2/hr). Calculations of concentrations with this average showed good agreement with field measured concentrations.

16. Littoral currents can reach speeds of about 50 centimeters per second (1.8 km/hr) as calculated from wave approach angles and breakers of approximately 1 meter in height.

17. The most frequently occurring wind speed is between 10 and 16 kts occurring 37.3% of the year. Wind speeds between 6 and 21 kts occur 75.7% of the year and indicate the predominance of moderate wind speeds in the study area. High wind speeds in excess of 27 kts occur only .4% of the year.

18. Winds from the east dominate the statistics occurring 52.5% of the year. The next most likely wind direction is northeast, occurring 23.9% of the year. Winds with an easterly component (NE,E,SE) account for 89.5% of the observed winds. The winds determine the flow directions and speed of the waste at the surface.

19. The most frequently occurring wave height is 1.5 meters which occurs 30% of the year. The average significant wave height is 1.35 meters. Wave heights in the range from 1 to 2 meters occur 73.4% of the year. Large wave heights greater than 3.5 meters, occur rather infrequently, accounting for only 1.4% of the time. Mass transport of water shoreward is determined by the heights and periods of waves.

20. The dominant wave period is 5-6 sec., accounting for 79.9% of the year. The average wave period is 6.4 sec. Wave periods greater than 9.5 sec. occur only 5.6% of the year.

21. Wave directions with a northeast component dominate the statistics accounting for 84.1% reflecting a strong trade wind influence. These statistics are based upon waves arriving from only those directions important to the north coast, 285°-75°. Waves from the north and northwest quadrats approach at least 16% of the year. These latter are mostly storm waves from the North Atlantic storm centers (winter season). Waste spreading during this season will be reversed toward the east along the shoreline.

22. Gradients in wave heights and associated wave power increase to the west to a maximum near Arecibo (zone of orthogonal convergence). From this point westward wave height decreases to a moderate level. Longer period waves (9 seconds) arrive nearly perpendicular to the shoreline and the spacing between wave rays reflects a more uniform distribution of energy along the coast.

23. The absolute values of wave height and power are greatly reduced (as indicated by wider orthogonal spacing) as a function of wave angle of approach. Wave height at the distillery is reduced from 1.82 meters (30°approach angle) to 1.33 meters for the 60°approach angle. Similar reductions in wave power occur from 12,130 to 6,490 watts per unit crest length. Even though the wave heights are generally reduced in the 30°approach angle example orthogonals arrive at steeper angle to the shoreline and adjacent coastline around the distillery, increasing littoral currents speed in a westward direction.

24. On a scale which shows more detail of the offshore bathymetry and an input wave power of 26,800 watts per unit crest length in deep water the shoreline values at the three locations discussed are from east to west 7,700, 16,300, and 12,130 watts per unit crest length. At no place along the coast do the wave orthogonals arrive perpendicular to the shoreline. This situation implies the existence of a strong longshore power component.

25. For a 5-second wave with an input wave height of 2 meters from the 60° (northeast), wave height decreases by 24 percent at the 2-meter contour and wave power decreases from 19,060 watts per unit crest length in deep water (200 meters) to 10,500 watts per unit crest length, a decrease of 45 percent.

26. A 7-second wave input from an angle of 30° displays a change in wave height along the shoreline from 1.45 meters at the eastern end of the embayment (orthogonal 12) to 2.11 meters at Arecibo (orthogonal 7) and a subsequent decrease to 1.82 at the location of the distillery (orthogonal 1). There is a comparable gradient in wave power along the

embayment shoreline which delivers considerable energy to the longshore area. Refraction patterns for 7 and 9 second input waves respectively display divergence of orthogonals in the general embayed area of Arecibo and a zone of convergence of orthogonals (energy) to the west. A 7-second wave with an input wave height of 2 meters arriving from 60° (northeast) exhibits a decrease in wave height of 18 percent at the 2 meter contour. Wave power decreases from 26,800 watts per unit crest length to 13,500 watts per unit crest length, approximately a 50% reduction. If this 7-second wave was to approach from 30° the general spacing between orthogonals is decreased--indicating a higher level of energy arriving at the shoreline.

Therefore, the fate of the effluents from the rum distillery is determined by a particular set of conditions operating at a given time as shown above. For example: During early morning hours when the wind blows from inland toward the offshore zone, and the tide is ebbing, the waste will spread in an offshore direction at speeds ranging from about 2 to 10 cm/sec., depending on the strength of the wind. Diffusion of the waste will take place at the same time, spreading at a rate of about .72 cm^2/second. The waste, being denser than seawater, will slowly sink and be under the influence of deeper currents, depending on the state of the sea (wave regime) and degree of turbulence.

The flood stage of the tide, if it occurs before 0900 hours, will spread the waste toward the east. After approximately 0900 or 1000 hours, when the east and NE winds start blowing strong and the sea becomes choppy, the waste at the surface levels will be driven westward along the shoreline at rates of transport that approximate 50 cm/sec., depending on the heights and periods of the waves and relative strength of the wind. An ebbing tide will be aiding this westward flow; a flooding tide will oppose this flow at the deeper layers of the water column reducing the speed of the currents and the spreading of the waste.

Waste will usually (70% of the time) disperse along the shoreline during the daylight hours at a rate of about 1.8 km/hr (maximum) with eastern and NE winds blowing at average speeds of about 10 to 15 knots. Rip current systems along the shoreline will transport diffused waste offshore from the western drift component. Waste will also be mixed (settling) with beach sediment. The effect of this mixing has not been investigated.

Thus, the dispersion, diffusion, settling, and final fate of the waste depends on the environmental conditions acting according to the results of the investigation performed. Given these differential sets of conditions for a particular moment in time and space, the trajectory and rate of transport of the waste can be predicted fairly accurately. Discharge of the waste should be programmed for those sets of dynamic conditions which could spread the waste offshore and to the west. With the knowledge gained about the circulation patterns resulting from any particular set of environmental

conditions, coupled with proper planning, harmful effects along the littoral zone of the coast can be prevented or minimized.

It is recommended that a waste tracing experiment be conducted to trace the waste for a long period of time with the proper (sensitive) equipment. Similar studies have been performed in other discharge areas.

SECTION VII

GEOGRAPHICAL CONSIDERATIONS

Physical Geography of Arecibo

The city of Arecibo is located on the north coast of Puerto Rico at 66° 44' W; 18° 28' N and lies 50 miles west of San Juan. The municipality, the largest of the island, covers an area of 81,000 acres comprising important portions of the north coastal plain and the humid hills. Much of the area lies in the karst or limestone region which varies from moderate slopes with broad shallow depressions to "haystack" topography characterized by numerous steep hills.

The Climate in Arecibo

Traditionally, Arecibo has been classified as lying in the subhumid region. This region extends from the northern part of the northwest meseta on the west, to the valley of the Río Grande de Manatí on the east. The average annual rainfall in this region ranges from 102 to 152 cm. The first four months of the year are relatively dry (winter months) with February and March being the driest. Rainfall increases in May but declines again in July. Thereafter, it increases again to a maximum in November. This subhumid region stretches only a few miles landward where rainfall increases rapidly to over 203 cm.

The precipitation and temperature data used here cover the period between 1966 and 1975. During this period, 1967 was the driest year, with only 96 cm of rainfall. The highest rainfall during this period was March 1973, with 43 cm. February and March are typically the driest months, with an average of 6 and 5 cm of rainfall, respectively. After March, rainfall increases gradually to a maximum of 10 cm by June. It decreases again in July as a result of the strengthening of the Atlantic high pressure system but increases again in August. The period from September to December is considered the wet season because it has an average rainfall ranging from 13 to 25 cm, respectively. Easterly waves during the hurricane season account for much of the rainfall in this region.

The average temperature for Arecibo during this 10 year period was a comfortable 77.86°F. The month with the coldest average temperature was February 1975, with 73.5°F, whereas the hottest was August 1967 and 1970 with 81.5°F. The difference in average temperature between the average hottest and coldest months for this period was only 8.0°F. The month with the highest average maximum temperature was August 1968 with 91.3°F. The

month with the lowest minimum average temperature was February 1972, with 63.4°F. The annual range in the average temperature is 6.11°F, while the diurnal range averages 19.6°F.

The wind regime discussed here covers data from the period September 1942 to May 1943 only. According to this information, 65 percent of the time the wind blows from the northeast to the east-southeast quadrant, with 45 percent of the time blowing from the east to east-northeast. Assuming this short period is representative of the wind regime in general, it is calm 6 percent of the time, blows between 2-5 km per hour 12 percent, from 6 to 19 km per hour 44 percent, from 21-38 km per hour 37 percent, and from 64 to 80 km per hour 1 percent. The average wind-speed for Arecibo is 16 km per hour.

In summary, Arecibo has a subhumid tropical maritime climate, making it a very comfortable place to live. It is neither excessively hot, nor excessively cold, excessively wet, or excessively dry. Even the hottest months in Arecibo are still cooler than the hottest months throughout the southern coast of Puerto Rico.

The Population

The population of the Arecibo municipality has increased somewhat unpredictably ever since the first census was taken by the U.S. Government in 1899. These changes observed in the population have been attributed to migration patterns from the rural areas to San Juan and the U.S. mainland. These patterns, in turn, have been associated with the state of the economy in Puerto Rico and the United States.

Age-Sex Pyramid for Arecibo

A comparison of age pyramids for the Arecibo area shows larger families with a higher population of children in rural areas. In the urban pyramid the middle years tend to be wider in contrast to the rural one, suggesting a larger proportion of middle-aged people in the city. There is also a tendency for more females than males for each age bracket from early adolescence to the top of the pyramid. In the case of rural Arecibo, this occurs for the ages 20-50 years. The explanation for this latter pattern may be that unemployed adult males tend to emigrate from the rural area in greater numbers than females. The case of males exceeding females for the age bracket of 50 or more may be associated with the fact that many females move in with their married children who live in the urban areas. Evidence in favor of the observation that adult males tend to emigrate outside the municipality rather than to the city of Arecibo is the predominance of females over males from early adolescence to the end of the pyramid. Also, the fact that females tend to outlive males by about 5 years is reflected in the drastic drop in the male-female ratio after 70 years of age.

The age-sex pyramid for urban Arecibo is more rectangular than the rural one. This is indicative of a lower proportion of people in the younger age brackets, presumably as a result of long-term reduction in the birth rate.

The increase in the life expectancy also increases the proportion of persons in the older age bracket.

Some Socio-economic Observations

According to the 1970 Census of Population, 2 percent of the urban residents were foreign-born, 92 percent were born in Puerto Rico, and 5 percent were born in the United States. The majority of these persons born in the United States are probably offspring of Puerto Rican emigrants once living in the United States. Among the persons 14 to 17 years of age, 81 percent were in school. The median school years completed was 8 years; approximately 30 percent of the population had 4 years of high school or more.

With respect to the families in urban Arecibo, 27 percent had children under 6 years of age, while 60 percent of the persons under 18 years were living with their parents. The cumulative fertility rate of women between 35 and 44 years of age was 2810.

From the economic point of view, 58 percent had incomes below the poverty level while 11 percent had incomes of $10,000 or more. Also, 24 percent of the females 16 years of age or older, were active in the labor force. For males, only 24 percent of those between 18 and 34 were in the labor force, while 18 percent of the males 65 years old or older were still active.

Areas of Recreational Interest

Beaches

Urban Arecibo has two areas that could be classified as beaches. One, about one kilometer long, is adjacent to the rum distillery on the west, and the other about a third of a mile long is on the east side of the distillery. At the widest point the former beach is about 70 meters wide and the latter 48 meters wide. Both are separated from the urban areas by cliffs 10 or more meters high. On the various occasions these beaches were visited, no more than a half a dozen persons, mostly adolescents, were seen; no one was swimming. Occasionally, someone would come to do line-fishing off the rocks and others were seen collecting shells along the shore.

Very strong wave action and winds of 40-48 km per hours were recorded in the area. Further, water at the beach, west of the distillery, was brownish in color as a result of the rum slops being discharged there. A strong smell of fermented molasses prevailed throughout all the visits made to this community.

Several local tourists were interviewed in regards to the paucity of visitors to these beaches. Their general response to the question pointed out to the strong wave action and rocky shores as the main deterrents to potential users. The beach along Barrio Obrero (west of the distillery) is

used by the residents of this neighborhood, particularly because many of their backyards end on the beach. Several other small beaches located to the east of the city of Arecibo are poorly developed, lack many visitors, and the sea is nearly always rough. Others are inaccessible.

State Forests

Other areas of recreational interest in Arecibo are two state forests: Bosque Estatal de Cambalache and the Unidad Forestal de Río Abajo. The first one is a state park owned by the Puerto Rico Land Authority but administered by the State Forest Service. It consists of 1560 acres of wooded area and is located in the karst region where exotic tropical vegetation and haystack topography are the dominant features. In spite of these attributes and considering that it is an excellent place for hiking, it is under-utilized by the local residents.

The other forest unit is larger, about 6,000 acres of wooded area and located in the south of the municipality. The temperature ranges from 70° to 80°F with 180 cm of rain a year. It has swimming pools and facilities for overnight stay. This area is becoming increasingly more popular among the residents of Puerto Rico.

Sports

Sports activities in Arecibo are limited mostly to traditional sports. A municipal office promotes and sponsors tournaments in baseball, basketball, soccer, field and track, bicycling, etc. at the community level. There are also professional basketball and baseball teams with the participation of local and mainland stars. Except for a few people who enjoy doing surfing occasionally, no water sports are practiced in the area.

Fishing Interests

The fishing community is located primarily in Jarealitos, a village east of Arecibo which was established to relocate families whose homes were affected by sea storms and river flooding. This is basically the only fishing community in the area. There are some part-time fishermen in Barrio Obrero but they do not contribute much to the economy of the region. Jarealitos is a very poor village. A survey revealed that 54% of the houses lacked some or all plumbing facilities. Ninety percent of all the houses are occupied by the owners and the rest are rented. Average figures for the 1970-76 period, based on fishery data recorded by the Commonwealth Department of Agriculture, show that fish caught by these fishermen constitute about 1% of the total fish caught in Puerto Rico.

In general the statistics indicate that the total fish caught has declined markedly in recent years. Many of the fishermen argue that the reason for this is that fishing is an art that is disappearing from Puerto Rico. They claim that because it is a marginal economic activity young men prefer to work in more secure and economically rewarding jobs. This reasoning appears to answer the question of why only old people (too old for retraining

in other jobs) are the ones still doing the fishing. It is believed that lack of incentives and poor facilities to keep the fish may account, also, for the apathy of these fishermen.

Further analyses of data and information provided for this study suggest that the fishermen of this area will venture into the sea not only if the weather conditions are favorable, but if the market conditions are attractive. It is realized that fishing has been the livelihood for these people for many years. It is a marginal economic activity. Its survival in the long run will depend on fair prices and the fishermen's ability to supplement their income through alternate jobs or welfare means.

Land Use in Arecibo

For the sake of simplicity the subject of land use in Arecibo was limited to an analysis dating back to 1950. A look at the land use patterns of the urban community indicates that Arecibo is a compact center lying west of the Río Grande de Arecibo and bordered by the Atlantic Ocean on the north. These two barriers restrict the urban growth to the north (because of the ocean) and to the east (because of the floodplain's susceptibility to floodings). Therefore, the only two directions the city can grow is south and west.

The traditional part of the city has an area of approximately 223 acres, and forms a triangle limited to the north and east by the Atlantic Ocean and the river, respectively. The Central Business District is located within this area. Along the northern part of the city, and extending into the shore, is a belt of high density, wooden houses with corrugated tin or zinc roofs, resembling a slum belt, about a 1.5 km in length. Along the eastern margin of the city, bordering an abandoned meander is a section of large warehouses.

Outside the compact urban area, about 2 km south of the town square, is a zone of medium density housing. At the extreme southeastern section of this residential area is Arecibo's winter league baseball park. About 1 km west of the baseball park and about 2 km southeast of the town square there is a government housing project of single-housing units. The housing area near the baseball park covers about 64 acres, while the government housing project covers about 40 acres.

Southwest of the traditional part of the city there is another section of medium density housing, which covers about 84 acres. The cemetery is also located in this area. Northwest of this area lies the rum distillery and a picturesque low income community known as Barrio Obrero. It is interesting to note that in 1950, the rum distillery, which is now located in the center of the urban complex, was then located about 1 km west of the western margin of the city. The rum distillery and the Barrio Obrero community cover about 42 acres.

The 1950 aerial photographs show the first signs of urban expansion to the west. At the time most of the rural land surrounding urban Arecibo was used for sugar cane, followed by pasture and brush. Urban Arecibo then encompassed an area of about 426 acres.

This horizontal growth towards the west continued vigorously until 1971 when it slowed down considerably. By 1977 this horizontal growth still remained as in 1971. However, several new housing projects were started as well as a section of the Diego Expressway. The extensive slum belt in the traditional part of the city was cleared.

Another observation which merits some attention in this report is the unrestricted construction (by owners) of houses along the major roads throughout the area. One major problem associated with this situation is the fact that land highly valued for its agricultural potential is subdivided for house lots, thus accelerating the inflation of land values.

The generalized land use patterns for 1977 show that the total area lies within the 2.5 kilometers from the rum distillery, or 2912 acres appoximately. The categories include the main urban and rural areas. Within the enclosed area, 54 percent can be considered urban, while 46 percent can be considered rural. This proportion in urban use compares with 50 percent in 1971, 29 percent in 1963, and 16 percent in 1950.