Seawater quality & phytoplankton of Barbados

SEAWATER QUALITY AND PHYTOPLANKTON OF INSHORE WATERS OF BARBADOS: A STUDY OF THE EFFECTS OF ORGANIC POLLUTION IN A TROPICAL ENVIRONMENT.

by
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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

SEAWATER QUALITY AND PHYTOPLANKTON OF INSHORE WATERS OF BARBADOS: A STUDY OF THE EFFECTS OF ORGANIC POLLUTION IN A TROPICAL ENVIRONMENT.

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Repeated observations of phytoplankton and related seawater quality characteristics have been made at Barbados inshore stations from July 1972 to July 1973 for comparison with an unpolluted site. Two very different types of phytoplankton associations were found not differentiated by normal types of chemical tests. The production effects of organic pollution in Barbados were indirect, producing changes in the resident phytoplankton associations. It was postulated that in the nutrient impoverished conditions of tropical seas considerable additions of nutrients may be accepted without widespread effects.

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RESUME

QUALITE DE L'EAU DE MER ET PHYTOPLANCTON DES EAUX COTIERES DE LA BARBADE: UNE ETUDE DES EFFETS DE LA POLLUTION ORGANIQUE DANS UN ENVIRONNEMENT TROPICAL

Robert R. Vezina

Plusieurs observations ont été faites sur le phytoplancton et les characteristiques connexes de la qualité de l'eau de mer à des stations cotières à la Barbade entre juillet 1972 et juillet 1973. On a comparé les résultats provenant de ces stations avec ceux provenant d'une station non polluée. On a trouvé deux types bien différents d'associations phytoplanctoniques; ces associations ne sont pas différenciées par les essais chimiques standards. Les effets de la pollution organique sur la production à la Barbade étaient indirects; la pollution produit des changements dans les associations phytoplanctoniques résidentes. Il ressort que dans les conditions d'appauvrissement en éléments nutritifs, typiques des mers tropicals, des additions considérables d'éléments nutritifs peuvent être acceptées sans effets étendus.

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The firm of Quirk, Lawler and Matusky Engineers of Tappan, New York, provided incubators for both BOD and coliform determinations, and Mr. R. Dennis of the same firm was kind enough to instruct me on the coliform procedure. Rum bottles for surface-current drift-bottle tests were provided by Mount Gay Distilleries Limited of Barbados. Dr. D.R. Carter of Barbados and Miss J. Acreman of the I.B.P. Laboratory at McGill University were helpful in solving the problems encountered with nitrate determinations in Barbados. I am thankful to Mr. K. Reeves of the Chemistry Dept. at the University of the West Indies for providing various chemicals which were sometimes in short supply due to shipping delays. Mr. B.S. Ott and Mr. J.K. Partlo are gratefully acknowledged for giving up much of their time in order to help during my field trips. Professor C. Lalli, Mr. S. Peck, Mr. H. Powles, and last but not least, the staff at the Bellairs Research Institute, are all sincerely thanked for their assistance.

TABLE OF CONTENTS

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TABLE OF CONTENTS (cont'd)...

PREFACE

This thesis is the first comprehensive investigation of the effects of organic pollution on the water column in Barbados inshore waters, and is the first study showing two stable, very different, inshore phytoplankton associations, not differentiated by normal types of chemical tests. It was previously known that analysis of the water column alone can be misleading when studying coastal marine pollution; this study further postulates that chemical measurements alone of the water column are not reliable as a guide to "water quality".

INTRODUCTION

The aim of this section is to point out the relative paucity of pollution studies in the tropics and to draw attention to the lack of quantitative methods for measuring the relationship between aquatic ecology and water quality. "Marine pollution" is defined and the chief pollutants are named, emphasizing domestic and industrial pollution, the basic concern of this thesis. The direct and indirect effects of enrichment are described. The attitude of developing countries and the situation in Barbados is discussed, along with how this study originated. The need for and limitations of baseline data are pointed out.

For the most part the historical statement is found under the DISCUSSION. Most work relevant to this study is widely scattered in the literature, in many reports dealing with specific parameters, rather than a few comprehensive pollution studies. An attempt has been made to condense the findings as much as possible.

This thesis is concerned only with the effects of organic pollution on the water column in the tropics. Other forms of pollution have been studied in a tropical environment, for example thermal pollution (Gerchakov et al, 1973) in Biscayne Bay and oil pollution (Lewis, 1971) on Barbados reef corals. McNulty (1961) in Biscayne Bay and Wade (1972) in Jamaica have described the effects of organic pollution on benthic populations. Odum (1973) examined the potential of pollutants to act as limiting factors on aquaculture. Carter (1973) listed publications found under such headings as antipollution measures, phosphates, sewage, eutrophication, and many others.

Most knowledge of the biological consequences of marine pollution is derived from studies in temperate waters where information, although inadequate, is "encyclopaedic compared with what we know about even the basic ecology of tropical waters, let alone the consequences of effluent disposal and accidental pollution in them" (Anonymous[2], 1970). It is a foregone conclusion that today we do not know how much waste of what kinds can be deposited in the oceans with impunity. Monitoring of natural bodies of water may be expensive but the "recent general awakening to the critical need to protect water as a vital and reusable resource" is ensuring that this important undertaking no longer remains inadequate (Mitchell, 1972). The Integrated Global Ocean Station System is one body which recognizes the need for information about pollution, going so far as to plan for world-wide monitoring of the oceans. However, Schachter and Serwer (1971) note that "because of our ignorance of the oceans we may not have reached the point where our scientific knowledge of ocean problems would justify a data-gathering system on a global scale". Sibthorp (1969) points out that since the oceans are the main influence in determining the weather throughout the world, pollution of the atmosphere and of the seas and oceans must interact with consequences which cannot at the moment be reliably forecast. He concludes that the research being carried out is inadequate in relation to views as to the seriousness of the problem and that the co-ordination of pertinent research could be improved. Alverson and Paulik (1973) stress the need to minimize duplication of effort and increase communication between groups studying the oceans.

Dickman (1969), describing changes in periphyton community structure, pointed to the lack of quantitative methods for measuring the relationship between water quality and aquatic ecology and claims that this is probably the single most important pollution problem today. Earlier

Margalef (1961) was "unable to draw a quantitative expression of the way variations in the possible energy flow are reflected in the relative biomass (of planktonic populations) supported".

The Intergovernmental Oceanographic Commission of UNESCO set up a working group on marine pollution to advise member-countries what further scientific research is required in this special field. One of the tasks of this working group was to produce a good definition of the term "marine pollution". This runs "Introduction by man of substances into the marine environment resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of seawater, and reduction of amenities" (Korringa, 1971).

Sibthorp (1969) and Mitchell (1972) described the chief pollutants. Sibthorp classifies them as: nuclear waste, oil pollution, pesticides, thermal pollution, detergents (from domestic sewage and from their massive use in dispersing oil pollution), heavy metal compounds, petrochemicals, dredging spoil and mining, industrial effluents, domestic sewage (this to the best of present knowledge is mainly a threat to amenity and public health, and also to biological resource productivity), solid objects, and miscellaneous and unspecified pollutants. Synergistic actions of pollutants are more severe at higher water temperatures (Anonymous[1], 1969).

Twelve European countries signed an antipollution pact in Oslo, Norway, on February 15, 1972 designed to stop the dumping of poisonous waste by ships and planes in the northeast Atlantic (Anonymous[5], 1972). The agreement was certainly an accomplishment, but ships and planes cause only a small part of marine pollution. "90% of this pollution is caused by industrial and domestic discharges through rivers,

estuaries, outfalls, and pipelines that are under national jurisdiction. No international action has been taken on this problem".

The following paragraph is taken from Schachter and Serwer (1971), unless otherwise noted:

Domestic wastes include domestic sewage, wastes from food-processing, detergents, and run-off from agricultural areas. Industrial wastes include heavy metals, radioactive nuclides, inorganic chemicals and heated water. The problem of domestic wastes depends in large part on population and its distribution, perhaps to a greater extent than any other form of pollution. The effects of both domestic and industrial wastes depend on the chemical composition of the wastes, their physical state, the method of discharge, the place of discharge, and local environmental conditions. Two of the more important polluting effects of a number of domestic and industrial wastes in the marine environment are over-fertilization and poisoning. Over-fertilization is due to an excessive flow of nutrients into the marine environment. The nutrients can be many different chemicals including the nitrates found in fertilizers and the phosphates found in detergents. Over-fertilization becomes evident when the population of a marine species, often a species of phytoplankton, increases very quickly, causing a bloom (Korringa, 1971). Ellis and Littlepage (1972) report that the production effects may be simple and direct, as when blooms of such phytoplankton as "red-tide" cause mass fish-kills of high food-chain species, or they may be indirect through a variety of subtle stresses eventually producing changes in the resident species associations. Blooms occur naturally - that is without the addition of nutrients into the marine environment by man - but they have become much more frequent with the increased disposal of nutrients by man. The red tide occurred along the Florida Gulf Coast in 1916, not again until 1932, not again until

1948, and then in 1952, 1953, 1954, and every year between 1957 and 1964 inclusive.

Less than 30% of the population of the United States is served by sewage treatment plants (Mitchell, 1972). Most plants in use depend on secondary treatment which removes much of the available organic matter, but only 30% of the phosporus and 20% of the nitrogen. Thus the conventional sewage treatment plant releases high concentrations of nutrients into surface waters. The remaining phosporus and nitrogen must be removed by tertiary treatment if eutrophication is to be reversed. Considering this example in North America, what is to be expected of developing countries? For a time, the developing countries regarded pollution control as a luxury they could not afford while they were struggling to develop their industries and exploit their natural resources, or, more importantly, to attract foreign capital and industry. This in itself was difficult enough without accepting the added burden of installing expensive sewage or industrial effluent treatment plants. There is some sign that this attitude is changing and that a longer-term view is being adopted (Anonymous[4], 1971). Schachter and Serwer (1971) report that the United Nations Development Programme has, in co-operation with the World Health Organization, a number of field projects on waste disposal in coastal areas of developing countries. WHO, in co-operation with FAO, offered its first course on coastal pollution control in 1970. Towle (1971) points out that the Caribbean Conservation Association is aware of people from larger continental areas travelling to the shores of previously isolated insular environments inadvertently threatening to alter the very qualities which make islands viable. Allen (1971) claims that several of the methods utilizing domestic and industrial wastes are being used more extensively in developing nations than in the industrialized world.

Barbados, as a developing nation, where the present study was undertaken, is no less aware of environmental problems. The Eastern Caribbean Water Quality Control Seminar was held at the Hotel Caribbee 10 - 12 May 1971. The following is taken from the Advocate-News, the Barbados national daily news publication, with dates given: 20/12/72 - The Barbados branch of the Women's Corona Society gave a report dealing with pollution under the headings of atmosphere, land, conservation, and the sea. The section on the sea deals with concern over dumping in the ocean and the flow of sewage into Carlisle Bay; 6/6/73 - There is a possibility of ocean surveillance by the Coast Guard to detect pollution in territorial waters by oil and other wastes; 29/6/74 - External Affairs Minister, Senator George Moe, at the U.N. law of the sea conference in Caracas, pointed out to the conference that Barbados, with its dense population of over 1500 persons to the square mile, now looks to its coastal waters and the waters of the region for the supplementing of food resources and advancing the economy. He paid special attention to pollution, urging adequate rules to protect the marine environment: "Barbados attaches great importance to this matter, for the very life blood of our country depends on the preservation of the marine environment." While Barbados believed that coastal states should have sovereign jurisdictional powers on marine pollution, it would accept "certain minimum international standards for pollution prevention and control, provided that these standards do not apply in such a way as to impede unduly the industrial development of developing nations".

In the report (1970) of a seminar sponsored by the Barbados National Trust at the University of West Indies, Cave Hill, (Planning for 1980 - an environmental study of Barbados), Dr. J.B. Lewis, former Director of the Bellairs

Research Institute, had the following to say: "A considerable amount of pollution is affecting Carlisle Bay at the present time. The annual consumption of water by industry, hotels and social services bordering the Bay is of the order of 2½ million gallons per month. . . if we allow for, say 20% consumption, then something like 2 million gallons of effluent of one sort or another is spilled into Carlisle Bay every month. This is an enormous quantity of sewage and, if it were not for the particular system of currents affecting the Bay, the effect would be intolerable. As it is, spot checks on the bacterial count have revealed levels of contamination which are not tolerated in most countries. There ought to be a system of monitoring the scale of pollution in Carlisle Bay, now. The consequences of increased pollution of the sea seem obvious enough, just more and worse of the same, dangerous bacterial counts, destruction of marine life including the reefs and uninhabitable beaches. The prevention of course lies in restrictions on effluents and responsible management of coastal centres of population. It seems likely that government legislation will be necessary but should be based on a preliminary survey. . . During the past decade there has been noticeable net loss of beaches along the west coast. . . The present degree of pollution is having an adverse effect upon the coral reefs, which not only act as a protective barrier against wave energy on the shore, but are also an important source of sand for the beaches."
In the same report it is pointed out that the character and quality of the environment in Barbados is unique in the world, and is a priceless asset to the present and future people of the Island. Tourism is fast becoming the island's principal source of employment and prosperity. "This simply means that environment will soon be the island's economic based material." Stephen E. Emtage, Director, Economic Planning Unit, notes that "we have a good opportunity in Barbados to avoid the mistakes which have been created and made by other developed

countries, for which they are now paying very heavily". One of the resolutions forwarded to the Barbados government by this same report was: "that the proper authorities be asked to institute an early and competent survey of the possible pollution of the coastal waters of the Island with a view to reducing or removing the dangers of such pollution".

Until a proposed sewerage system is installed serving the central Bridgetown area (which is commercial, industrial and residential - about one square mile), where provision will be made for the treatment of tank loads of sewage collected from hotels and other large coastal buildings outside the sewered area, the present system of controlled dumping of the wastes at sea remains the lesser of two evils (2 - 12 tanks of excreta are dumped into the sea every night). For disposal of sewage from cesspool emptiers in inland areas is liable to contaminate the underground reservoirs which are the only supply of domestic water. The Barbados government is receiving financial assistance from the Inter-American Development Bank, and Q, L and M Engineers in co-operation with the Ministry of Health and Wallace Evans and Partners (of Barbados) conducted preliminary studies, studied the existing sewage disposal methods for the wider area outside of the central design area (including parts of Christ Church) and are planning and designing this system. It is expected to be a piped system conducting effluent mainly by gravity flow to a treatment plant in the Emmerton area (Figure 1). The latest information about the outfall is that it will be 1,000 feet long and will conduct the treated effluent (biological treatment by aeration followed by chlorination) from the plant to the sea in an area just south of the Deep Water Harbour.

The Barbados Government requested that the Bellairs Research Institute conduct a physical survey of the ocean currents and a biological survey of the water quality of inshore waters affecting the beaches on the west coast. The

coastal current study was financed by the government and conducted by Mr. Steve Peck of the Marine Sciences Centre, McGill University, under the supervision of Dr. Grant Ingram.

In order to make a balanced decision, in order to plan properly, one needs factual information which will show what the present situation is and allow one to possibly predict the outcome of one's actions. Barbados must keep its environment at least as good as, or even better than, it is now, if only for economic reasons. Ketchum (1970) notes how experience has shown that cleaning up a polluted aquatic environment is much more expensive than protecting it in the first place.

Dunstan and Menzel (1971) observe how sewage outfalls into estuaries and coastal waters have increased sharply in the past 15 years. Although several studies have been made of the in situ effects on marine populations of sewage outfalls, "the information concerning the phytoplankton is often inconclusive since data on unpolluted baseline conditions is limited and our understanding of phytoplankton ecology in unpolluted waters is far from complete". Mitchell (1972), describing the use of structural changes in algal communities to assess pollution, reports that the general effects of stress caused by industrial and municipal wastes and agricultural runoff are: reduction of the number of species present; an increase in the range of numbers of individuals per species; changes in selective predator or parasite pressure upon particular segments of the algal communities, resulting in a shift in balance within the community; and a shift in dominance within the community favoring some species over others. "In view of its involvement in industry, microbiology is easily amenable to engineering applications in applied ecology. Microorganisms promise to be excellent tools for model laboratory studies in ecology, just as they are already in biochemistry and genetics."

The limitations of any study must be kept in mind. For example, Johannes (1971), working in Kaneohe Bay, Oahu, Hawaii, where more than 3.5 million gallons of sewage receiving only primary or secondary treatment are poured into the Bay daily, reported the following: "the destruction of the bay's reefs by sewage and sediment pollution were well underway 18 months ago when a multidisciplinary study led to the publicly expressed statement that Kaneohe Bay was not badly polluted. The studies upon which this opinion was based involved examination of the water overlying the reefs, but not of the reefs themselves. The mistaken conclusion drawn from this work is instructive, for it points clearly to the fact that analysis of water alone can be inadequate and dangerously misleading when studying coastal marine pollution. Whereas polluted water and its planktonic contents are continually flushed and diluted by tides, the bottom and its associated organisms serve as a reservoir for pollutants. Bottom communities may thus be stressed much more by pollutants, which concentrate there through settling and sorption, than the transient plankton communities above them." McAlice (1970), observing the small-scale distribution of estuarine phytoplankton in Narragansett Bay, Rhode Island and the Damariscotta River, Maine, showed that statistically significant differences in population density can usually be demonstrated within any series of collections when the collecting interval is more than 10 cm! Björnberg (1971) further points out: "(In tropical habitats). . . Many species are present and, because of unknown factors, one amongst the most frequently found species can suddenly dominate the others in number during a certain length of time. Therefore the study of tropical ambients should always be carried out during several years, and in the most varied conditions."

With or without baseline studies, solutions to problems of stress are not always easy. It was thought necessary

to replace phosphates in detergents with nitrogen - containing nitrilotriacetic acid (Ryther and Dunstan, 1971) but this is now known to only worsen the situation. Sibthorp (1969) made an observation particularly applicable to Barbados: "It would be possible in some instances to discharge noxious wastes one mile off the coast knowing that they will become harmless in a short or long period of time by admixture with the water or carriage out to sea. On the other hand, wastes discharged much further out, in a less favourable place, some hundreds of miles in some instances, might be swept back onto the shore."

Korringa (1970) shows how pollution can mean different things to different people: "nature protectionists wish at the cost of any price to maintain the status quo; fishery people are after a high productivity and therefore are in favor of increasing fertility and of a reduction in the number of species occurring in the area, together with the greatest possible number of individuals of the species they are interested in; in the recreational sector - sport fishery excluded - one prefers clean transparent water if possible devoid of living organisms which are considered as a nuisance". We have to decide, therefore, what we really want from pollution control. How far do we want to go in controlling marine pollution? How much money do we want to spend on it? "The inshore marine environment must be protected against deterioration resulting from the discharge of municipal and industrial wastes. This environment has the capacity to receive a certain amount of waste discharge without damage to its other uses and in fact a valuable and legitimate use of the near-shore marine environment is as a diluting and assimilating medium for waste materials, provided that these are introduced within the capacity of the environment. By capacity is meant a rate of introduction which will not result in degradation from the standpoint of other uses, such as fishing and recreation. . . In

some cases, the added cost of locating the outfall in a region of greater receiving capacity may be less than the added cost of more complete waste treatment" (Sibthorp, 1969). Many pollutants in the sea are degraded fairly quickly or do not move far from where they were put, and any problem they create is a purely local one. It may be argued that if a country chooses to foul its own doorstep, that is its own affair so long as it harms no-one else. Sometimes developed countries impose obligations on developing countries which they did not have to bear when they were developing their own industries. Many developing countries are "anxious to preserve their environmental resources alongside their new industries and one suspects that they are more concerned about this than many of the foreign businesses that are undertaking the industrial developments" (Anonymous[3], 1971). "Although it is unfashionable to say so, there seems no reason why some areas of sea should not be highly polluted, providing it is with pollutants that will have a purely local effect. . . This is the essence of good management and is the way to avoid diverting resources better spent elsewhere by straining to maintain a pollution-free environment everywhere" (Anonymous[6], 1972).

Barbados was thought to be an excellent study site because of the apparent concern shown by its people for pollution, and because of previous studies carried out of unpolluted areas which could be compared with a study of comparatively polluted areas. The word "comparative" is used because it was also thought that Barbados presented an opportunity to assess an area in which pollution was just beginning. Sander (1971) raised the possibility that significant uninhabited islands may have smaller island mass effects than heavily populated ones. Man-made pollution was considered to have little effect on his results, as the study area was

picked deliberately to avoid the area near Bridgetown. Steven (1971) chose a station (10 km west of Speightstown) "about 3 miles north of the one studied by Beers et al (1968)". He notes that the shift "was made to be certain of avoiding an area of relatively high chlorophyll concentrations which was discovered in 1967, and extends seawards for several miles west and south-west of Bridgetown". The Island has a simple topography, being small and completely devoid of important rivers, estuaries or fjords, so any effects of organic pollution would certainly be coming from the Bridgetown and Deep Water Harbour areas.

The first of the general objectives was to conduct a preliminary survey of the existing water conditions affecting the beaches on the West Coast of Barbados. The survey would be preliminary insofar as it will be a baseline study for comparison with a future study after the installation of a proposed sewage treatment plant and outfall serving the Bridgetown area. Various physical and chemical parameters were employed to conduct this survey over a one-year period on a weekly basis. An area was picked which visually seemed to be polluted and measurements were made for comparison with an area known from previous work not to be polluted. It was intended to show pollution depicted by gradients decreasing from the Deep Water Harbour to points further north along the coast. The work of the previous authors in the unpolluted area was confirmed and updated, and a definitely polluted area was picked half-way through the project to compare with the previous two areas. The second objective was to attempt to assess pollution through changes in the structure of the algal communities. Phytoplankton, identified to genera and lumped into major groups, were studied to determine if any differences existed in community structure of the populations found at the three areas.

METHODS

Description of Stations

The sampling area is shown in Figure 1(drawn to scale). The main group of stations (3-10) was designed to form a grid pattern comprising four 'inner' (3,6,7, and 10) and four 'outer' (4,5,8, and 9) stations, each 'outer' station lying on an east-west axis from the respective 'inner' station. The first two stations (3,4) of the grid were located west of Indian River. The last two (9,10) were off the Paradise Beach Club and were 2½ km north of stations 3 and 4. Station 10 was located in Fresh Water Bay. Station 2 was located in the mouth of the Deep Water Harbour. Station 11 (Bellairs) was located off the Bellairs Research Institute, 7 km north of Paradise Beach Club. Station 1 was located just south of the Deep Water Harbour.

Before these stations were fully included in the work plan, surface-current drift-bottle tests were carried out (briefly described below).

It was decided in January 1973 to monitor Carlisle Bay and the careenage. Station E was located right at the mouth of the careenage, while station F was located between the two bridges crossing the careenage in the heart of Bridgetown. The approximate locations of stations A - G are shown in Figure 1.

In addition there were 4 stations on the south coast, at St. Lawrence, Accra Beach, the Asta Hotel, and the Hilton Hotel (not shown in Figure 1).

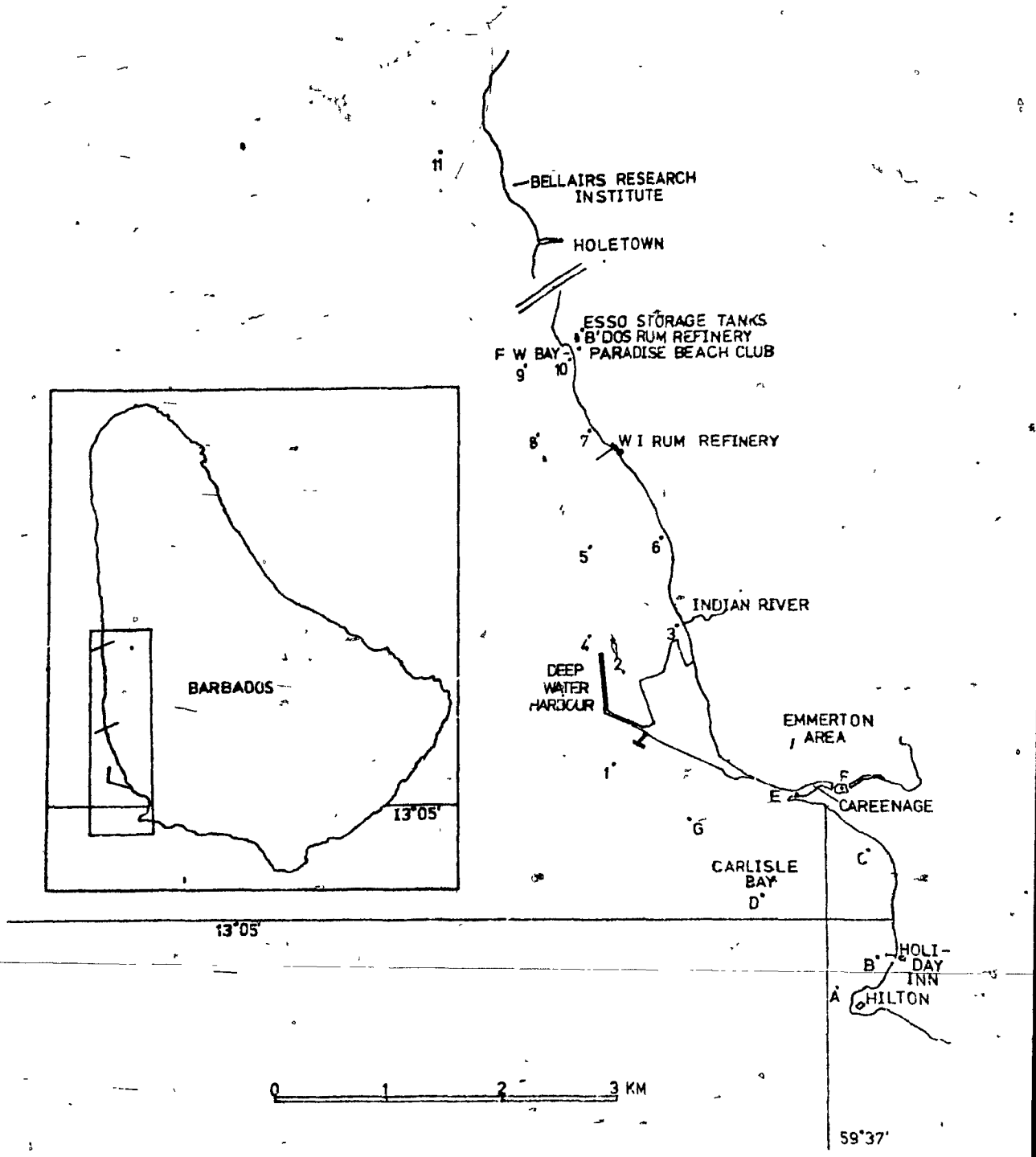


Figure 1. The sampling stations (excluding south coast stations) on the west and south-west coasts of Barbados.

The stations were numbered or lettered in the order which they were visited. Surface (1m) samples only were collected at all stations. The depths of stations 1 - 11 and E and F were as follows:

Station	Depth (m)
11 (Bellairs)	28
3,6,7,10	2
4	14
5,8	6
9	20
2	20
1	41
E,F	6

By forming a grid pattern of stations north of the harbour it was intended to show concentration gradients in the levels of different parameters, being greater nearer the harbour and progressively improving as distance from the harbour increased. The water at Bellairs was known to be unpolluted, based upon previous work (discussed above). It was intended to compare Bellairs with the harbour - Paradise Beach area, at the same time bringing up to date the data at Bellairs.

During the sampling period the exact location of the proposed treatment plant and outfall was never firmly decided upon. Therefore the monitoring stations were set up in a manner thought best to depict the existing conditions of the seawater affecting the beaches on the west coast. Any future work in the same area after installation of the outfall will definitely be useful to assess the impact of the outfall around Bridgetown and the harbour area and remedial action may be implemented if needed before any harmful effects spread further north along the west coast.

Collection of Samples

Stations 1 - 11 were visited on as close to a weekly-basis as was possible (weather permitting) from July 1972 to July 1973. Work at stations A - G was started in January 1973 and carried out on a monthly-basis (except March) until July 1973. Stations 1 and 11 were always sampled when doing stations A - G. The south coast stations were occupied two times during June 1973. Stations 1 - 11 or stations A - G were visited between 0800 and 1000 (local time) on any sampling day in a motor launch. The south coast stations were reached from shore.

All samples were taken from a depth of 1 m and collected by hand.

Water samples were collected with Van Dorn bottles of 7 l capacity. Subsamples were taken immediately after collection from these bottles for chlorophyll a, phytoplankton (limited to stations 3, 9, 10, 11, and F), nitrate + nitrite - N, phosphate -P, particulate matter, and salinity (periodic collections only) determinations.

Samples for D.O. and BOD were taken with a Knudsen bottle. BOD samples were taken weekly initially, but monthly after January 1973.

Coliform samples were taken directly with sterilized BOD bottles. The glass stoppers were not removed until the bottle was submerged. Work was commenced in April 1973 for stations 1 - 11 and was done monthly until July 1973. Stations A - G were done in July 1973 only.

Temperatures were determined with a reversing thermometer (periodic data only).

Treatment of Samples

Water for pigment analyses was poured into 7 l heavy grade polyethylene bottles and kept under cover until returned to the laboratory. Usually 5 l, but sometimes as little as 2 l (station F), were filtered through 4.25 cm glass fiber filters. From July 1972 until 9/5/73 Reeve Angel glass fiber filters, grade 934AH, were used. After that Whatman GF/C filters were used. About 1 ml of magnesium carbonate suspension (1 gm in 100 ml distilled water) was added to the last few hundred ml being filtered. The filter pads were placed immediately in 90% acetone - the filters were never frozen before extraction. Chlorophyll a measurements were based on the modified method of Richards with Thompson (1952) as given by Strickland and Parsons (1968) using a Beckman DU spectrophotometer. The Parson - Strickland equation was used.

Half-liter water samples were taken and immediately preserved with 2% neutralized formaldehyde for subsequent examination and enumeration of the phytoplankton. The cells were allowed to settle at least 72 hours in graduated cylinders and then reduced by slow siphoning to a little less than 50 ml. These concentrates were stored in vials and, when required, made up to 50 ml with distilled water, half of which was poured into 25 ml, 2.5 cm diameter settling cylinders. The samples were examined with a Zeiss-Utermöhl inverted microscope. Twenty-five fields, about 1% of the total, were counted for each sample and an average value obtained by multiplying first by 4 (since the concentrate examined was from 250 ml of sample only), then by 100, to give cell numbers per liter. Very careful counts and identifications were made. Usually the plankters were identified to genus, very seldom to species, and less often to major groups.

Two 130 ml polyethlene bottles were filled with water for micronutrient analysis and immediately put into a portable freeze box aboard the vessel. Upon return to the laboratory they were placed in deep freeze until required for analysis within two or three weeks. Nitrate + nitrite -N was measured by the modified method of Morris and Riley (1963) as given by Strickland and Parsons (1965). Phosphate -P was measured by the method of Murphy and Riley (1962) as given by Strickland and Parsons (1968). Commencing November 1972 all samples were filtered prior to freezing. A turbidity correction for all samples, excluding the high nitrate samples requiring the use of a 1 -cm cell only, was made.

Great care had to be taken to prevent contamination of nitrate samples by tapwater during thawing.

Particulate matter was measured by the method of Strickland and Parsons (1968) taken from Banse, Falls and Hobson (1963) using up to 2 l samples kept in the same 7 l polyethylene bottles described for pigment analyses. Usually 2 l were filtered through 47 - mm HA Millepore filters (0.45 μ, white, plain) for the 'outer' line of stations, 1 l for the 'inner' line of stations and 0.5 l for the careenage stations.

All salinities were measured with an inductively coupled salinometer model 601 MK III made by Auto Lab Industries, P/L Sydney.

Dissolved oxygen and 5-day BOD were measured using a modification of the classical Winkler procedure as given by Strickland and Parsons (1968). Light and dark bottles (300 ml BOD bottles) were filled being careful to minimize turbulence and agitation of the samples. The light bottles

were immediately "pickled" at sea after collection. There was no possibility of oxygen being lost when the samples 'warmed' to room temperature as the air-conditioned laboratory was always 2 - 3 °C lower than the field temperature. The BOD samples were left in the BOD incubator for 5 days at 20 °C. Three titrations per sample were always done immediately after acidification of the sample and the starch end-point detector was used.

A standard technique for the enumeration of total coliforms was used taken from "Recommended Procedures for the Examination of Sea Water and Shellfish."* The culture dishes used were Millepore plastic (disposable) petri dishes (48 x 8.5 mm). The filter membranes (47 mm HA - 0.45 μ - white, grid), absorbent pads and nutrient ampoules were also from Millepore. The filtered samples were incubated at 35 °C ± 0.5 °C for 22 - 24 hours. During autoclaving the glass stoppers of the BOD bottles were supported away from the neck of the bottles with aluminum foil. When the autoclave was opened the stoppers were pushed into place immediately.

* fourth edition, 1970. The American Public Health Assoc., Inc. 1740 Broadway, New York, N.Y. 10019

FURTHER DESCRIPTION OF THE STUDY AREA

Deep Water Harbour

The Deep Water Harbour, opened on 6/5/61, is now called the Bridgetown Harbour. The main breakwater is 1700 feet long. The lesser breakwater has 3 sugar loading towers on it. This port was constructed to handle 150,000 tons of cargo annually, but it now handles an annual figure of 340,000 tons. Plans are being prepared for a $24 million expansion program making it a modern port.

Indian River

Water from surrounding districts flows into Indian River which leads to the sea at Lands End, St. Michael. The mouth of the river was blocked making the water stagnant and an excellent breeding ground for mosquitoes. At one time the Ministry of Health would clear the mouth occasionally, relieving some of the stench, but it appears that this is no longer the case.

Carlisle Bay

The Advocate-News had the following to say about Carlisle Bay (9/6/74): We have among us people who knew when the first seaplanes came to Barbados fifty-odd years ago. At that time Carlisle Bay had a clean, white sand bottom. It is on record that the waters of the bay were so clear that the pilots had difficulty in discerning the surface. With the emptying of our drains into the sea, Carlisle Bay has a bottom as opaque as anywhere else - and that did not build up overnight.

Surface Currents

Prior to regular sampling the surface circulation was determined in the harbour - Fresh Water Bay area at low tide(12/6/72) and at high tide (19/6/72). The circulation was much the same at both tides as the tidal range mean is only 2.3 feet in Barbados.

At station 1 the drift bottles travelled NNW; at station 2 the bottles first drifted to the edge of the harbour mouth and then proceeded seaward; at the 'inner' line of stations they followed a more WNW direction; at the 'outer' line of stations the bottles travelled NNW, ~~as at station 1. At about ½ mile north of Fresh Water Bay~~ the current was going directly offshore. This seemed to be the dividing point as SSW currents were observed from the north part of the island. At station 11 the bottles proceeded SSW. It was noted that there was no danger of inshore surface currents carrying effluent back to the shore. This current pattern agreed with that of Emery (1972).

It was explained above how, for the present, the disposal of sewage (from septic tanks and suck wells) from city and coastal buildings is best done by disposal at sea. The site authorised for such disposal is off Cowell Street in Bridgetown. In this position on the coast the general flow of currents is in a WNW to NW direction and takes the wastes away from the land. There are no bathing beaches near this point and there is no history of wastes coming back to the land from this point (Advocate-News, 18/7/72).

RESULTS

The grid of stations from the harbour to Fresh Water Bay was laid out in the expectation that some degree of pollution emanated from the harbour and it was thought that there would probably be a gradient along a north-south axis. In fact, the significant differences found in the different parameters studied were generally on an east-west axis between the 'inner' and 'outer' lines of stations. The harbour mouth station was in some respects intermediate between them. In general, considering physical-chemical parameters only, the 'outer' line stations were the same as the Bellairs station for which there was previous information from 1968 to 1970 (Sander and Steven, 1973). The Bellairs and the careenage stations were considered to be extremes in terms of nutrient enrichment in Barbados. The 'inner' line of stations seemed to be somewhere in between the two extremes, and so would the 'outer' line if only phytoplankton were considered. Judging from the physical-chemical results of the 'outer' line of stations, the community structure of the phytoplankton population was completely unexpected.

The parameters are presented emphasizing the absence of a north-south gradient. The Bellairs, Combined 'outer', Combined 'inner', harbour mouth, and careenage (Station F) stations only are discussed, as they were representative of the different situations found in Barbados. The data for stations A-E, G, 1, and the four south coast stations are listed in the appendix as they may be useful as baseline data for future studies. Only the phytoplankton data for the results presented below are not listed in the appendix, due to the quantity. The summarized data which

show the average levels of the parameters studied are presented in Tables 1 - 14 of this section.

Physical Characteristics

Maximum and minimum temperatures found were 29.2°C (station 6, 3/8/72) and 26.8°C (station 11, 1/4/73) respectively. The salinity maximum was 35.8‰ (station 6, 1/4/73) while the minimum value obtained was 31.3‰ (station 10, 21/7/73).

Treatment of Results

Absence of seasonal variation (Sander and Steven, 1973) permits differences between stations to be compared by simple variance tests as if values varied randomly around mean annual values. Stations and groups of stations were compared by t tests using the 5% level of significance. Due to the large range of cell concentrations at all stations statistical tests were not performed on the phytoplankton data. The small amount of data for station F, temperature, salinity, and coliform counts, did not warrant statistical testing.

Dissolved Oxygen

Data for D.O. concentrations are found in Table 1. The Bellairs station was richest in oxygen. The means of the combined 'outer' and 'inner' stations were significantly different. Although the harbour mouth station was poorer in oxygen than at Bellairs, it was richer than either the combined 'inner' or 'outer' stations.

The careenage, from 6 determinations, had about half the D.O. concentration found elsewhere.

Station 10 at Fresh Water Bay had a higher D.O. concentration (4.38 ml/l) than the other 'inner' stations and it was the only 'inner' station higher in D.O. than the harbour mouth. Stations 3, 6, and 7 showed values of 3.76, 3.85 and 4.01 ml/l respectively.

TABLE 1

Dissolved Oxygen Concentrations by Station or Combined Stations

Stations	Harbour Mouth	Combined 'Inner'	Combined 'Outer'	Bellairs	Careenage
No. of observations	44	176	176	50	6
Mean ml/l ± SE	4.28 ± .03	4.00 ± .03	4.19 ± .02	4.46 ± .03	2.23
Significance Tests	S.D.	S.D.	S.D.	S.D.	

N.S. = not significant; S.D. = significant difference
SE = standard error.

Biochemical Oxygen Demand

BOD data are summarized in Table 2. Although there was a significant difference between the combined 'outer' and 'inner' stations there was none between the Bellairs station and either the combined 'outer' or 'inner' stations. The harbour mouth station had a higher oxygen demand than either at Bellairs, the combined 'inner' or combined 'outer' stations.

The careenage was the only area where the BOD approached half the D.O. concentration.

TABLE 2

Biochemical Oxygen Demand by Station or Combined Stations

Stations	Harbour Mouth	Combined 'Inner'	Combined 'Outer'	Bellairs	Careenage
No. of observations	27	108	107	33	6
Mean ± SE ml/l	.29 ± .02	.24 ± .01	.19 ± .01	.20 ± .02	.90
Significance Tests	S.D.	S.D.	N.S.		
		N.S.	S.D.		
	S.D.				

Total Coliforms

The final counts are found in Table 3. The appendix listing (Table 28) shows the volumes sampled and hour of collection for each station, and also 3 surface determinations for water at Bellairs by the Coral Reef Club raft (about 4 m deep).

Generally, the harbour mouth and Indian River stations (except for the careenage) had the highest coliform counts.

TABLE 3

Total Coliform Colonies/100 ml

Stations / Date	Harbour Mouth	'Inner' 3	6	7	10	'Outer' 4	5	8	9	Bellairs	Careenage
18-4-73	100	180	3	49	73	0	0	0	0	4	-
19-5-73	210	190	51	17	61	40	23	2	44	32	-
16-6-73	200	220	31	43	280	450	310	110	8	21	-
14-7-73	-	-	-	-	-	-	-	-	-	31	TNTC
21-7-73	88	86	2	52	56	17	31	26	9	2	-

TNTC = too numerous to count

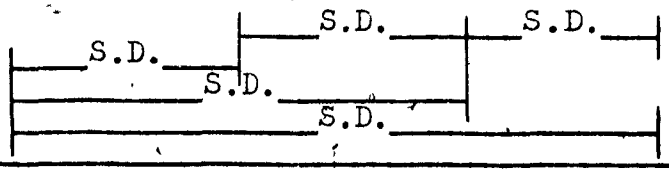
Particulate Matter

Table 4 shows the summarized particulate matter data. The means differed significantly between the Bellairs station and the combined 'outer' stations, and also between the combined 'outer' and 'inner' stations. The harbour mouth station was intermediate between the combined 'inner' and 'outer' stations, and was significantly greater than the Bellairs station.

Particulate matter at the careenage station was greater than elsewhere.

TABLE 4

Particulate Matter by Station or Combined Stations

Stations	Harbour Mouth	Combined 'Inner'	Combined 'Outer'	Bellairs	Careenage
No. of observations	45	179	179	51	6
Mean ± SE mg/l	1.66 ± .14	3.14 ± .19	1.17 ± .06	.88 ± .11	8.07
Significance Tests					

Phosphate - P

PO_4-P data are summarized in Table 5. There were no significant differences between the means at the Bellairs, combined 'outer', combined 'inner', or harbour mouth stations. The six observations at the careenage station indicated the presence of localized phosphate enrichment.

TABLE 5

PO_4-P Concentrations by Station or Combined Stations

Stations	Harbour Mouth	Combined 'Inner'	Combined 'Outer'	Bellairs	Careenage
No. of observations	48	192	192	54	6
Mean ± SE µg-at/l	.081 ±.026	.065 ± .004	.075 ±.008	.055 ±.007	2.671
Significance Tests		N.S.	N.S.		
			N.S.		
		N.S.			

Nitrate + Nitrite -N

The data for NO_3 + NO_2-N are summarized in Table 6, representing mean values from April 1973 to July 1973. There was obvious enrichment at the Fresh Water Bay area (see DISCUSSION) and at the careenage station. In fact, significance tests have not been done because of the order of magnitude differences found at the Fresh Water Bay area, where freshwater origin was suspected. The harbour mouth station was lower than at Bellairs.

TABLE 6

$NO_3 + NO_2$ - N Concentrations by Station

Stations	Harbour Mouth	'Outer' 4	5	8	9	Bellairs	Careenage
No. of observations	12	11	12	12	12	15	3
Mean ± SE µg-at/l	.252 ±.048	.319 ±.081	.543 ±.091	.899 ±.277	4.259 ±1.497	.402 ±.095	2.355

Stations	'Inner' 3	6	7	10
No. of observations	12	12	11	12
Mean ± SE µg-at/l	.471 ±.084	1.018 ±.637	.631 ±.141	29.140 ± 8.732

Chlorophyll a

Plant pigment data are summarized in Table 7.

There was no difference between the chlorophyll at the Bellairs station and the 'outer' line of stations. The chlorophyll concentration of the 'inner' line was 2.3 times greater than the 'outer' line. The harbour mouth station was intermediate between the 'inner' and 'outer' lines, and greater than at the Bellairs station.

The chlorophyll concentration in the careenage was 7 to 16 times greater than elsewhere, or about an order of magnitude.

TABLE 7

Chlorophyll a Concentrations by Station and Combined Stations

Stations	Harbour Mouth	Combined 'Inner'	Combined 'Outer'	Bellairs	Careenage
No. of observations	45	182	183	52	6
Mean ± SE mg/m^3	.430 ±.026	.614 ±.026	.270 ±.009	.273 ±.021	4.357
Significance Tests	S.D.	S.D.	N.S.		
	S.D.	S.D.			
	S.D.				

Phytoplankton

12 samples were counted at the Bellairs station (one per month, taken at approximately the same time each month), 4 at the careenage station and all at stations 3, 9 and 10.

Table 8 shows the average weekly cell count /l for the year for the major phytoplankton groups at the different stations. The average weekly total for the year and the range found throughout the year of total cells/l at each station is also shown, at the bottom of the Table.

When counts are mentioned regarding Trichodesmium this refers to numbers of filaments rather than cells, as practiced by other authors (eg. Hulburt, 1962, 1968). Davis (1955) reports Euglena and Chlamydomonas to be in the Class Mastigophora, but in an Order other than Dinoflagellata. Fritsch (1961) lists Euglena as a separate Class of algae, and Chlamydomonas as Chlorophyceae. This report considers Euglena to be a dinoflagellate, and agrees with Fritsch for the green algae.

TABLE 8

Phytoplankton - Average Weekly cells/l ($x10^3$) for the Year

Stations	'Inner' sta.3	sta.10	'Outer' sta.9	Bellairs sta.11	Careenage sta. F
No. of observations	44	44	44	12	4
Diatoms -Centric	36.4	36.0	24.4	36.4	184.0
-Pennate	21.6	19.2	13.6	11.6	40.0
Ttl.Diatoms	58.0	55.2	38.0	48.0	224.0
Dinoflagellates	57.2	55.6	31.2	12.0	560.0
Trichodesmium thiebaudii	1.2	0.8	1.6	3.6	8.0
Blue-greens except Trichodesmium	-	-	-	-	2.0
Ttl. Blue-greens	1.2	0.8	1.6	3.6	10.0
Chlorophyta	0.4	2.4	0.4	-	8.0
Average Weekly Total	116.8	114.0	71.2	63.6	802.0
Range	41.2 - 904.0	34.8 - 710.4	25.6 - 510.8	10.4 - 210.8	752.0 - 940.0

In the careenage samples there were considerable numbers (averaging 12,000 over 4 collections) of a Euglena-like organism, 30μ x 12 μ, included in the Dinoflagellate numbers.

Coccolithophores and Silicoflagellates were sometimes present in small numbers, but they never amounted to sufficient numbers to enable them to be included in averages.

The number of centric diatoms was more or less the same at Bellairs and the 'inner' and 'outer' lines, but pennate species were about twice as numerous at the 'inner' line stations, not surprising since most pennate forms are tychopelagic.

Dinoflagellates were 2.6 to 4.8 times more numerous at the 'outer' and 'inner' lines, respectively, than at Bellairs.

Worth stressing is the fact that, although the 'outer' line stations had the same chlorophyll a concentration as at Bellairs, the 'outer' station shifted somewhat in composition as did the 'inner' line. Dinoflagellates were the major cause of the overall shift found between the harbour and Fresh Water Bay.

The careenage had greater numbers of all groups, but the major contributors were centric diatoms and dinoflagellates.

The range of cell concentrations at all stations was very large. Average total numbers were similar at Bellairs and the 'outer' station; only the change in composition was noticeable mainly due to dinoflagellates being in greater concentration between the harbour and Fresh Water Bay area. The 'inner' stations were 1.6 times greater in

numbers of cells /l than the 'outer' station.

Table 9 shows the percentage contribution by the major groups to the phytoplankton at the different stations averaged for the year.

TABLE 9

Phytoplankton - % Contribution - Average for the Year

Stations	'Inner' sta.3	'Inner' sta.10	'Outer' sta.9	Bellairs sta.11	Careenage sta.F
No. of observations	44	44	44	12	4
Diatoms - centric	31.2	31.6	34.3	57.2	22.9
- pennate	18.5	16.8	19.1	18.3	5.0
Ttl. Diatoms	49.7	48.4	53.4	75.5	27.9
Dinoflagellates	49.0	48.8	43.8	18.9	69.8
Trichodesmium thiebaudii	1.0	0.7	2.2	5.6	1.0
Blue-greens except Trichodesmium	-	-	-	-	0.3
Ttl. Blue-greens	1.0	0.7	2.2	5.6	1.3
Chlorophyta	0.3	2.1	0.6	-	1.0

Diatoms contributed 75.5% to the phytoplankton at Bellairs, while 18.9% were dinoflagellates and the rest Trichodesmium.

Diatoms dropped about 25% at the 'inner' and 'outer' stations, while the dinoflagellates rose to about 50%; therefore the 'inner' and 'outer' stations made similar shifts in percentage composition.

Only the careenage station was in an area where all the major groups were substantially represented (excepting coccoliths and silicoflagellates). Diatoms took a further drop to 27.9%; dinoflagellates rose even higher to 69.8%.

Tables 10 - 14 are extended descriptions of the phytoplankton composition for each station averaged for the year. The most abundant genera contributing to the major groups are listed, with the average cell concentrations for the year for each genus. The percentage contributions of the major genera to the average total cell counts for the year are also given.

All representatives of dinoflagellates that were present in sufficient numbers to figure in the averages for the year are listed, regardless of importance. Nitzschia is divided into 3 groups, ie. N. seriata, N. closterium and N. spp., and a note of the total Nitzschia concentration is given for each station. Blue-greens are in three groups also, ie. Trichodesmium thiebaudii, Anabaena sp. and "blue-greens other" (than the previous two).

Following each major genera listing for each station (part A) is information concerning the less important (in terms of numbers) contributors (part B). Different genera each contributing the same proportion are given. Where different genera were counted but had insufficient numbers to figure in the averages over the year they are noted as "counted - no average." Where different genera were seen occasionally through additional scanning of the samples these are noted as "also seen - not counted."

TABLE 10 - A*

Bellairs - Phytoplankton - Average for the Year

Group	Genus	Average cells/l($\times 10^3$)	Average % Total
Diatoms	Chaetoceros spp.	34.0	53.5
	Thalassiothrix sp.	3.6	5.7
	Nitzschia seriata	3.2	5.0
	Navicula spp.	1.6	2.5
Dinoflagellates	naked flagellates	11.2	17.6
	Gymnodinium spp.	0.4	0.6
	Peridinium spp.	0.4	0.6
Blue-greens	Trichodesmium thiebaudii	3.6	5.6

TABLE 10 - B

	Average Percentage Total	: Contributors
Diatoms	1 - 2%	: Nitzschia spp, Rhizosolenia spp, unidentified pennate diatoms.
	< 1%	: Coscinodiscus spp, Leptocylindrus spp, Hemiaulus sp, Unidentified centric diatoms, Asterionella sp, Nitzschia closterium, Tabellaria sp.
	counted - no average	: Bellerochea sp, Eucampia sp, Bacteriastrum spp, Pinnularia sp, Licmophora sp, Pleurosigma sp, Bacillaria sp.
Blue-greens		: blue-greens other.
Chlorophyta		: Closterium sp.
Silicoflagellates		: silicoflagellate sp.
	Also seen - not counted	
Diatoms		Biddulphia sp, Dactyliosolen sp.
Dinoflagellates		: Ceratium spp.

Total Nitzschia - 4.8 cells /l, or 7.5%

*explained in text

TABLE 11-A

'Outer' station 9 - Phytoplankton - Average for the Year

Group	Genus	Average cells /l($x10^3$)	Average % Total
Diatoms	Chaetoceros spp.	20.8	29.2
	Nitzschia seriata	4.0	5.6
	Navicula spp.	2.4	3.4
Dinoflagellates	naked flagellates	30.4	42.7
	Gymnodinium spp.	0.8	1.1
Blue-greens	Trichodesmium thiebaudii	1.6	2.2

TABLE 11-B

	Average Percentage Total	:	Contributors
Diatoms	1 - 2%	:	Thalassiothrix sp, Nitzschia spp, Coscinodiscus spp, Leptocylindrus spp, Rhizosolenia spp, Striatella spp, Asterionella sp, Nitzschia closterium, unidentified pennate diatoms.
	<1%	:	Climacodium sp, Dactyliosolen sp, unidentified centric diatoms, Fragilaria spp, Licmophora sp, Pleurosigma sp, Tabellaria sp.
Chlorophyta	counted - no average	:	Green sp, Closterium sp, Pleurotaenium sp.
Diatoms		:	Corethron sp, Melosira sp, Thalassiosira sp, Skeletonema sp, Biddulphia sp, Bellerochea sp, Eucampia sp, Hemiaulus sp, Bacteriastrum spp, Pinnularia sp, Climacosphenia sp, Bacillaria sp, Synedra sp, Amphora sp, Diatoma sp, Grammatophora sp, Diplonies sp.
Dinoflagellates		:	Euglena sp, Peridinium spp, Ceratium spp.
Blue-greens		:	Anabaena sp, blue-greens other.
Coccolithophores		:	coccolith sp.
Silicoflagellates		:	silicoflagellate sp.

Total Nitzschia - 6.0 cells /l, or 8.4%

TABLE 12-A

'Inner' station 10 - Phytoplankton - Average for the Year

Group	Genus	Average cells/l($\times 10^3$)	Average % Total
Diatoms	Chaetoceros spp.	30.0	26.3
	Navicula spp.	4.4	3.9
	Nitzschia seriata	2.4	2.1
	N. spp.	2.0	1.7
	Fragilaria spp.	2.0	1.7
	unidentified pennate diatoms	2.0	1.7
	Coscinodiscus spp.	1.6	1.4
	Thalassiothrix sp.	1.6	1.4
Dinoflagellates	naked flagellates	44.4	39.0
	Peridinium spp.	8.0	7.0
	Gymnodinium spp.	3.2	2.8
Blue-greens	Trichodesmium thiebaudii	0.8	0.7
Chlorophyta	F.W. chlor.*	2.0	1.7
	Green sp.	0.4	0.4

* - Fresh water green sp.

(cont'd). . .

TABLE 12-B

'Inner' station 10 - Phytoplankton - Average for the Year

Group	Average Percentage Total	Contributors
Diatoms	1%	Biddulphia sp, unidentified centric diatoms, Nitzschia closterium.
	< 1%	Leptocylindrus spp, Asterionella sp, Licmophora sp, Thalassiosira sp, Rhizosolenia spp, Bellerochea sp, Striatella spp, Pleurosigma sp, Amphora sp, Tabellaria sp, Grammatophora sp.
	counted - no average	Corethron sp, Melosira sp, Eucampia sp, Isthmia sp, Bacteriastrum spp, Dactyliosolen sp, Pinnularia sp, Climacosphenia sp, Synedra sp, Diplonies sp.
Dinoflagellates		Prorocentrum sp, Ceratium spp.
Blue-greens		Anabaena sp, blue-greens other.
Chlorophyta		Closterium sp, Pleurotaenium sp.
Coccolithophores		coccolith sp.
Silicoflagellates		silicoflagellate sp.
	also seen - not counted	
Diatoms		Cerataulina sp, Hemiaulus sp, Climacodium sp.

Total Nitzschia - 5.6 cells /l, or 4.9%

TABLE 13-A

'Inner' station 3 - Phytoplankton - Average for the Year

Group	Genus	Average cells/l($x10^3$)	Average % Total
Diatoms	Thalassiosira sp.	24.4	20.9
	Chaetoceros spp.	6.8	5.8
	Nitzschia closterium	4.0	3.4
	Navicula spp.	3.2	2.8
	Thalassiothrix sp.	2.4	2.1
	unidentified centric diatoms	2.0	1.7
	Nitzschia seriata	2.0	1.7
	N. spp.	2.0	1.7
	Coscinodiscus spp.	1.6	1.4
Dinoflagellates	naked flagellates	50.8	43.5
	Gymnodinium spp.	3.6	3.1
	Peridinium spp.	2.8	2.4
Blue-greens	Trichodesmium thiebaudii	1.2	1.0

(cont'd) . . .

TABLE 13-B

'Inner' station 3 - Phytoplankton - Average for the Year

Group	Average Percentage Total	Contributors
Diatoms	1%	Asterionella sp, Licmophora sp, Pleurosigma sp, unidentified pennate diatoms.
	< 1%	Leptocylindrus spp, Tabellaria sp, Skeletonema sp, Rhizosolenia spp, Fragilaria spp, Striatella spp, Gyrosigma sp, Bacillaria sp, Synedra sp, Amphora sp.
Chlorophyta		Green sp, Chlamydomonas sp, Closterium sp, Closteridium sp, Pleurotaenium sp.
	counted - no average	
Diatoms		Guinardia sp, Biddulphia sp, Cerataulina sp, Eucampia sp, Hemiaulus sp, Climacodium sp, Isthmia sp, Bacteriastrum spp, Dactyliosolen sp, Pinnularia sp, Diatoma sp, Diplonies sp,
Dinoflagellates		Euglena sp, Prorocentrum sp, Ceratium spp.
Blue-greens		Anabaena sp, blue-greens other.
Coccolithophores		coccolith sp.
Silicoflagellates		silicoflagellate sp.
	also seen - not counted	
Diatoms		Melosira sp, Streptotheca sp, Climacosphenia sp.

Total Nitzschia - 8.0 cells /l, or 6.8%

TABLE 14-A

Careenage - Phytoplankton - Average for the Year

Group	Genus	Average cells/l ($x10^3$)	Average % Total
Diatoms	Coscinodiscus spp.	164.0	20.4
	Chaetoceros spp.	16.0	2.0
	Nitzschia seriata	14.0	1.8
	Navicula spp.	10.0	1.2
Dinoflagellates	Peridinium spp.	424.0	52.9
	naked flagellates	118.0	14.7
	Euglena sp.	12.0	1.5
	Gymnodinium spp.	6.0	0.7
Blue-greens	Trichodesmium thiebaudii	8.0	1.0
	blue-greens other	2.0	0.3
Chlorophyta	F.W. chlor.*	8.0	1.0

*Fresh water green sp.

TABLE 14-B

	Average Percentage Total	: Contributors
Diatoms	< 1%	: unidentified pennate diatoms, Leptocylindrus spp, unidentified centric diatoms, Thalassiothrix sp, Licmophora sp, Pleurosigma sp, Nitzschia closterium, N. spp.
	counted - no average	
Chlorophyta		: Green sp, Closterium sp.
	also seen - not counted	
Diatoms		: Melosira sp, Rhizosolenia spp, Fragilaria sp, Tabellaria sp, Grammatophora sp.

Total Nitzschia - 18.0 cells/l, or 2.2%

Diatoms

Chaetoceros spp. dominated the Bacillariophyceae at Bellairs, the 'outer' station 9 and the 'inner' station 10, while Thalassiosira sp. dominated at the 'inner' station 3. Coscinodiscus spp. were by far the dominant diatoms at the careenage. These were well-defined pill-like boxes about 40μ in diameter on the average.

Navicula spp. and Nitzschia seriata were very abundant at all stations.

Dinoflagellates

The small naked flagellates were by far the most common dinoflagellates at Bellairs, the 'outer' station and the 'inner' stations, being 17.6%, 42.7% and 39.0% (station 10) to 43.5% (station 3), respectively, of the total plankton. These flagellates at the careenage station, though numerous, accounted for only 14.7% of the total phytoplankton. Here, the high percentages of naked flagellates found between the harbour and Fresh Water Bay were replaced by Peridinium spp, being 52.9% of the total plankton, with an average of 424, ooo cells/l. These abundant Peridinium spp. had an average diameter of 40μ.

Gymnodinium spp. were found at all stations. Euglena sp, besides being prominant at the careenage station, was "counted - (with) no average" at the 'outer' station and 'inner' station 3.

Blue-greens

Trichodesmium thiebaudii was found at all stations; 3,600 filaments /l at Bellairs, 1,600 at the 'outer' station,

800 at 'inner' station 10, 1,200 at 'inner' station 3, and finally 8,000 at the careenage station. Percentages shown would be greater if filaments were converted to number of cells.

Information on the other major groups may easily be extracted from the tables.

Replicability of Data

Estimates of sampling error, short-term variability and the reliability of the counting technique have been made by replication.

Ten subsamples were taken from each of three single large water samples collected at approximately $\frac{1}{2}$ -mile offshore from Nurse's Jetty. Each set of ten subsamples was then used for replicate determinations of one of the following parameters: $NO_3 + NO_2 - N$, $PO_4 - P$, and phytoplankton cells /l. The large volumes of water required for accurate determinations of particulate matter and chlorophyll a rendered subsampling from a single sample impractical in these cases. Likewise, the size of a Knudsen bottle limits the number of subsamples of D.O. concentrations in a single sample.

Series of ten successive samples were taken at the same location to assess the short-term variability of $NO_3 + NO_2 - N$, $PO_4 - P$, particulate matter, chlorophyll a concentrations, D.O. concentrations, and BOD levels. The series of the first four parameters were collected over a period of one hour, while the D.O. and BOD series were sampled during thirty minutes.

The results have been tabulated in Tables 32 and

33 in the Appendix. The summarized data (Table 15), showing the coefficients of variation, indicate that an error of less than 10%, except for two parameters, can be expected generally from subsampling of a single sample or from repeated sampling. For phosphates it is known that the method used is not sensitive for values under .030 µg - at/l. (Strickland and Parsons, 1968).

TABLE 15

Summarized Data of Replicate Sampling

	Subsampling of Single Sample		Repeated Sampling	
	No. of Samples	Coefficient of Variation	No. of Samples	Coefficient of Variation
$NO_3 + NO_2 - N$ µg - at/l	10	2.70%	10	6.45%
$PO_4 - P$ µg - at/l	10	13.81%	10	14.44%
Part. Matter mg/l	-	-	10	8.68%
Phytoplankton cells/l	10	8.14%	-	-
Chlorophyll a mg/m^3	-	-	10	6.72%
D.O. ml/l	-	-	10	0.66%
BOD ml/l	-	-	10	10.59%

DISCUSSION

There was very little evidence, from chemical measurements, of the Deep Water Harbour contributing any pollution to areas immediately north of it along the west coast. Differences in chemical measurements between the 'outer' and 'inner' lines were similar to the offshore - inshore gradients shown by Sander and Steven (1973) and are explicable in terms of greater organic production in very shallow water.

It was mentioned in the INTRODUCTION that examination of the water column alone is insufficient when studying coastal marine pollution (Johannes, 1971). The present study further points out that chemical measurements alone of the water column are not a reliable guide to "water quality". Two very different types of phytoplankton associations were found off the west coast, not differentiated by normal types of chemical tests. One was the normal diatom-dominated association, found at the Bellairs station. The other association had at least as many dinoflagellates as diatoms, found between the harbour and the Fresh Water Bay area, at both the 'inner' and the 'outer' lines of stations. The two different phytoplankton associations showed a high degree of stability during the course of this study. As a matter of fact, although tropical inshore nannoplankton - dominated associations have been reported (see below), this is the first study showing two stable, very different, inshore phytoplankton associations. Phytoplankton blooms were virtually non-existent. It is concluded that up to the time the collections were completed for this study the production effects of organic pollution at the 'inner' and 'outer' line stations were indirect, showing subtle stresses which have produced changes in the resident phytoplankton associations, as described by Ellis and Littlepage (1972).

It can be seen that pollution effects were not very obvious between the harbour and the Fresh Water Bay area, except for differences in the composition of the phytoplankton. However, at the careenage station there was nutrient enrichment, lowered D.O. concentrations, increased BOD levels, and reduced generic diversity with an abundance of Peridinium spp. and Coscinodiscus spp. These highly localized pollution effects shown at the careenage station might imply that in the nutrient impoverished conditions of tropical seas considerable additions of nutrients may be accepted without the effects being widespread. Of course one might consider that the localized effects were simply due to there being little flow out to sea from the careenage, but flushing of the system in the careenage was thought to be extensive (see below).

The limited temperature and salinity data agreed well with work reported by Steven and Brooks (1972) and Sander and Steven (1973). The low salinity in July 1973 at all stations indicated the presence of Amazon River water (Steven and Brooks). The careenage water appeared to be as saline as Carlisle Bay water or inshore water along the west coast, which might indicate efficient flushing of the system, but more regular S°/oo determinations might be revealing.

The Bellairs station was the only area where oxygen concentration reached saturation values for seawater, judging by the T°C and S°/oo (Green and Carritt, 1967). Except for the careenage station BOD was very low. If the pollutional strength of the wastes from the proposed outfall proves to be great, the BOD level will rise. For this reason the BOD test should be continued after the outfall is in operation. However, the COD test would be better, as this is a direct measurement of organic carbon. The BOD test is at best a very indirect method (Mitchell, 1972).

Data from Mr. R. Dennis of Q, L and M Engineers showed a total coliform count of 180 colonies / 100 ml at Accra Beach in the afternoon on April 11, 1973. In the morning the count was 12. At Indian River corresponding to station 3 on April 12, 1973, the count was 140. On the same day in careenage water the count was 1,900. 1,000 total coliforms /100 ml of sample is the generally accepted bacteriological standard for bathing areas laid down by WHO. Faecal coliforms should not exceed 350/100 ml. A government study conducted in 1967 revealed that total coliforms on the northern shore of Kingston Harbour, Jamaica, were consistently in excess of 2,400 MPN /ml (Wade et al, 1972). The tourist city, Miami Beach, had to impose a drinking ban in 1973 because of unsafe bacteria counts (Advocate-News, 14/3/73). After a six-week study the EPA reported that 12 of Melbourne's 13 most popular beaches were unsafe for swimming because of excessive E. coli levels (Hughes, 1974). Mitchell (1972) gave a good account of the coliform count.

Surface particulate matter at Bellairs was less than that found by Sander and Steven (1973) at their Bellairs Reef 25 m station. Their mean value of 1.12 mg/l corresponds more closely to the combined 'outer' stations. Burkholder and Burkholder (1958) found the weight of suspended solids collected from the surface of Bahia Fosforescente, Puerto Rico, during a red-tide on 6/2/'57 to be 14.4 mg/l. The bay averages 3.5 m in depth. The careenage station approached this weight once and surpassed it once, but never due totally to living organic matter, as live cells counted never reached bloom proportions. Bassin et al (1972) report the mean surface concentration of total suspended matter in the central Caribbean to be 135 µg/l, 116 µg/l in the north western Caribbean and 180 µg/l in the surface water of the Antilles region. Harris (1972)

found the total suspended matter in the Gulf of Mexico to range from 600 µg/l in the open Gulf to 2.4 mg/l in near-shore waters (surface values). The highest concentrations of total and organic suspended matter were found either in shelf or surface waters.

The surface layers in tropical regions have extremely little phosphate at any time, but an appreciable fraction of phosphorus may be present in dissolved organic form (Raymont, 1963). At a station, 9 km due west of Speightstown, Barbados, Steven and Brooks (1972) found nitrate and phosphate concentrations to be considerably less than the value which limits growth of phytoplankton. The mean of 38 determinations by Sander and Steven (1973) for PO_4 - P at their Bellairs Reef 25 m station was .056 µg-at/l; the present author found the value to be.055 µg-at/l. Thomas and Dodson (1968) found for batch cultures of Chaetoceros gracilis, a tropical oceanic diatom, the rate of growth was limited by phosphate concentrations below approximately 0.22 µg - at/l and final cell numbers were a linear function of initial phosphate concentration up to about 0.8 µg - at/l.

The Bellairs station had a lower nitrate - nitrite concentration than found by Sander and Steven (1973) between 1968 and 1970 (0.774 µg - at/l) at their Bellairs Reef 25 m station. If the 29 µg - at/l can be explained at the 'inner' station 10 the 'outer' station 9 will be self-explanatory. The salinity reduction at Fresh Water Bay was as much as 1.7 °/oo from the limited data. In other words, as much as 5% fresh water (possibly more at times?) was being added to the Bay. This 5% fresh water raised NO_3 + NO_2 - N by ≈ 28 µg - at/l, so the NO_3 + NO_2 - N content of the Island's freshwater should have been 17,360 parts per billion (1 µg - at/l = 31 ppb). Tests showed that Barbados

tap water was very high in NO_3 + NO_2 - N content, and initial NO_2 - N was also very high. The I.B.P. laboratory at McGill University measured 2 subsamples and found Barbados tap water to contain 104.490 µg - at/l NO_3 + NO_2 - N (or 3,239 ppb). Therefore, it was suspected that nitrate enrichment at the Fresh Water Bay area was due to fresh water origin, probably from the fresh water springs known to exist below tide level in this Bay.

The methods for nitrate determination are not as accurate as those for detecting phosphate so fewer accurate figures are available for nutrient nitrogen compounds in seawater (Raymont, 1963). Normally, natural freshwater has less N and P than seawater. But in Israel because of nitrogenous fertilizers penetrating the soil tap water was unsafe for consumption by babies (Advocate-News, 4/4/74). This stage has not been reached yet in the Barbados fresh water but it is apparent that the heavy use of fertilizers could very well soon become a problem. Corcoran and Alexander (1963) found in the Florida Current at a station 40 miles east of Miami nitrate values ranging from 0.0 to 10 µg - at/l. Harrison (1973), on the topic of blooms, reports that the nitrate levels in the Pamlico River estuary change quite drastically, sometimes reaching levels greater than 60 µg - at NO_3 - N/l during the months of the bloom. The estuary is naturally rich in phosphorus, with concentrations averaging greater than 2 µg - at P/L throughout the year. Mitchell (1972) described the role of nitrogen in eutrophic processes. 80 - 90% of the total nitrogen present in municipal wastes is in the form of NH3 and urea. Nitrate and nitrite can also result from nitrifying activity if oxidizing conditions prevail.

Sander and Steven (1973) found the chlorophyll concentration to be .216 mg/m^3 at their Bellairs Reef 25 m

station between 1968 and 1970. The present value was .273 mg/m^3 averaged from 52 determinations. Long-term measurements of chlorophyll a will indicate gradual changes in the standing crop of phytoplankton. Ellis and Littlepage (1972) claimed that in view of our ignorance of the in situ effects of industrial discharges on biological production, chlorophyll a monitoring should be included in all monitoring programs as a basic biological parameter. Strickland (1960) pointed out that chlorophyll estimations are useful only because "an estimate correct to little better than an order of magnitude is better than no estimate at all." Deevey and Bishop (1942) claimed that chlorophyll measurements provide comparative data on eutrophication.

The 'inner' line stations were 1.6 times greater in numbers of cells /l than the 'outer' station. The same figure for chlorophyll a concentration was 2.3, which suggests that these two methods of measuring standing crop were comparable. Sander and Steven (1973) found the diatoms to be 83.3% at their Bellairs Reef 25 m station, while the armoured and naked flagellates were 8.3%. The present work agrees well with only slight variations. Coccoliths reported as high as 4.1% of total phytoplankton between 1968 and 1970 by Sander and Steven are now felt by Sander to have been overcounted; his later counts are lower (personal communication).

Many authors besides Sander and Steven (1973) have found diatoms to be largely responsible for the increase of phytoplankton close to shore. Davis (1955) reports that on the high seas in tropical oceans the dinoflagellates replace the diatoms in considerable part, but "it appears . . . that this does not hold for many inshore tropical waters." Teixeira and Tundisi (1967), studying equatorial waters, found that "the main bulk of the phytoplankton consisted of centric diatoms at . . .(inshore stations)" near Brazil.

Hulburt (1968), working in the western Caribbean Sea, found high numbers of cells near coasts characterized by an abundance of Coccolithus huxleyi and various species of diatoms. Bacon (1971) found diatoms were always the most abundant constituents of the plankton populations in estuaries of the Caroni mangrove swamp, Trinidad, between 1965 and 1967. Hulburt and Corwin (1972) reviewed several plankton studies and reported that very close to shore large quantities of diatoms normally occur in isolation from the diluting effect of the nutrient poor water that can support only the coccolithophorid type of flora (for the Gulf of Mexico). Björnberg (1971) found an increase in the relative numbers of diatoms towards the North Coast of South America. Hulburt et al (1960) and Teixeira and Tundisi (1967) and many other authors have found coccoliths to be abundant in offshore waters. But very often the nannoplankton or even all the naked species are not investigated (Teixeira and Tundisi). Björnberg (1971) pointed out that the oligotrophic waters such as the Sargasso Sea and tropical oceanic water are characterized by a relatively larger percentage of nanno-plankton than phytoplankton. Small quantities of nutrients favour the development of smaller organisms because these have a relatively larger surface to absorb food, and reproduce with less nutrients available than a large organism. Raymont (1963), quoting other authors, claimed that in open oceanic waters the diatoms may decline from more than 60% of the phytoplankton in temperate areas to less than 5% in the tropics, and the dinoflagellates and coccolithophores may make up as much as 50% of the tropical phytoplankton.

Davis (1955) stressed that the Dinoflagellata are especially important in the open sea in tropical regions, but at times they are of great significance in all marine waters. Steidinger and Williams (1970), working with mostly armoured dinoflagellates in the eastern Gulf of Mexico, found that inshore stations exhibited higher dinoflagellate counts but had less species diversity. The high inshore

counts were generally of small species while larger species occurred offshore. This pattern agrees with the work reported by Hulburt (1963). Carpenter (1973) noted an increase in the dinoflagellate cell concentrations in heated pools, but acknowledges that temperature is not the only controlling factor for an abundance of dinoflagellates.

The naked flagellates make up the largest number of nannoplankton. "The high rate of reproduction of most nannoplankton permits the establishment of dense cultures in a comparatively short time. In the sea their actual numbers may be very high at times, even out-weighing the more obvious diatoms and dinoflagellates . . ." (Raymont, 1963). The nannoplankton organisms are perhaps more abundant and of greater importance in inshore waters. Jones and Spencer (1970) found that even during the bloom of the larger centric diatoms the nannoplankton species formed the greater proportion (by volume) of the phytoplankton standing crop in the Menai Straits. Malone (1971) and McCarthy et al (1974) give excellent reviews of the importance of nannoplankton in both temperate and tropical oceanic and neritic phytoplankton communities. Malone, working in the eastern tropical Pacific and Caribbean region, found the nannoplankters to be the most important producers in all the environments studied, but netplankton productivity was significantly higher in neritic than in oceanic waters. "Geographic variations in netplankton and nannoplankton primary productivity and standing crop are poorly documented in the marine environment. Recent investigations in both temperate (Yentsch and Ryther, 1959; Gilmartin, 1964; . ...) and tropical waters (Steemann Nielsen and Jensen, 1957; Holmes, 1958; Teixeira, 1963) have demonstrated that nannoplankton are often responsible for 80 - 99% of the observed phytoplankton productivity."

McCarthy et al (1974) found the nanoplankton to be responsible for 89.6% of the productivity in the Chesapeake Bay Estuary over a 2 year study.

Although blooms did not occur in Barbados during the time of this study, several authors have reported blooms elsewhere in the tropics, for example Hela (1955) and Odum et al (1955) for Florida, Steven (1966) for Jamaica, Burkholder et al (1967) for Puerto Rico, and Balech (1967) for the Gulf of Mexico. Chlorophyll a for some neritic blooms in southern Puerto Rico ranged from 0.4 to 166.0 mg/m^3. Steven found the N:P ratio in Kingston Harbour to be unusually high before the bloom and low after the bloom. The addition of organic nutrients to nitrogen-rich seawater might have provided conditions favoring the growth of Exuviella.

Burkholder et al (1972), working in the Virgin Islands, where blooms have been observed to attain chlorophyll values in the range from 25 to 206 mg/m^3, thought that blooms of Thalassiosira rotula, Peridinium quadrideus and Ceratium hircus were stimulated by run off from the land in protected shallow waters where the salinity at the surface may be reduced to about 60% of the usual value. Harrison (1973) points out that although nitrate metabolism may be an important factor in bloom timing, temperature, salinity, and flushing of the system are also involved. Sander and Steven (1973) found land runoff in Barbados to be slight during their study and the salinity of the careenage certainly suggests, from the few observations, that flushing is maximal in Barbados.

Even though blooms did not exist, we have a situation north of the harbour where the normal inshore diatom - dominated plant association has been replaced by one with the small naked flagellates gaining importance. This may

be due to different light requirements known to exist for some species of flagellates, (if it is feasible for light to vary from place to place at a depth of 1 m), or biological conditioning of the sea water and succession may play a role (Raymont, 1963). Samuel et al (1971), discussing tropical phytoplankton, thought that the liberation of extra cellular products of photosynthesis may play an important part in the transfer of energy within the marine ecosystem. Prakash and Rashid (1968) note that humic substances, in small amounts, exert a stimulatory effect on marine dinoflagellates. "Because of their high concentration in coastal waters, humic substances may thus be regarded as an ecologically significant entity influencing phytoplanktonic production."

It will be remembered that one of the reasons for studying the effects of pollution in Barbados was to be able to assess water quality in an area in which pollution was just beginning. Certainly this was the case for the area just north of the harbour. Even the million plankton cells /l reached in the careenage were no where near numbers experienced in other areas. Bainbridge (1957) suggests that maximal densities for phytoplankton are of the order of 0.5 cells /mm^3 (500 cells /cc) for diatoms and 2.5 cells /mm^3 for flagellates. Where concentrated patches occur approximately twenty times these densities of both diatoms and nannoplankton may be experienced. Ferguson Wood (1966) found the shallow water shoreward of the 100 fathom line in the Amazon region to be extremely rich, up to 17×10^6 organisms /l. Hargraves et al (1970), working in the Lesser Antilles region, found surface chlorophyll a at 3 harbour stations to average 12.1 mg/m^3, ranging from 5.6 to 15.7 mg/m^3. The authors state that the harbours were much richer in chlorophyll than any of the offshore stations, and were high in nitrate but not in phosphate (their

work omitted most of the nannoplankton and small naked flagellates, as nets were used for collecting the phytoplankton). However, the work done by Beers et al (1968) showed that gross primary productivity, chlorophyll, phosphate and nitrate levels were generally lower at Jamaica than at Barbados over a period exceeding 2 years.

Qasim and Reddy (1967) studied the Cochin backwater, a shallow, semi-enclosed body of water, (during the monsoon months) which seems very similar to the careenage in Barbados. Chlorophyll a for surface water ranged from 2.96 to 7.34 mg/m^3, PO_4 - P from .39 to 1.23 µg - at/l and NO_3 - N from 1.79 to 7.01 µg-at/l. "Diatoms and dinoflagellates made up nearly 80% of the (phytoplankton) crop." Björnberg (1971) reports waters of the most productive inshore bays, such as Piscadera in Curaçao, to contain "high numbers of Coscinodiscus gigas (?)". Coscinodiscus spp. were very abundant in the careenage. Björnberg also reports that Trichodesmium thiebaudii is characteristic of off-shore waters and of high-salinity coastal waters, which further indicates that the careenage, with high numbers of Trichodesmium, was saline, and probably well-flushed.

Combined phytoplankton and pollution studies are not common in the literature. Caperon et al (1971) did a 4 month study of weekly sampling in Kaneohe Bay, Hawaii. The authors report that the south sector of the bay, site of two sewage outfalls, showed the greatest population instability and had the highest concentrations of chlorophyll a, nitrate, phosphate, and the highest primary productivity. Sykes and Boney (1970), although working on the Irish coast, obtained results interesting to this study. They gave evidence for the localized abundance of certain diatoms in relation to inshore waters (away from large urban centres) subjected to the effects of land pollution. The present study observed Thalassiosira to be abundant at station 3, while Coscinodiscus was dominant at station 10,

only 2½ km away. From Hulburt (1970): "Since densities rarely exceed 10^6/l in the open and coastal ocean, there is no possibility of an abundant species monopolizing the nutrient supply and forcing a less abundant form to extinction . . . Plankton concentrations in the estuaries may come close to or exceed 10^9/l, and monopolization of the nutrient supply should aid in the continued dominance of the abundant forms, eventually bringing about the extinction of many of the residual forms."

Barbados should take note of the work of Barnes (1973), who determined the nature of the sewage wastes from 18 hotel developments along a 160 km stretch of coastline in the heart of the tourist belt extending from Montego Bay to Ocho Rios, Jamaica. At one hotel effluent entering the absorption field with a bacterial content of 18,000 + total coliforms per 100 ml of effluent was reduced to less than 1,000 even at the point of discharge after treatment. However, at most hotels the wide fluctuations in the loading of the treatment plants (due to transient numbers of residents) and the lack of competent operators did not make for efficiency. Counts 16 times the required standard of 1,000 total coliforms per 100 ml of sample were recorded and some outfalls were observed no more than 15 metres from the shore.

Of general interest to phytoplankton studies is the work by Dunstan and Menzel (1971), who worked with cultures of natural populations of phytoplankton in dilute, chlorinated sewage effluent. Their work suggests that when environmental conditions, primarily nutrient levels, become favorable for the rapid growth of phytoplankton, an entire community of organisms having similar growth potentials may develop simultaneously with little or no selective pressure on one another. Rather, it is in the quantitatively stabilized population, where further growth depends on recycling

of a growth-limiting nutrient, that competition and selection appear to take place. Jensen and Rystad (1973) describe some practical attempts to use dialysis cultures for monitoring the capacity of sea water to support the growth of phytoplankton, and they further investigate the relationship between nutrient concentration and algal growth (3 spp. only).

Haderlie (1971) provided baseline data before construction of an additional breakwater in Monterey Harbour actually began, and proposed to continue the investigation for several years until some new equilibrium was established. It is to be hoped that Barbados will follow this good example after the installation of the proposed outfall.

Hutchinson (1961) speculated on how it is possible for a number of species of phytoplankton to coexist in a relatively isotropic or unstructured environment all competing for the same sorts of materials. The results of a study in Bedford Basin by Platt and Filion (1973) support the speculations of Margalef (1967) and Richerson et al (1970), who did not regard the phytoplankton community as an assemblage of species with essentially similar requirements and responses living in an environment with essentially no spatial (at least horizontal) structure. Platt and Filion ascribe the spatial heterogeneity in production efficiency observed on 6 out of 10 sampling days (six stations, 1 hour collecting time) either to local variations in the physicochemical characteristics of the medium, or to local differences (taxonomic or physiological) in phytoplankton community structure. The present study does not cast much light on the subject. The only indications of spatial horizontal structure were in the two very different, stable, phytoplankton associations, not differentiated by normal types of chemical tests.

FUTURE WORK

Although this study has led to some interesting results, it has certainly left many questions unanswered. Phytoplankton associations depend on more than nutrient uptake; other factors may include advection, diffusion, grazing pressure, or sinking. A study of the secondary producers in the harbour - Fresh Water Bay area might be very revealing. C^{14} measurements at the 'inner' stations would help to determine the "efficiency" of the plankters in this area; although there were signs of stress there was no apparent reduction in generic diversity. In fact diversity appeared to increase in the harbour - Fresh Water Bay area.

The harbour water is worth further study as the different parameters studied do not agree with results reported in other areas of the Caribbean. A phytoplankton study with a view to determine why chlorophyll a concentration is low would be instructive.

Before it was discovered that the careenage water was saline this area was regarded as being uninteresting to a marine biologist. The prospects for future study are vast; indeed, Mr. J.K. Partlo has already commenced a further study of the phytoplankton and in addition is studying the zooplankton and keeping a regular watch on the salinity. He was initially under the supervision of the late Professor D.M. Steven and is continuing under Professor Finn Sander.

SUMMARY

1. Repeated collections of surface (1m) water samples were carried out at weekly intervals from July 1972 to July 1973 to provide information on the (early) effects of organic pollution on phytoplankton associations and seawater quality using a grid pattern of stations immediately north of the Deep Water Harbour on the west coast of Barbados. The stations forming the grid were compared with the Bellairs Station occupied concurrently and considered to be representative of unpolluted conditions in the area.

2. Rather than the expected north-south gradient the significant differences found in the different chemical parameters studied were generally on an east-west axis between the 'inner' and 'outer' lines of stations forming the grid pattern, with the 'outer' line stations being much the same as the Bellairs station.

3. Evidence was given proving that chemical measurements alone of the water column are not a reliable guide to "water quality," as two very different types of phytoplankton associations were found off the west coast not differentiated by normal types of chemical tests; ie. at both the 'inner' and 'outer' lines of stations there existed a stable phytoplankton association comprised of mostly small naked flagellates and diatoms, each contributing nearly 50% to the total population, and different from the Bellairs phytoplankton association.

4. Blooms did not occur in Barbados, as the production effects of organic pollution at the 'inner' and 'outer' line stations were still indirect, showing only subtle stresses which produced changes in the resident phytoplankton associations.

5. Less frequent sampling of careenage water provided evidence that in the nutrient impoverished conditions of tropical seas considerable additions of nutrients may be accepted without the effects being widespread.

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APPENDIX

TABLE 16

Chl a (mg/m^3) for Stations 1-11; 7/72 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
11/ 7/72	.214	.449	.520	.183	.171	.262	.216	-	.141	.306	.221
20/ 7/72	.310	.474	.542	.241	.299	.294	.323	.226	.244	.442	.346
26/ 7/72	.634	.599	.544	.646	.529	1.313	.717	.914	.870	1.241	.411
1/ 8/72	.133	.213	.397	.170	.158	.256	.261	.165	.130	.304	.148
9/ 8/72	.094	.196	.432	.115	.139	.203	.263	.129	.136	.371	.136
16/ 8/72	.191	.277	.404	.169	.177	.323	.399	.284	.183	.719	.213
23/ 8/72	.201	.352	.452	.152	.206	.415	.290	.192	.210	.574	.237
30/ 8/72	.196	.230	.655	.184	.281	.519	.291	.195	.197	.362	.172
5/ 9/72	.224	.240	.340	.110	.153	.431	.214	.161	.173	.421	.087
11/ 9/72	.219	.298	.348	.157	.178	.313	.363	.176	.152	.381	.175
18/ 9/72	.128	.401	.451	.217	.179	.303	.370	.160	.158	.751	.169
26/ 9/72	.111	.303	.899	.218	.283	.324	.773	.337	.259	.705	.133
2/10/72	.103	.380	.378	.143	.193	.404	.346	.114	.153	.387	.124
9/10/72	.150	.284	.508	.232	.232	.367	.401	.151	.193	.455	.249
16/10/72	.339	.548	.541	.344	.455	.326	.548	.428	.437	1.001	.585
23/10/72	.149	.672	1.117	.456	.406	.824	1.049	.321	.564	.901	1.032
7/11/72	.182	.348	.973	.332	.378	.503	.528	.213	.202	.459	.168
23/11/72	.189	.185	.993	.175	.280	1.604	.895	.197	.225	.640	.104
6/12/72	.251	.612	.796	.453	.300	.527	.403	.205	.160	.385	.209
12/12/72	.234	.408	1.371	.297	.228	.808	.476	.196	.182	.805	.216
23/12/72	.173	.608	.761	.291	.404	2.111	.667	.262	.234	.799	.286
29/12/72	.207	.272	.278	.191	.161	.428	.477	.183	.140	.430	.313

(cont'd)...

TABLE 16 (cont'd)

Chl a (mg/m^3) for Stations 1-11; 7/72 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
5/ 1/73	.282	.457	.671	.222	.181	.508	.609	.217	.157	.946	.349
12/ 1/73	.310	.534	.842	.367	.349	.846	.828	.343	.358	.674	.353
22/ 1/73	.398	.586	.561	.369	.343	.309	.609	.344	.344	.927	.421
30/ 1/73	.417	-	-	-	-	-	-	-	-	-	.488
6/ 2/73	.385	.634	.511	.373	.295	.302	.417	.222	.211	.697	.278
14/ 2/73	.573	-	-	-	-	-	-	-	-	-	.274
21/ 2/73	.300	.665	.585	.280	.308	.578	.713	.271	.285	.682	.403
28/ 2/73	.381	-	-	.372	.313	.331	.420	.318	.401	.866	.453
7/ 3/73	.166	.566	2.127	.346	.214	.456	.643	.208	.243	.700	.162
14/ 3/73	.230	.978	.730	.590	.354	.602	.364	.222	.198	1.403	.105
21/ 3/73	.138	.174	.678	.208	.173	.385	.410	.192	.231	1.154	.176
29/ 3/73	.172	.519	3.111	.337	.174	.787	.793	.160	.281	.751	.185
4/ 4/73	.160	.551	-	.437	.248	.409	.483	.204	.248	.915	.147
11/ 4/73	.305	.469	.442	.250	.220	.332	.449	.265	.225	.635	.244
16/ 4/73	.267	-	-	-	-	-	-	-	-	-	.211
18/ 4/73	.317	.370	.733	.362	.350	1.286	.913	.435	.299	.493	.216
25/ 4/73	.176	.558	.718	.232	.408	.750	1.062	.609	.378	1.159	.414
2/ 5/73	.184	.715	1.060	.302	.398	.704	.517	.669	.212	1.322	.249
9/ 5/73	.129	.242	.312	.178	.167	.356	.380	.143	.143	.425	.212
14/ 5/73	.263	-	-	-	-	-	-	-	-	-	.247
16/ 5/73	.272	.466	.679	.415	.349	.451	.544	.383	.300	.639	.483
25/ 5/73	.213	.277	.664	.249	.213	.349	.552	.441	.399	.942	.204
30/ 5/73	.172	.185	.467	.159	.157	.188	.258	.164	.198	.373	.277
6/ 6/73	.224	.310	.419	.163	.202	.325	.327	.238	.258	.328	.232
13/ 6/73	.164	.470	.904	.287	.346	.343	.444	.268	.287	.494	.269
18/ 6/73	.181	-	-	-	-	-	-	-	-	-	.293
20/ 6/73	.171	.342	.483	.181	.280	.510	.571	.226	.249	.575	.337
27/ 6/73	.350	.336	.596	.350	.327	.399	.636	.254	.315	.590	.263
4/ 7/73	.260	.605	1.216	.246	.356	.525	.510	.319	.260	.426	.248
16/ 7/73	.285	-	-	-	-	-	-	-	-	-	.293

TABLE 17

D.O. (ml/l) for Stations 1-11; 7/72 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
14/ 7/72	4.41	4.50	3.37	4.51	4.03	4.88	4.41	4.46	4.79	4.63	4.83
20/ 7/72	4.66	4.62	4.82	4.79	4.40	4.27	4.38	4.31	4.68	4.77	4.83
26/ 7/72	4.69	4.72	3.64	4.67	4.02	4.19	4.80	4.52	4.81	4.81	4.95
1/ 8/72	4.69	4.55	3.79	4.68	4.49	3.60	4.12	4.12	4.36	4.36	4.55
9/ 8/72	4.68	4.71	3.56	4.77	4.71	4.54	4.85	4.61	4.75	4.67	4.82
16/ 8/72	4.18	3.98	4.03	4.07	3.86	3.41	4.01	3.94	4.09	4.27	4.10
23/ 8/72	4.05	4.12	3.20	3.47	3.73	3.63	3.60	4.12	3.83	3.92	4.02
30/ 8/72	4.07	3.96	3.14	3.62	3.96	3.66	4.15	4.15	4.08	4.27	4.07
11/ 9/72	4.10	3.84	3.74	3.69	3.48	3.17	3.11	3.91	3.85	4.09	4.11
18/ 9/72	4.60	4.40	4.33	4.07	3.92	4.03	4.19	4.46	4.15	4.37	4.38
26/ 9/72	4.35	4.22	4.10	4.36	4.15	3.56	3.65	3.85	3.95	4.15	4.36
2/10/72	4.27	4.11	3.82	4.11	4.15	3.81	4.22	4.36	4.21	4.27	4.42
9/10/72	4.37	4.28	3.82	4.30	4.34	4.00	3.85	3.81	4.08	4.28	4.39
16/10/72	4.25	4.10	4.16	3.88	3.79	3.40	3.87	4.07	4.30	4.27	4.30
23/10/72	4.66	4.42	4.67	4.49	4.48	3.86	3.89	4.05	3.97	4.36	4.52
7/11/72	4.10	4.18	3.04	4.05	3.50	3.51	3.40	3.96	3.99	4.10	4.40
15/11/72	4.37	4.27	4.03	4.47	3.82	3.80	4.01	4.31	4.32	4.58	4.51
23/11/72	4.54	4.49	4.35	4.45	4.09	4.40	3.56	4.50	4.45	4.60	4.59
6/12/72	4.15	4.02	3.13	3.93	3.77	3.44	3.69	4.04	4.15	4.31	4.40
12/12/72	4.51	4.35	3.20	4.08	4.03	3.12	4.13	4.21	4.38	4.50	4.61
23/12/72	4.35	4.14	3.20	3.89	3.74	3.70	3.83	4.29	4.29	4.15	4.43
29/12/72	4.44	4.40	4.25	4.31	3.95	3.95	3.82	4.36	4.26	4.43	4.57

(cont'd)....

TABLE 17 (cont'd)

D.O. (ml/l) for Stations 1-11; 7/72 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
5/ 1/73	4.34	4.20	3.38	4.22	4.07	3.66	3.44	4.17	4.29	4.45	4.23
12/ 1/73	4.40	4.15	4.00	4.25	4.13	3.87	3.38	4.28	4.20	4.52	4.50
30/ 1/73	4.47	-	-	-	-	-	-	-	-	-	4.47
6/ 2/73	4.44	4.33	3.78	4.30	4.28	3.89	4.32	3.87	4.16	4.06	4.50
14/ 2/73	4.34	-	-	-	-	-	-	-	-	-	4.40
21/ 2/73	4.39	4.28	4.11	4.29	4.35	3.91	3.87	4.01	4.47	4.55	4.48
7/ 3/73	4.42	4.31	3.11	4.19	3.87	3.50	4.30	3.98	4.17	4.45	4.55
14/ 3/73	4.34	4.25	3.97	4.26	4.20	3.80	4.12	4.27	4.36	4.33	4.52
21/ 3/73	4.59	4.53	4.04	4.49	4.42	4.03	4.59	4.24	4.32	4.70	4.61
29/ 3/73	4.45	4.30	3.64	4.21	4.44	4.31	4.22	4.53	4.18	4.90	4.41
4/ 4/73	4.49	4.30	3.84	4.27	4.31	3.68	4.19	4.01	4.14	4.45	4.44
11/ 4/73	4.34	4.08	3.93	4.22	4.22	3.92	4.07	3.88	4.09	4.73	4.41
16/ 4/73	4.41	-	-	-	-	-	-	-	-	-	4.32
18/ 4/73	4.25	4.08	2.98	4.25	3.64	4.10	3.89	4.01	4.21	4.22	4.54
25/ 4/73	4.36	4.11	3.98	4.43	3.71	3.50	3.90	3.90	4.44	4.40	4.24
2/ 5/73	4.28	4.20	4.05	4.26	3.98	3.74	3.94	3.82	4.04	4.07	4.36
9/ 5/73	4.54	4.36	4.41	4.32	4.19	3.94	4.27	4.04	4.54	4.67	4.56
14/ 5/73	4.49	-	-	-	-	-	-	-	-	-	4.37
16/ 5/73	4.41	4.16	3.47	4.19	4.28	3.70	3.80	3.99	4.04	4.00	4.28
25/ 5/73	4.48	4.16	4.23	4.30	4.14	4.06	4.22	4.15	4.23	4.38	4.50
30/ 5/73	4.45	4.15	3.57	4.44	4.36	4.13	4.24	4.26	4.24	4.04	4.42
6/ 6/73	4.34	4.46	3.95	3.94	4.23	3.91	4.52	4.34	4.46	4.45	4.54
13/ 6/73	4.38	4.22	2.37	4.29	4.20	3.79	3.83	4.19	4.05	3.93	4.31
18/ 6/73	4.46	-	-	-	-	-	-	-	-	-	4.35
20/ 6/73	4.49	4.30	4.14	4.51	3.95	4.00	4.04	4.40	4.42	4.42	4.48
27/ 6/73	4.70	4.51	3.97	4.60	4.62	3.91	3.98	3.96	4.32	4.34	4.72
4/ 7/73	4.55	4.37	3.15	4.24	3.85	3.93	3.94	4.16	4.54	4.28	4.64
16/ 7/73	4.53	-	-	-	-	-	-	-	-	-	4.53

TABLE 18

BOD (ml/l) for Stations 1-11; 7/72 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
14/ 7/72	.21	.72	.30	.34	.52	.53	.27	.76	.35	.16	.29
20/ 7/72	.25	.42	.33	.25	.15	.18	.23	.25	.23	.21	.12
26/ 7/72	.27	.24	.05	.28	.13	.46	.32	.17	.36	.45	.36
1/ 8/72	.18	.27	.15	.14	.08	.19	.40	.30	.21	.08	.13
9/ 8/72	.32	.30	.18	.12	.20	.28	.33	.15	.13	.22	.23
16/ 8/72	.29	.35	.42	.25	.20	.26	.40	.26	.31	.31	.28
23/ 8/72	.17	.33	.17	.08	.17	.37	.19	.28	.17	.32	.29
30/ 8/72	.28	.33	.21	.11	.10	.31	.29	.21	.19	.34	.30
11/ 9/72	.39	.25	.17	.22	.20	.19	.76	.41	.30	.35	.41
18/ 9/72	.19	.24	.27	.13	.12	.11	.32	.16	.13	.32	.14
26/ 9/72	.06	.24	.14	.19	.34	.17	.51	.27	.15	.29	.15
2/10/72	.22	.20	.16	.43	.16	.27	.22	.23	.18	.28	.20
9/10/72	.18	.27	.22	.21	.13	.14	.18	.15	.08	.21	.17
16/10/72	.12	.29	.23	.34	.16	.18	.39	.19	.21	.22	.23
7/11/72	.25	.27	.19	.21	.11	.14	.20	.15	.07	.13	.22
15/11/72	.20	.28	.53	.32	.11	.22	.31	.27	.21	.36	.25
6/12/72	.14	.29	.06	.12	.10	.14	.45	.16	.16	.27	.24
12/12/72	.26	.32	.33	.19	.29	.15	.37	.35	.39	.43	.40
23/12/72	.12	.23	.12	.05	-	.20	.19	.11	.08	.14	.15
29/12/72	.17	.23	.13	.10	.10	.11	.28	.25	.15	.20	.19

(cont'd)....

TABLE 18 (cont'd)

BOD (ml/l) for Stations 1-11; 7/72 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
5/ 1/73	.14	.07	.10	.26	.10	.08	.41	.18	.09	.18	.15
30/ 1/73	.28	-	-	-	-	-	-	-	-	-	.23
6/ 2/73	.22	.31	.18	.19	.08	.00	.25	.24	.17	.17	.17
14/ 2/73	.13	-	-	-	-	-	-	-	-	-	.07
7/ 3/73	.19	.30	.43	.14	.09	.15	.34	.20	.04	.15	.13
4/ 4/73	.19	.23	.04	.10	.16	.06	.09	.12	.08	.15	.12
16/ 4/73	.15	-	-	-	-	-	-	-	-	-	.08
2/ 5/73	.20	.37	.24	.23	.10	.21	.17	.18	.34	.29	.16
14/ 5/73	.17	-	-	-	-	-	-	-	-	-	.05
6/ 6/73	.16	.20	.12	.08	.14	.07	.22	.15	.25	.40	.22
18/ 6/73	.00	-	-	-	-	-	-	-	-	-	.00
4/ 7/73	.30	.21	.09	.00	.11	.08	.15	.18	.16	.27	.27
16/ 7/73	.04	-	-	-	-	-	-	-	-	-	.06

TABLE 19

Partic. Matter (mg/l) for Stations 1-11; 7/72 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
11/ 7/72	1.37	1.78	4.37	1.75	1.46	4.82	3.81	1.56	1.54	2.64	.96
20/ 7/72	1.87	1.91	2.90	.98	1.12	2.13	1.80	1.46	.90	1.05	1.52
26/ 7/72	1.11	.99	2.54	1.34	1.72	24.48	4.75	2.79	1.43	6.12	1.13
1/ 8/72	.32	1.49	2.32	.67	.89	1.88	4.34	1.89	1.32	1.56	.76
9/ 8/72	.40	.99	3.60	.64	1.11	3.13	3.00	1.49	1.55	2.63	.86
16/ 8/72	.50	1.63	1.88	.78	.85	1.92	2.26	1.78	1.08	1.21	1.14
23/ 8/72	.44	1.44	2.47	1.17	1.31	2.15	1.71	.92	1.20	1.89	1.04
30/ 8/72	.57	1.25	2.60	1.62	1.25	1.78	1.31	.81	.95	1.15	.74
5/ 9/72	.75	1.04	2.61	1.01	.95	2.71	1.18	.67	.86	1.70	.41
11/ 9/72	1.10	1.77	2.20	1.00	1.05	2.39	2.79	1.07	1.45	1.21	.70
18/ 9/72	.88	1.33	1.75	1.62	1.11	2.41	3.18	1.02	.97	1.25	1.23
26/ 9/72	.46	1.72	2.12	1.59	.83	3.52	7.97	.87	1.40	4.48	.48
2/10/72	1.53	2.06	2.12	1.31	.76	2.42	2.53	.74	2.84	1.30	.90
9/10/72	1.38	1.42	2.18	1.13	.84	2.68	2.54	1.23	.97	1.06	.88
16/10/72	.60	1.68	1.66	.85	.75	2.53	4.22	.87	.74	1.21	.54
23/10/72	1.30	2.98	1.97	1.80	4.18	9.61	14.35	2.31	4.18	4.29	.91
7/11/72	.62	.97	2.49	.89	.81	3.18	2.76	.94	.66	1.94	.50
15/11/72	.85	2.68	4.90	.75	1.52	4.79	-	1.87	1.13	2.93	.65
23/11/72	.31	.52	2.02	.44	.91	4.42	5.11	.60	.96	1.63	.26
6/12/72	.46	2.68	1.88	.57	.92	2.19	1.43	.78	.65	1.17	.58
12/12/72	.30	.88	3.30	.53	.26	3.56	1.80	.34	.64	1.27	.37
23/12/72	.21	1.73	5.31	.62	1.17	6.93	3.50	.57	.50	1.77	.33
29/12/72	.27	.62	.78	.38	.65	2.36	1.86	.89	.46	.79	.35

(cont'd)....

TABLE 19 (cont'd)

Partic. Matter (mg/l) for Stations 1-11; 7/72 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
5/ 1/73	.07	1.09	1.50	.74	.92	3.09	4.08	.92	.43	1.63	.37
12/ 1/73	.32	3.34	2.59	.87	1.23	5.56	3.72	.72	.59	1.86	.37
22/ 1/73	.24	1.89	.63	.35	.94	3.94	5.58	.68	.78	.74	.57
30/ 1/73	.48	-	-	-	-	-	-	-	-	-	.56
6/ 2/73	.24	1.06	1.03	.43	.41	1.47	2.73	.74	.62	1.12	.30
14/ 2/73	.34	-	-	-	-	-	-	-	-	-	.25
21/ 2/73	.16	1.15	3.59	.50	.69	4.36	7.35	1.28	.62	2.80	.47
28/ 2/73	.38	1.04	.96	.48	.47	2.90	4.19	.83	.58	.82	.03
21/ 3/73	.43	.75	2.97	.72	.59	3.02	4.77	.76	1.19	6.22	.53
29/ 3/73	.48	1.18	3.82	.75	.50	10.78	13.70	1.09	1.78	3.40	.79
4/ 4/73	.67	2.03	3.38	1.14	1.15	3.82	4.66	1.31	-	2.36	.73
11/ 4/73	.71	1.40	1.91	.60	.90	2.60	2.86	.73	1.40	2.91	.45
16/ 4/73	.49	-	-	-	-	-	-	-	-	-	.55
18/ 4/73	.60	1.53	1.88	.56	1.12	2.71	7.42	1.19	.90	1.38	.52
25/ 4/73	.44	1.25	3.15	.31	1.66	7.32	10.97	2.42	1.45	6.08	.62
2/ 5/73	.24	4.08	1.40	.27	.96	1.24	3.46	.96	.55	1.65	.66
9/ 5/73	1.15	1.22	2.23	.73	.91	3.01	2.60	.87	.80	2.38	.97
14/ 5/73	.75	-	-	-	-	-	-	-	-	-	.84
16/ 5/73	.72	1.76	2.11	2.91	4.64	4.76	5.11	1.83	1.28	3.51	3.50
25/ 5/73	1.27	1.57	2.00	1.27	2.33	1.95	2.34	1.25	.89	2.34	3.93
30/ 5/73	.61	.94	1.61	.72	.67	1.25	1.03	.46	.96	1.60	.31
6/ 6/73	.56	1.00	1.03	.59	.81	2.22	1.21	.59	.67	1.66	.51
13/ 6/73	.55	1.22	1.74	.54	.87	1.68	2.98	1.07	.77	1.49	.52
18/ 6/73	4.67	-	-	-	-	-	-	-	-	-	1.51
20/ 6/73	2.15	5.17	3.52	2.42	4.83	3.62	5.19	4.09	2.36	2.52	2.80
27/ 6/73	1.15	1.03	2.32	.95	1.03	2.48	2.98	1.24	1.31	1.11	.90
4/ 7/73	.64	3.28	2.68	1.21	3.45	3.79	4.04	4.26	2.10	1.93	2.10
16/ 7/73	2.07	-	-	-	-	-	-	-	-	-	2.17

TABLE 20

PO_4-P (µg-at/l) for Stations 1-11; 7/72 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
11/ 7/72	.068	.152	.131	.115	.105	.131	.089	.115	.121	.168	.073
20/ 7/72	.046	.076	.056	.030	.035	.020	.005	.025	.046	.030	.056
26/ 7/72	.040	.056	.076	.066	.101	.005	.015	.020	.056	.091	.051
1/ 8/72	.094	.073	.125	.078	.120	.068	.010	.094	.062	.099	.062
9/ 8/72	.047	.062	.057	.036	.052	.057	.036	.068	.068	.088	.026
16/ 8/72	.042	.031	.062	.062	.099	.021	.016	.104	.062	.083	.047
23/ 8/72	.096	.024	.106	.091	.072	.067	.014	.019	.043	.086	.019
30/ 8/72	.086	.053	.144	.120	.110	.019	.082	.096	.072	.096	.101
5/ 9/72	.077	.106	.149	.110	.096	.010	.067	.086	.110	.125	.072
11/ 9/72	.032	.032	.000	.021	.005	.021	.000	.054	.000	.000	.000
18/ 9/72	.016	.000	.000	.043	.032	.043	.016	.027	.064	.064	.027
26/ 9/72	.086	.043	.118	.038	.108	.113	.075	.097	.075	.113	.091
2/10/72	.043	.097	.108	.075	.059	.043	.108	.059	.065	.065	.091
9/10/72	.080	.133	.197	.160	.128	.080	.101	.144	.154	.133	.223
16/10/72	.057	.036	.041	.062	.072	.077	.000	.062	.021	.026	.021
23/10/72	.000	.014	.037	.080	.014	.014	.000	.019	.014	.136	.009
27/10/72	.000	.019	.000	.875	.051	.501	.014	.051	.473	.042	.089
7/11/72	.144	.067	.144	.041	.092	.087	.175	.051	.072	.067	.375
15/11/72	.091	.048	.091	.091	.118	.081	.081	.091	.457	.070	.059
23/11/72	.054	.048	.081	.043	.075	.081	.097	.065	.086	.124	.048
6/12/72	.032	.081	.124	.097	.118	.075	.059	.054	.065	.140	.086
12/12/72	.140	.107	.107	.059	.097	.070	.043	.070	.038	.048	.027
23/12/72	.005	.075	.081	.081	.124	.054	.081	.059	.059	.021	.064
29/12/72	.059	.059	.069	.079	.104	.074	.059	.069	.049	.035	.044

(cont'd)....

TABLE 20 (cont'd)

PO_4-P (µg-at/l) for Stations 1-11; 7/72 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
5/ 1/73	.030	.039	.118	.069	.039	.059	.005	.054	.059	.054	.104
12/ 1/73	.030	.069	.059	.064	.059	.039	.064	.044	.079	.069	.074
22/ 1/73	.040	.055	.065	.070	.099	.035	.015	.065	.050	.080	.070
30/ 1/73	.055	-	-	-	-	-	-	-	-	-	.065
6/ 2/73	.061	.066	.051	.046	.051	.051	.005	.046	.041	.061	.076
14/ 2/73	.046	-	-	-	-	-	-	-	-	-	.020
21/ 2/73	.090	.100	.075	.105	.120	.095	.025	.110	.050	.075	.030
28/ 2/73	.065	.065	.080	.050	.040	.125	.005	.050	.115	.030	.045
7/ 3/73	.015	.050	.000	.030	.085	.000	.005	.085	.035	.045	.025
14/ 3/73	.010	.045	.060	.030	.035	.020	.015	.010	.035	.065	.005
21/ 3/73	.047	.042	.053	.068	.058	.068	.047	.084	.042	.079	.037
29/ 3/73	.058	.074	.058	.047	.095	.037	.047	.084	.074	.089	.068
4/ 4/73	.041	.051	.030	.046	.061	.051	.020	.051	.025	.127	.010
11/ 4/73	.061	1.285	.076	.056	.036	.076	.051	.020	.025	.046	.046
16/ 4/73	.030	-	-	-	-	-	-	-	-	-	.076
18/ 4/73	.010	.046	.061	.020	.036	.025	.025	.010	.025	.117	.066
25/ 4/73	.030	.005	.040	.000	.030	.035	.010	.015	.010	.025	.015
2/ 5/73	.015	.000	.025	.020	.035	.035	.010	.040	.056	.172	.015
9/ 5/73	.086	.051	.086	.061	.091	.030	.035	.061	.051	.051	.045
14/ 5/73	.030	-	-	-	-	-	-	-	-	-	.045
16/ 5/73	.051	.045	.056	1.257	.101	.076	.045	.061	.030	.136	.020
25/ 5/73	.045	.076	.071	.051	.056	.177	.025	.040	.066	.040	.040
30/ 5/73	.035	.076	.040	.035	.051	.051	.056	.035	.061	.182	.035
6/ 6/73	.063	.049	.093	.068	.054	.034	.059	.054	.054	.083	.039
13/ 6/73	.020	.035	.060	.040	.035	.055	.045	.040	.055	.164	.025
18/ 6/73	.030	-	-	-	-	-	-	-	-	-	.045
20/ 6/73	.040	.060	.060	.035	.065	.090	.045	.055	.050	.090	.035
27/ 6/73	.000	.000	.010	.000	.000	.010	.000	.010	.000	.070	.000
4/ 7/73	.020	.025	.040	.030	.030	.030	.020	.015	.010	.030	.015
16/ 7/73	.030	-	-	-	-	-	-	-	-	-	.015

TABLE 21

NO_3+NO_2-N (µg-at/l) for Stations 1-11; 4/73 - 7/73

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
11/ 4/73	.830	.326	1.069	.874	.775	8.004	1.723	3.718	11.534	4.307	.370
16/ 4/73	.266	-	-	-	-	-	-	-	-	-	-
25/ 4/73	.059	.067	.360	.094	.775	.150	.738	1.093	.256	4.352	.190
2/ 5/73	.415	.148	.267	.258	.539	.301	.207	.770	13.109	67.741	.750
9/ 5/73	.826	.314	.365	.372	.411	.097	.350	.572	.604	.475	.037
14/ 5/73	.485	-	-	-	-	-	-	-	-	-	.172
16/ 5/73	.207	.280	.457	.518	.348	.282	.846	.437	.900	69.461	.929
25/ 5/73	.209	.040	.344	-	.346	.325	.440	.987	.562	7.429	.075
30/ 5/73	.000	.166	.050	.000	.080	.278	.177	.145	5.887	62.906	.989
6/ 6/73	.736	.703	.621	.644	.515	1.004	.489	.499	.574	3.074	.091
13/ 6/73	.037	.234	.247	.257	.346	.411	.307	.419	11.991	67.117	.842
18/ 6/73	.000	-	-	-	-	-	-	-	-	-	.047
20/ 6/73	.053	.240	.302	.022	1.176	.378	1.174	.169	.164	16.879	.242
27/ 6/73	.138	.273	.855	.191	.266	.593	-	1.385	5.394	41.000	.932
4/ 7/73	.026	.235	.714	.280	.940	.397	.491	.595	.128	.941	.194
16/ 7/73	.150	-	-	-	-	-	-	-	-	-	.170

TABLE 22

Chl a (mg/m^3) for Stations A-G; Jan.-July (excl. March) 1973

STATION / DATE	A	B	C	D	E	F	G
30/ 1/73	.604	.596	.598	.545	.968	2.763	.465
14/ 2/73	.632	.638	.883	.619	.992	3.478	.623
16/ 4/73	.356	.326	.460	.396	2.064	5.326	.341
14/ 5/73	.298	.380	.415	.349	3.432	7.055	.534
18/ 6/73	.164	.227	.204	.154	.400	5.664	.211
16/ 7/73	.332	.308	.407	.298	.668	1.853	.299

TABLE 23

D.O. (ml/l) for Stations A-G; Jan.-July (excl. March) 1973

STATION / DATE	A	B	C	D	E	F	G
30/ 1/73	4.29	4.40	4.32	4.39	3.79	2.29	4.42
14/ 2/73	4.09	4.21	4.01	4.26	3.07	1.87	4.18
16/ 4/73	4.38	4.38	4.26	4.38	3.38	2.27	4.42
14/ 5/73	4.37	4.32	4.27	4.34	3.18	2.19	4.38
18/ 6/73	4.47	4.41	4.40	4.44	4.18	2.38	4.44
16/ 7/73	4.44	4.48	4.39	4.55	3.43	2.35	4.54

TABLE 24

BOD (ml/l) for Stations A-G; Jan.-July (excl. March) 1973

STATION / DATE	A	B	C	D	E	F	G
30/ 1/73	.25	.35	.55	.28	.41	.80	.25
14/ 2/73	.00	.18	.55	.27	.27	.99	.13
16/ 4/73	.24	.12	.40	.08	.33	1.43	.18
14/ 5/73	.21	.23	.09	.16	.27	1.04	.24
18/ 6/73	.03	.00	.00	.00	.08	.51	.02
16/ 7/73	.06	.13	.24	.00	.12	.64	.11

TABLE 25

Partic. Matter (mg/l) for Stations A-G; Jan.-July (excl. March) 1973

STATION / DATE	A	B	C	D	E	F	G
30/ 1/73	.23	.65	.95	.40	2.09	2.89	.50
14/ 2/73	.74	.32	1.27	.12	.96	2.65	.38
16/ 4/73	.53	.48	1.00	1.17	13.10	5.38	.38
14/ 5/73	3.89	4.76	3.72	1.63	6.52	12.02	1.35
18/ 6/73	1.77	3.72	2.30	1.22	7.44	9.22	1.84
16/ 7/73	2.29	3.76	3.48	2.62	17.87	16.25	4.84

TABLE 26

PO_4-P (µg-at/l) for Stations A-G; Jan.-July (excl. March) 1973

STATION / DATE	A	B	C	D	E	F	G
30/ 1/73	.075	.035	.144	.065	.139	1.034	.084
14/ 2/73	.025	.020	.107	.031	.575	1.446	.056
16/ 4/73	.015	.086	.102	.015	.564	2.012	.097
14/ 5/73	.086	.091	.051	.182	.859	2.636	.066
18/ 6/73	.030	.040	.060	.040	.134	4.975	.060
16/ 7/73	.025	.015	.085	.010	.795	3.925	.025

TABLE 27

NO_3+NO_2-N (µg-at/l) for Stations A-G;
May, June and July 1973

STATION / DATE	A	B	C	D	E	F	G
14/ 5/73	.073	.533	.105	.170	1.168	1.885	.458
18/ 6/73	.042	.125	.000	.000	1.079	1.297	.000
16/ 7/73	.328	.167	.367	.105	1.150	3.884	.222

TABLE 28-A

Total Coliforms for Stations 1-11; 4/73 - 7/73

STATION	VOLUME SAMPLED (ml)	COUNT	FINAL COUNT (colonies/100 ml)	TIME
		18/4/73		
1	100	2	2	0745
2	20	24	100	0755
	50	49		
3	20	31	180	0805
	50	92		
4	100	0	0	0815
5	100	0	0	0825
6	100	3	3	0830
7	50	6	49	0840
	100	68		
8	100	0	0	0850
9	100	0	0	0900
10	20	25	73	0915
	50	26		
11	100	4	4	0945
		19/5/73		
1	100	9	9	0935
2	20	70	210	0940
	50	79		
3	20	76	190	0943
	50	58		
4	100	40	40	0947
5	100	23	23	0952
6	100	51	51	0958
7	50	5	17	1002
	100	21		
8	100	2	2	1006
9	100	44	44	1009
10	20	15	61	1012
	50	28		
11	100	32	32	1043

(cont'd)....

TABLE 28-A (cont'd)

Total Coliforms for Stations 1-11; 4/73 - 7/73

STATION	VOLUME SAMPLED (ml)	COUNT	FINAL COUNT (colonies/100 ml)	TIME
		16/6/73 (Includes sample by Coral Reef Club Raft)		
1	100	43	43	0840
2	20	44	200	0848
	50	97		
3	20	44	220	0851
	50	113		
4	100	451	450	0855
5	100	307	310	0858
6	100	31	31	0902
7	50	12	43	0906
	100	52		
8	100	107	110	0910
9	100	8	8	0915
10	20	83	280	0918
	50	111		
11	100	21	21	0940
Coral Reef Club Raft	50	27	23	0945
	100	7		
		21/7/73 (Includes sample by Coral Reef Club Raft)		
1	100	17	17	0915
2	50	44	88	0930
3	50	43	86	0940
4	100	17	17	0950
5	100	31	31	1000
6	100	2	2	1010
7	100	52	52	1020
8	100	26	26	1030
9	100	9	9	1040
10	50	28	56	1055
11	100	2	2	1125
Coral Reef Club Raft	100	21	21	1137

TABLE 28-B

Total Coliforms for Stations A-G; 7/73

STATION	VOLUME SAMPLED (ml)	COUNT	FINAL COUNT (colonies/100 ml)	TIME
		14/7/73		
(Includes Stations 1 and 11, plus sample by Coral Reef Club Raft)				
A	100	306	310	0921
B	100	TNTC	TNTC	0925
C	100	TNTC	TNTC	0930
D	100	292	290	0917
E	20 50	TNTC TNTC	TNTC	0940
F	20 50	TNTC TNTC	TNTC	0950
G	100	123	120	1000
1	100	107	110	1006
11	100	31	31	1040
Coral Reef Club Raft	100	11	11	1048

TNTC - Too numerous to count.

TABLE 29

Temperature (^{o}C) for Stations 1-11 and A-G

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
3/8/72	28.0	28.2	29.0	28.2	28.6	29.2	29.0	28.8	28.4	28.4	28.2
1/1/73	27.1	27.2	27.7	27.1	27.1	27.6	27.4	27.3	27.4	27.5	27.1
1/4/73	27.0	27.3	27.8	27.0	27.1	27.7	27.3	27.1	27.1	27.3	26.8
21/7/73	27.8	27.9	28.0	27.9	27.8	28.0	28.0	27.9	27.9	28.0	27.9

STATION / DATE	A	B	C	D	E	F	G	1	11
1/1/73	27.2	27.3	27.5	27.1	27.5	-	27.1		
1/4/73	27.3	27.4	27.5	27.1	27.4	27.5	27.1		
14/7/73	27.4	27.5	27.6	27.5	27.9	28.1	27.5	27.7	27.7

TABLE 30

Salinity (^{o}/oo) for Stations 1-11 and A-G

STATION / DATE	1	2	3	4	5	6	7	8	9	10	11
3/8/72	35.5	34.9	35.0	34.9	34.9	35.3	35.0	35.0	34.5	34.1	35.5
1/1/73	35.0	35.3	35.1	35.1	35.2	35.4	35.4	35.4	35.3	33.7	35.2
1/4/73	35.6	35.7	35.7	35.6	35.5	35.8	35.5	35.6	35.6	35.1	35.6
21/7/73	32.4	32.6	32.7	32.5	32.6	32.8	32.6	32.6	32.5	31.3	32.7

STATION / DATE	A	B	C	D	E	F	G	1	11
1/1/73	35.1	35.3	35.4	35.2	35.0	-	35.0		
1/4/73	35.6	35.6	35.6	35.6	35.5	35.3	35.6		
14/7/73	32.8	32.7	32.7	32.7	32.5	32.4	32.7	32.7	32.8

TABLE 31

South Coast Sampling

STATION	Chl a mg/m^3	D.O. ml/l	BOD ml/l	Partic. Matter mg/l	PO_4-P µg-at/l	NO_3+NO_2-N µg-at/l
			4/6/73			
St.Lawrence	.221	4.55	.10	3.67	.049	.057
Accra Beach	.281	4.61	.06	2.81	.044	.124
Asta Hotel	.420	6.53	.38	2.28	.039	.057
Hilton Hotel	.796	4.98	.27	4.89	.112	.358
			11/6/73			
St.Lawrence	.277	5.01	.32	1.73	.024	.236
Accra Beach	.292	4.78	.12	1.62	.039	.659
Asta Hotel	.277	4.98	.26	1.43	.063	.262
Hilton Hotel	.316	4.68	.18	1.33	.278	1.388

TABLE 32

Replication by Subsampling of Single Sample

SAMPLE	NO_3+NO_2-N µg-at/l	PO_4-P µg-at/l	Phytoplankton cells/l
1	.075	.025	40400
2	.073	.020	42000
3	.073	.020	45200
4	.076	.020	53200
5	.075	.025	44400
6	.076	.020	47200
7	.073	.020	42800
8	.076	.020	44600
9	.071	.015	41600
10	.069	.020	46000
Mean	.074	.021	44740
±S.D.	±.002	±.0029	±3644
C.V.	2.70%	13.81%	8.14%

S.D. = standard deviation; C.V. = coefficient of variation

TABLE 33

Replication by Repeated Sampling

SAMPLE	NO_3+NO_2-N µg-at/1	PO_4-P µg-at/1	Particulate Matter mg/1	Chlorophyll a mg/m^3	D.O. ml/1	BOD ml/1
1	.053	.015	2.68	.110	4.61	.20
2	.060	.020	2.49	.129	4.55	.15
3	.058	.020	2.44	.116	4.55	.16
4	.065	.015	2.07	.110	4.55	.18
5	.062	.015	2.28	.114	4.56	.18
6	.060	.015	2.79	.110	4.54	.15
7	.064	.015	2.46	.120	4.57	.18
8	.065	.020	2.32	.125	4.59	.17
9	.064	.020	2.31	.133	4.53	.15
10	.065	.015	2.31	.126	4.60	.19
Mean	.062	.018	2.42	.119	4.57	.17
±S.D.	±.004	±.0026	±.21	±.008	±.03	±.018
C.V.	6.45%	14.44%	8.68%	6.72%	0.66%	10.59%

S.D. = standard deviation; C.V. = coefficient of variation