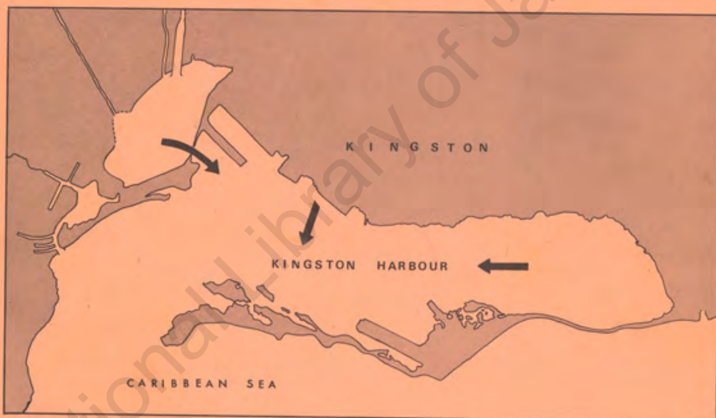
Barry A. Wade

THE POLLUTION ECOLOGY OF KINGSTON HARBOUR; JAMAICA

SCIENTIFIC REPORT OF THE U.W.I. - O.D.M.
KINGSTON HARBOUR RESEARCH PROJECT
1972 - 1975

VOLUME 2



BY

BARRY A. WADE

RESEARCH REPORT FROM THE ZOOLOGY DEPARTMENT
UNIVERSITY OF THE WEST INDIES. MONA
NUMBER 5
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THE POLLUTION ECOLOGY

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VOLUME II

PART 4 - BENTHIC ECOLOGY

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FOREWORD

This volume comprises Part 4 of a 5-Part report on the pollution ecology of Kingston Harbour, Jamaica, which is arranged as follows:

Volume I

Part 1. General Introduction

2. Water Quality

3. Oxygen Balance

Volume II

Part 4. Benthic Ecology

Volume III

Part 5. Pollution Abatement and Harbour Improvement

The work has been made possible by a 3-year grant from the United Kingdom Ministry of Overseas Development to the University of the West Indies (Scheme R 2669) and by previous funding from the University's Research and Publication Fund. The author is greatly indebted to these sources for their financial support.

In addition to those persons and organisations previously acknowledged for their assistance (Wade, 1976), the author is grateful to Mr. Laurie Hammond for his help with the mathematical computations.

All the field work was carried out from the Port Royal Marine Laboratory of the University of the West Indies.

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PART 4
BENTHIC ECOLOGY

1. INTRODUCTION

The usefulness of marine benthic organisms in the detection and monitoring of pollution in the sea has long been recognised and many workers have studied the benthos either to determine the effect of different kinds of pollution on them or to measure the degree of pollution as indicated by their changes. Two recent review papers by Pérès and Bellan (1972) and Reish (1972), in discussing some of the work done in this field, have stressed the practical application of such work. However, these authors have differed in their approach for whereas the former have emphasised a population or community approach to pollution monitoring, the latter has stressed the single species method, favouring in particular the indicator organism concept. However, whichever approach is taken, and there is most often scope for both, there is no doubt that the efficacy of the methods have been well established. Furthermore, since fairly standard field and laboratory techniques which are both simple and inexpensive have been developed for studying the benthos, workers all over the world have been able to study the benthos with a fair degree of consistency and confidence. Hence, the body of information on the benthos and the effects of pollution on them is growing rapidly both in scope and in the level of understanding.

For these reasons, use of the benthos for monitoring the condition of Kingston Harbour has proved to be most attractive, and a great deal of information on recent deterioration of the harbour has been obtained by benthic surveys since 1968 (Wade 1972a, Wade et al 1972). Furthermore, since 1971, these surveys have been conducted simultaneously with water quality and oxygen balance studies

(Wade 1976) which have thus provided excellent support data for interpretation of the results.

It is somewhat surprising that despite the wide use of the benthos in pollution studies, not much information is available in this regard from tropical areas and almost none exists from other parts of the Caribbean. The only published works in the Caribbean from outside Jamaica on pollution and the benthos are by Seiglie (1968, 1971) on the relationship between certain species of foraminifers and pollution in Puerto Rico. However, these studies, drawing attention to the usefulness of certain species as indicator organisms,do not seem to have been applied to pollution monitoring in any of the environments studied. The nearest location where this has been done is Biscayne Bay, Florida (McNulty 1961, 1970),but conditions there are subtropical and the area supports only few species in common with the Caribbean.

Hence, this study in Kingston Harbour is the first of the kind in the Caribbean. It is hoped that it will form the basis for future such work and that it will lead to greater application of benthic ecology for pollution monitoring in the area.

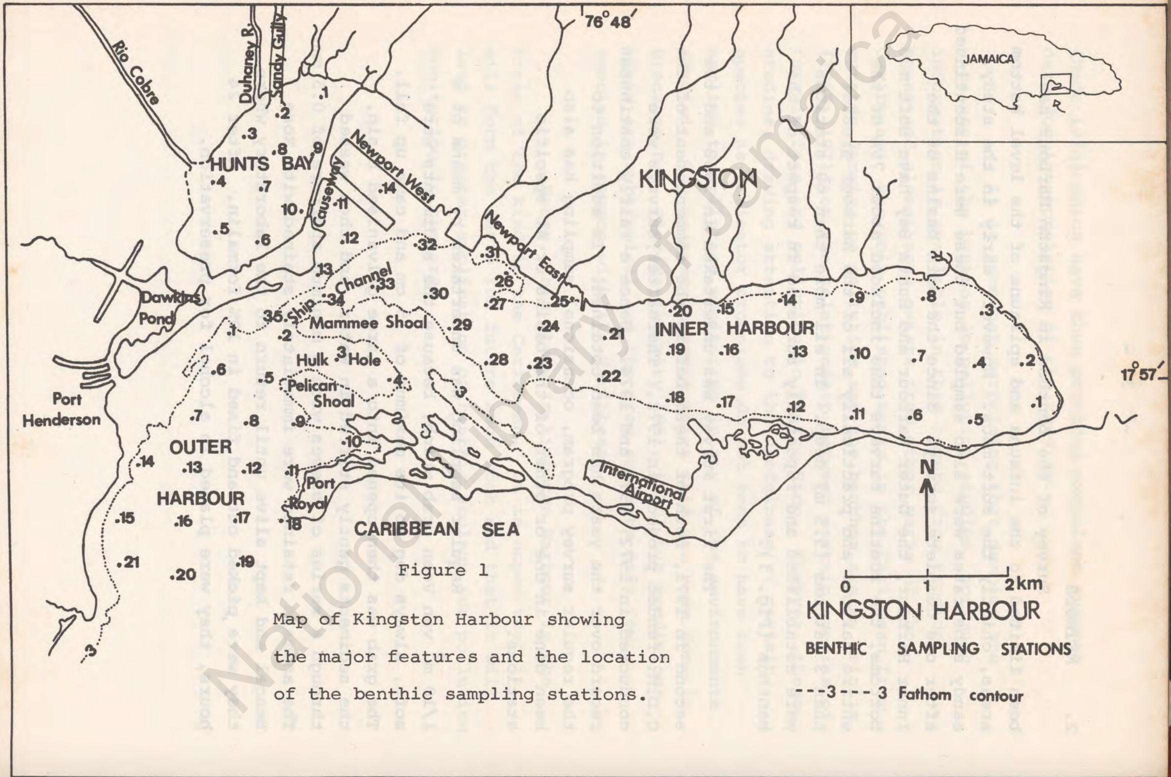


Figure 1

Map of Kingston Harbour showing the major features and the location of the benthic sampling stations.

2. METHODS

Survey of the benthos in Kingston Harbour has been limited to the infauna and epifauna of the level bottom areas, chiefly the soft muds. However, early in the study, sandy substrates were also sampled but these were discontinued after one complete survey. Since the main basins of the Inner Harbour, the Outer Harbour and Hunts Bay have soft mud bottoms, the routine surveys thus included about 75% of the entire harbour and practically all of the harbour greater than 3 fathoms (5.5 m) deep. In all more than 60 stations were established and repeatedly surveyed in respect of the benthos (Fig. 1).

The first survey was undertaken in 1968 and the second in 1971, both of these before the commencement of the O.D.M. funded project in 1972. Thereafter, surveys were conducted in 1972, 1973 and 1974. Hence a fairly continuous record over the years has been obtained. In addition to the regular survey program, occasional sampling has also been done in one or other of the basins or at specific stations.

Regular sampling was undertaken by means of a 1/10 m^2 van Veen grab which, because the sediments were soft, always dug to its maximum of 15 cm and came up full. The grab was then opened into a large galvanised basin, the sediments gently stirred in water, and then washed through a series of sieves with a minimum aperture of 0.5 mm. The animals retained were immediately stained with Rose Bengal and kept alive until return to the laboratory where they were picked out and fixed in 10% formalin. After 24 hours, they were placed in alcohol for preservation.

Other sampling devices used on occasions were a rectangular naturalist's dredge fitted with a burlap bag, a sled dredge, and an otter trawl.

All the animals collected were sorted into their major taxa and then separated at the species level. Because of the inadequacy of much of the Caribbean taxonomic literature, it was impossible to identify most of the species. However, since the interpretation of the data in this study is based on the recognition of different species rather than on their specific identification, this in itself has presented no great problem. Nevertheless, it is useful to know with what level of accuracy sorting to species has taken place. Based on a confirmation of a sample of polychaetes, crustaceans and bivalves (the most abundant taxa) by taxonomic specialists at the commencement of the study, it is felt that separation of the species in this study began at more than 95% accuracy and improved significantly throughout the study.

The help of Dr. Meredith Jones, Dr. Lion Gardiner and Dr. Jeremy Woodley with the identification of certain taxa is gratefully acknowledged.

3. BOTTOM TOPOGRAPHY AND SEDIMENTS

The bottom topography in Kingston Harbour is marked by two very separate and distinct areas: the shallow sandy areas around the periphery of the harbour, and the deeper muddy basins in the Inner and Outer Harbours and in Hunts Bay.

The major sandy areas are located on the south side of the Inner Harbour from just east of the airport to the ship channel and on the west side of the Outer Harbour along the Port Henderson spit. These areas are by and large bounded by the 3 fathom (5.5 m) contour except that they do not occur within Hunts Bay. The major shoals are the Mammee and Pelican shoals and, in parts of these, the depth of water may be less than 50 cm at low tide.

The slope of the bottom is gradual down to the 3 fathom (5.5 m) depth after which it falls more rapidly to 6 fathoms (11.0 m) and more before levelling off again. Within the 3 fathom (5.5 m) contour, the bottom is covered alternately by bare patches of sand and meadows of the turtle grass, Thalassia testudinum. In a few places, especially in the Port Henderson shallows, there are also a few outcrops of coral, but these are mostly dead.

The sand is almost entirely of calcium carbonate material and is made up of the fragmented remains of coralline algae, especially Halimeda, and calcareous animals. It is coarse to very coarse in texture and generally has a median diameter in excess of 1.0 mm. The organic content is low to medium, rarely exceeding 3.0% (McShine 1971).

Below 3 fathoms (5.5 m), the carbonate sand gives way quickly to soft muds, mostly of silts and clays, but also with some fine quartz and carbonate sand. The predominant textural class is clayey silt which is only moderately sorted, and the organic content is generally quite high, being in excess of 4%. The depth of these muds is usually greater than 75 cm and the bottom is smooth with no vegetational cover whatsoever. However, in Hunts Bay and part of the Outer Harbour (Hulk Hole) there is a fair amount of plant debris on the mud surface.

The Government of Jamaica (1968) report has provided a distribution map of bottom material in Kingston Harbour. However, the sediments are not described in standard oceanographic terminology and there is no indication of the number of samples taken or their location. Hence, in order to substantiate this map, spot checks were made throughout the harbour at the commencement of this study. These checks showed good general agreement with the map and provided additional information on the size and sorting of the sediments. This information is represented by the data in Table 1 for four typical samples from the major sediment areas in the Inner Harbour Basin, the Outer Harbour basin, Hunts Bay, and the Mammee Shoal. In summary, they confirm the soft sediments to be of clayey silt and the sand sediments to be of coarse sand. Minor variations occur in each of these categories, but they are small and insignificant.

Hence, two main categories of sediments may be recognised in Kingston Harbour: the coarse sands of the shallow areas and the clayey silts of the Inner and Outer Harbour basins and Hunts Bay.

Table 1. Data on representative sediment samples from 4 main regions in Kingston Harbour

Station	% Sand (53 µ)	% Silt (2-53 µ)	% Clay (2 µ)	% Silt-clay	Predominant Fraction	Textural Class[1]	Median Diameter (mm)	Sorting Coefficient (mm)	Organic Matter (%)
Inner Harbour (13)	2.00	71.19	26.81	98.00	silt	clayey silt	0.014	0.017	9.9
Outer Harbour (8)	11.75	62.22	26.03	88.25	silt	clayey silt	0.031	0.023	4.1
Hunts Bay (7)	16.32	59.41	24.27	83.68	silt	clayey silt	0.009	0.013	10.5
Mammee Shoal	99.80	0.20	-	0.20	sand	sand	1.05	0.38	1.3

Notes: (1) Textural class designation after Shepard (1954)

(2) Sorting Coefficient $= \frac{80\% - 20\%}{2}$

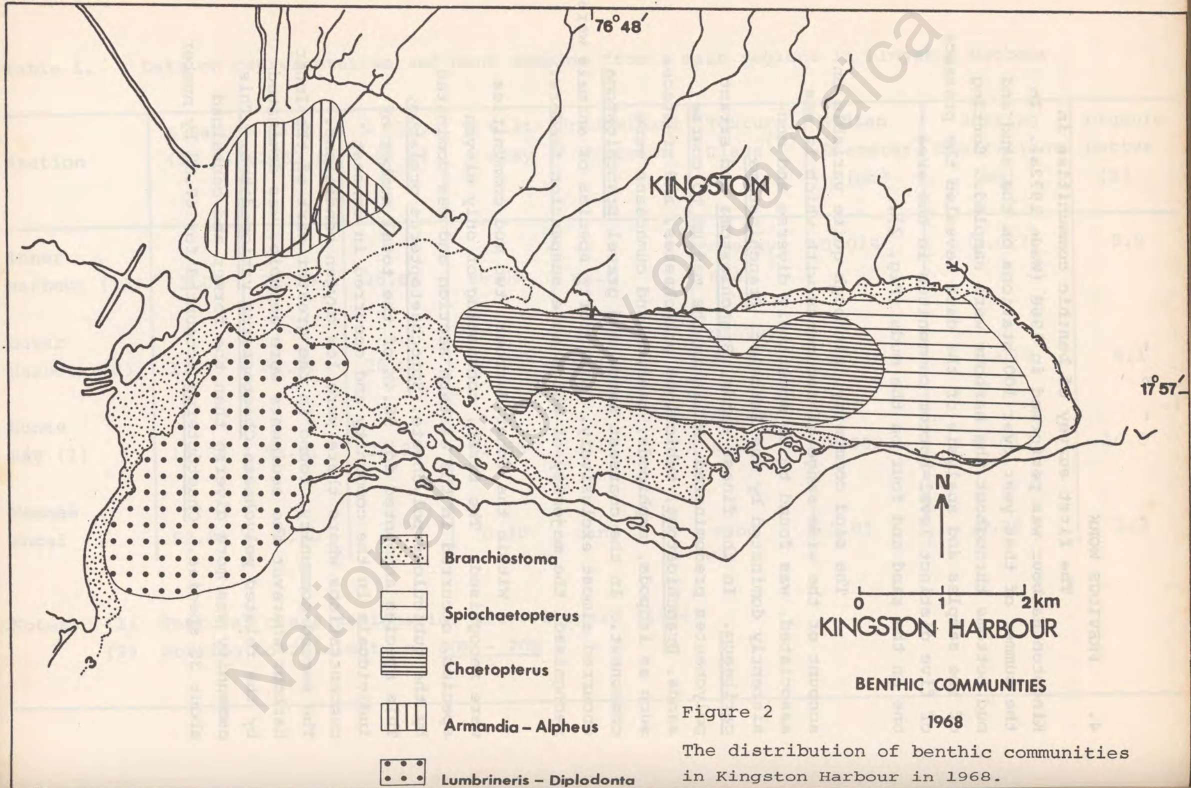


Figure 2

The distribution of benthic communities in Kingston Harbour in 1968.

4. PREVIOUS WORK

The first survey of benthic communities in Kingston Harbour was performed in 1968 (Wade 1972a). In the summer of that year over 100 stations on the sand and mud bottoms throughout the harbour were sampled. Sorting of the samples and analysis of the data revealed the presence of five distinct level-bottom communites in the area - one on the sand and four on the muds (Fig. 2).

The sand community, although quite variable on account of the wide range of sediments with which it was associated, was found to be moderately diverse and consistently dominated by the lancelet, *Branchiostoma caribaeum*. In the finest sands, *Branchiostoma* and errant polychaetes predominated, while in the medium to coarse sands, *Branchiostoma*, tubiculous polychaetes, and crustacea such as isopods, amphipods, tanaids and cumaceans were commonest. In the coarsest sands and gravel *Branchiostoma* occurred almost exclusively. Over forty species of animals were recognised, the majority of which were suspension feeders.

Within the Inner Harbour, two mud communities were recognised. The first, consisting of only eleven species, occurred in the eastern section and was dominated by the tubiculous polychaete, *Spiochaetopterus oculatus*. This species accounted for 96.4% of the total number of individuals in the community and occurred in densest concentrations where there were low oxygen conditions. The second community, found in the greater part of the Inner Harbour wherever the sediments were aerobic, was dominated by the related polychaete *Chaetopterus variopedatus*. This community was more diverse than the former and contained about 35 species. *Chaetopterus* accounted for 47.0% by number of all individuals. The distinctive feature of this community was its high biomass with one square metre of the bottom having a standing crop of 7 kg wet weight or 1.6 kg dry weight. Chaetopterus itself occurred in densities as high as 400 per square metre and accounted for more than 95% of the biomass.

The third mud community occurred in Hunts Bay and was dominated by the opheliid polychaete Armandia sp. and the snapping shrimp Alpheus sp. This was a fairly low diversity and density community with no outstanding characteristics.

The fourth mud community was found in the Outer Harbour and was marked by its extremely high diversity. No single species dominated this community numerically and together the two most common species comprised only 21.3% by number of all individuals. The outstanding characteristics of this community were described in a separate paper by Wade (1972b) in which it was shown that the level of diversity of the community was unique to stable tropical environments and probably had its equal in only few other parts of the world. However, despite a high diversity, the density and standing crop were surprisingly low.

The results of this first survey gave interesting insights into the harbour ecology. Firstly the steep increase in diversity from the eastern end of the Inner Harbour out to the Outer Harbour indicated a rapid improvement of the environment over a relatively short distance. From observation, this improvement appeared to be associated with better oxygen conditions in the Outer Harbour due to greater tidal circulation and the absence of waste outfalls. Thus, pollution appeared to be directly implicated in the low diversity within the Inner Harbour. Further evidence of this was given by the occurrence of Spiochaetopterus as the dominant organism in the innermost section of the harbour and near to the northern gully outfalls, and its previously described relationship with organic pollution in Florida by McNulty (1961).

Secondly, the reduced diversity in Hunts Bay could mean that estuarine conditions in Hunts Bay were severe enough to affect the benthos. Since the greatest salinity fluctuations in Hunts Bay were seasonal rather than tidal, a number of species, if settled in Hunts Bay at the right time of year, could survive for most of the year and only be decimated during the rainy season. Hence, the community could be made up largely of opportunistic species, many of which could come from the Outer Harbour. Indeed, the summer sampling in Hunts Bay indicated just that since some of the species found there, including the two dominant ones, also occurred in the Outer Harbour.

This first survey showed no clear evidence of pollution as a factor in Hunts Bay. Rather the presence of some species from the Outer Harbour suggested somewhat healthy conditions. Thus, the increase in diversity from Hunts Bay to the Outer Harbour appeared to be along a fluctuating salinity gradient caused by the seasonal discharge of large volumes of freshwater in Hunts Bay.

The Outer Harbour environment in 1968 appeared to be ideal for the support of what Sanders (1968) called a "predominantly biologically accomodated community". That is, one which is the result of an environment which is physically stable and undisturbed and which therefore suffers no physiological stress. That such a unique environment should occur in Kingston Harbour was of immense interest. However, that it should occur in close proximity to such obviously stressed environments as the Inner Harbour and Hunts Bay was even more remarkable. The questions which clearly begged to be answered were whether this environment could retain its integrity and, if so, for how long, or whether it would soon become subject to similar stresses as the rest of the harbour. Only repeated surveys could tell.

Due largely to the nature of the substratum, the community of the sand bottom showed inherent differences from those of the soft muds. Hence, as Sanders (1968) has pointed out, direct comparisons of community structure could not be made across the two types of habitats. Furthermore, sampling of the sand bottoms required different techniques for best results with the result that a separate sampling program would be necessary for its proper study. For these reasons, no further monitoring of this community was undertaken by this author and all later effort was devoted to a study of the mud-bottom communities. However, McShine (1971) redescribed the sand community at Mammee Shoal and showed that although it could be regarded as healthy, it was affected by seasonal freshwater run-off out of Hunts Bay. Since that time, it is possible that this community may also have become affected by pollution, but good data to support this are not available. At any rate, this community has never really been carefully studied and our knowledge of it is therefore still rudimentary.

Following the initial survey of 1968 and the indication that pollution was a factor in the determination of community structure in parts of Kingston Harbour, it became obvious that if the pollution were to spread, more and more of the communities would become affected by it.

Thus, a reinvestigation of the communities could be useful in throwing light on the spread of pollution and also in assessing its possible future influence on the ecology of the harbour as a whole. Thus, two further surveys were undertaken in 1970 and in 1971 and the results were reported by Wade et al (1972).

The results were startling for between 1968 and 1971, levels of changes had taken place in the communities such as could not have been predicted. In short, they showed an extremely rapid deterioration of the Inner Harbour and Hunts Bay communities and the development and spread of a massive abiotic zone in the Inner Harbour (Fig. 3). Only the Outer Harbour community appeared to be unchanged.

Between 1968 and 1971, Chaetopterus had completely disappeared from the Inner Harbour and Spiochaetopterus had moved westward to take over its place. Where previously Spiochaetopterus had occurred, the bottom had become abiotic and this now covered more than half the area of the Inner Harbour. In Hunts Bay, an entirely new community had appeared dominated by the polychaete Capitella capitata, and all the previous species which had hitherto been shared with the Outer Harbour had disappeared. This new community was of very low diversity.

By 1971, monitoring of dissolved oxygen levels had begun and it became immediately obvious that the deterioration of communities in the Inner Harbour and Hunts Bay was proceeding along two very steep oxygen gradients - one from the Inner Harbour to the Outer Harbour; the other from Hunts Bay to the Outer Harbour. Thus, further evidence of pollution in the Inner Harbour was confirmed and new evidence for Hunts Bay became available. Indeed, not only

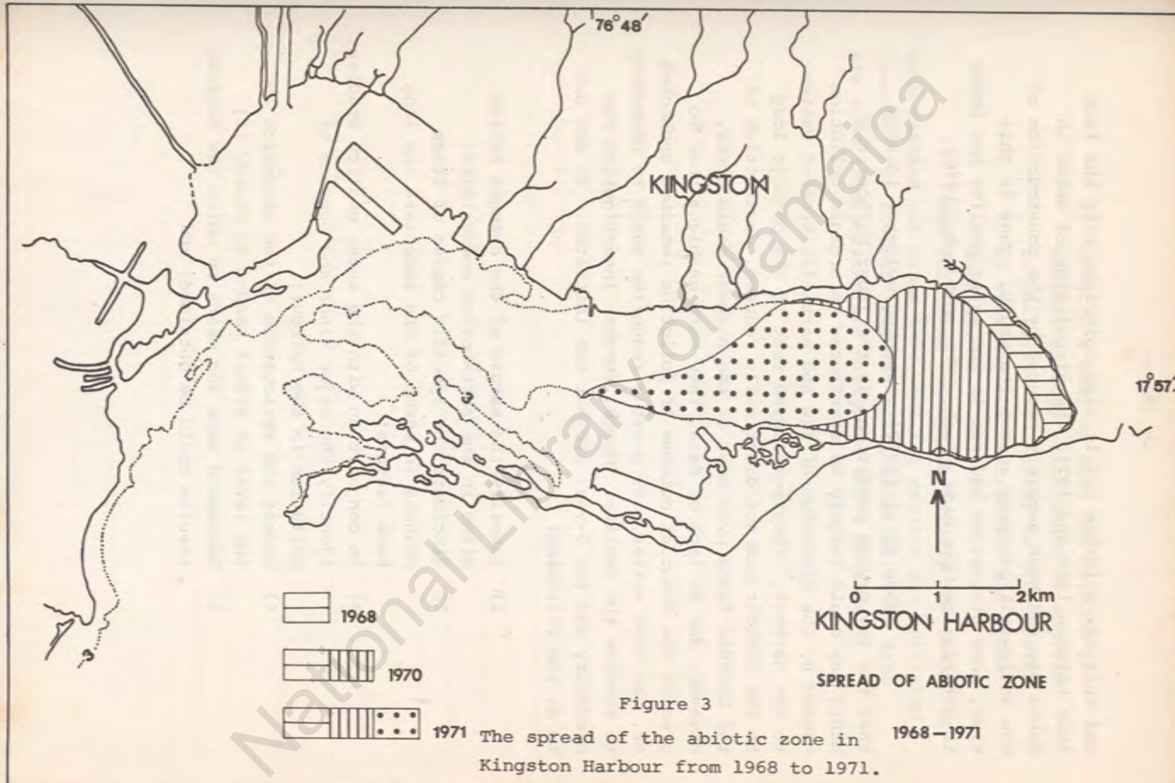


Figure 3

The spread of the abiotic zone in Kingston Harbour from 1968 to 1971.

was this new evidence but it also coincided with the fact that between 1968 and 1971, the circulation of water in Hunts Bay had been severely reduced by the construction of the solid-fill causeway across its mouth. Thus in this time, some stagnation had set in and water quality had begun to deteriorate.(See Wade et al, 1972, and Wade, 1976).

Wade et al (1972) presented evidence to show that the low oxygen conditions in the Inner Harbour and Hunts Bay could largely be attributed to organic pollution caused by the discharge of raw and partially treated wastes to the harbour. They postulated that if the organic load to the harbour were not drastically reduced, destruction of the benthic fauna over most of the harbour could occur. However, due to lack of data, they were unable either to predict the eventual outcome if pollution remained unchecked or, for that matter, how great a reduction would be necessary to reverse the decline. Hence, further investigation was necessary and the 3-year project was initiated. It set out to do the following:

1) Identify the nature of the changes taking place in the soft-bottom communities;
2) Elucidate the specific causes of these changes in terms of the immediate and long term factors;
3) In conjunction with the water quality studies, identify the major kinds and sources of pollution in the harbour;
4) Assess the seriousness of the situation and the level of effort needed to remedy it;
5) Recommend ways and means by which the desired results could be obtained; and

6) Develop a body of data and methods in benthic ecology which could be applied to pollution monitoring in other parts of Jamaica, the Caribbean, and areas outside.

The following account is largely the result of work carried out since 1972 when the project was initiated. However, for obvious reasons, previously collected data are also incorporated and discussed where necessary.

5. THE POLLUTION PATTERN

It has been demonstrated by a number of workers (Filice, 1959; Reish, 1959; Bellan, 1967, to name a few) that the nature and degree of pollution in an area may conveniently be categorised according to its effect on the benthos. Thus, domestic and industrial organic pollution resulting primarily in depleted oxygen levels have produced essentially four clearly recognisable benthic zones in San Francisco Bay, the Long Beach - Los Angeles Harbour and the Port of Marseilles. These are a very polluted zone (maximum pollution), a polluted zone (heavy pollution), a semi-healthy zone (mild pollution) and a healthy zone (no pollution). Pérès and Bellan (1972) have reviewed the terminology used by various workers in describing these zones and, although there is some overlap in their usage, it is clear that the concepts are well understood and accepted. Thus, in the very polluted zone, there are no benthic organisms whereas in the polluted zone, there are only a few species, usually dominated by the polychaete *Capitella capitata* or a similar species. In these two zones, oxygen is usually absent or very low and the substratum is a black sulphide mud. In the semi-healthy zone, there are more species but still below the number in the healthy zone. Dominance by one or a few species (usually polychaetes) is marked and there may be a pronounced increase in density which McNulty (1961) has called the fertiliser effect. In this zone, the oxygen level is still below saturation and black sulphide mud is also present. In the healthy zone, however, the oxygen level rises to near saturation and the mud becomes grey. The number of species reaches its maximum and dominance is greatly reduced. Also the density of animals falls off and becomes stable.

Wade *et al* (1972) have suggested that the deterioriation in benthic communities in Kingston Harbour has been due to organic pollution from raw or partly treated domestic and industrial wastes. If this is true, then we might expect to find the characteristic zonation pattern described above in the

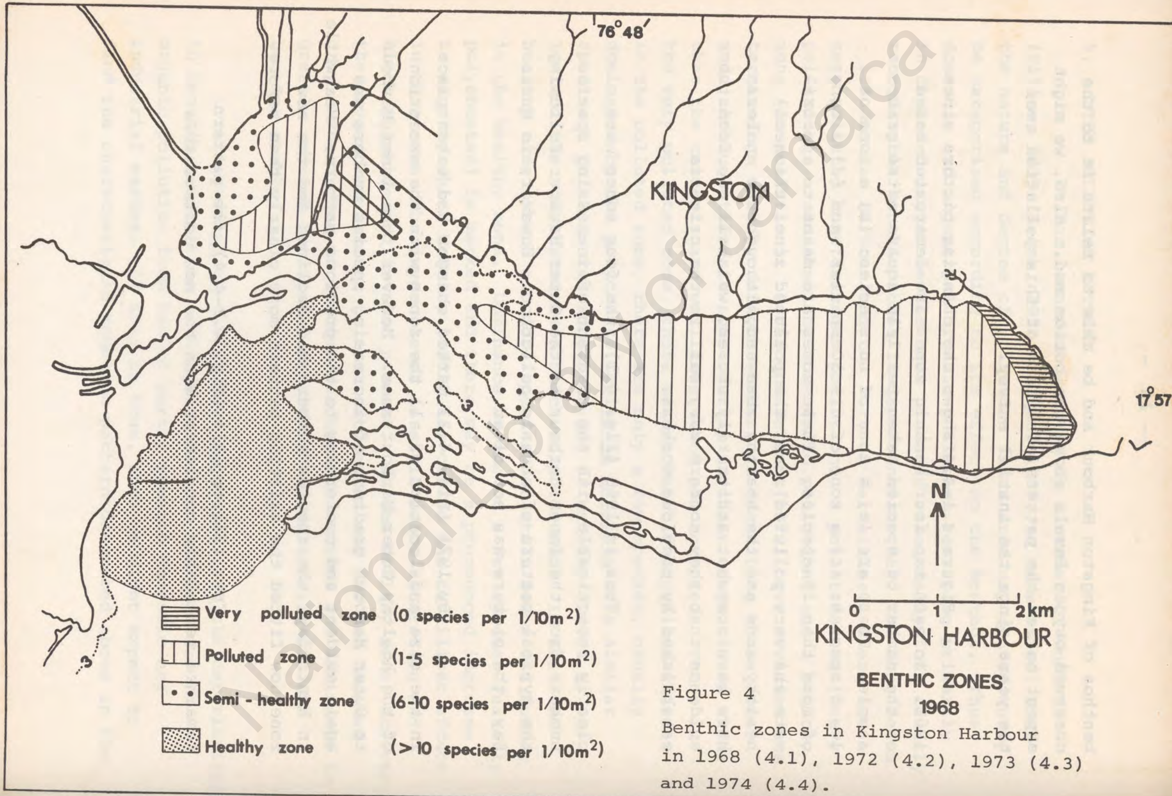


Figure 4

Benthic zones in Kingston Harbour in 1968 (4.1), 1972 (4.2), 1973 (4.3) and 1974 (4.4).

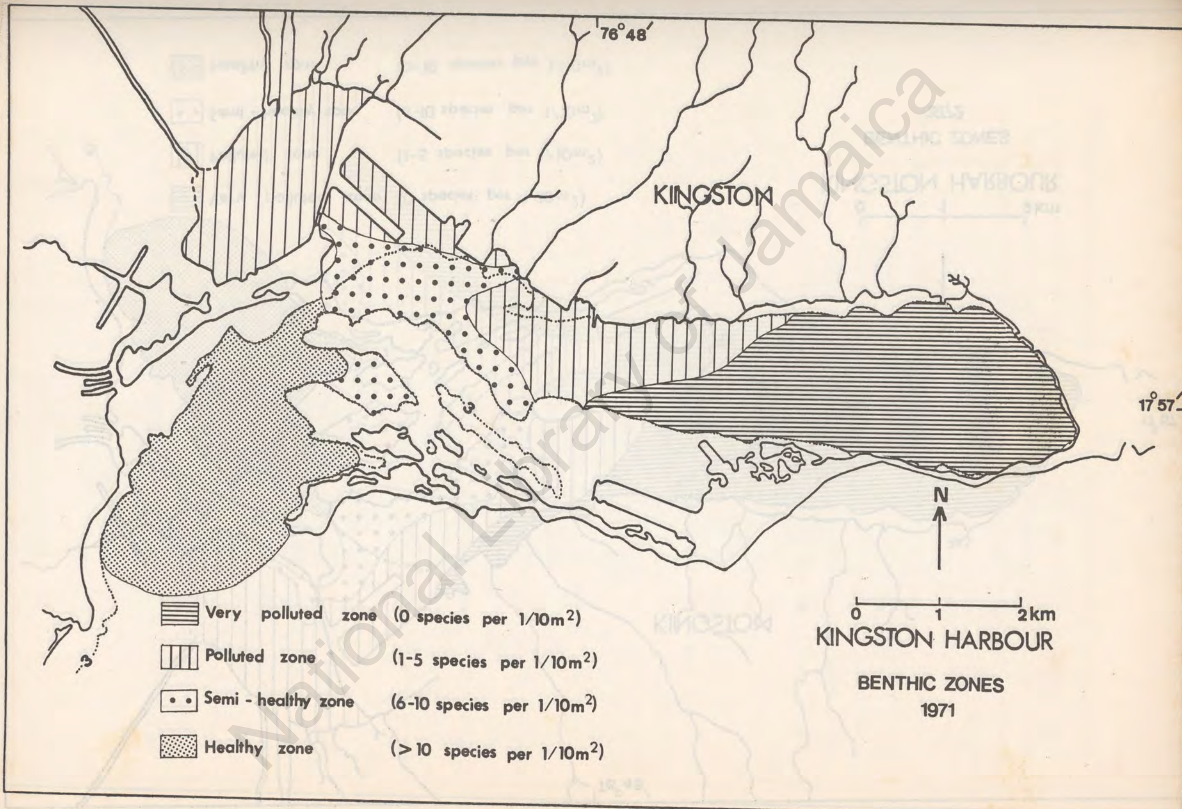
benthos of Kingston Harbour and be able to relate it to the observed oxygen levels above the bottom mud. Also, we might expect to see the pattern of spread of this pollution over the years since the initial survey.

Figure 4.1-4.4 shows the changing picture since 1968. In each map four benthic zones are demarcated based on the number of species taken per 1/10 square metre grab sample. These are (a) a zone of no species; (b) a zone of 1 - 5 species; (c) a zone of 6 - 10 species; and (d) a zone of more than 10 species. These zones are meant to approximate the very polluted zone, the polluted zone, the semi-healthy zone and the healthy zone and,although the numbers have been somewhat arbitrarily chosen, we shall see from the evidence that they conform very well to the criteria established by previous workers.

Thus,in 1968 (Fig. 4.1), the four zones were clearly recognisable with the gradient of increasing species numbers from the Inner Harbour to the Outer Harbour following the typical pattern of organic pollution. However, in Hunts Bay, the picture was not clear.

By 1971 (Fig. 4.2) marked changes had taken place in the size and location of all the zones with the exception of the healthy Outer Harbour zone. However, the Inner Harbour to Outer Harbour gradient of increasing species numbers was again evident and conforming to the previous pattern. Meanwhile in Hunts Bay, the species numbers had declined and the new zone now fitted the existing pattern more clearly than before.

From 1971 to 1974 (Fig. 4.2-4.4) the pattern remained remarkably consistent with the now unmistakable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3
N
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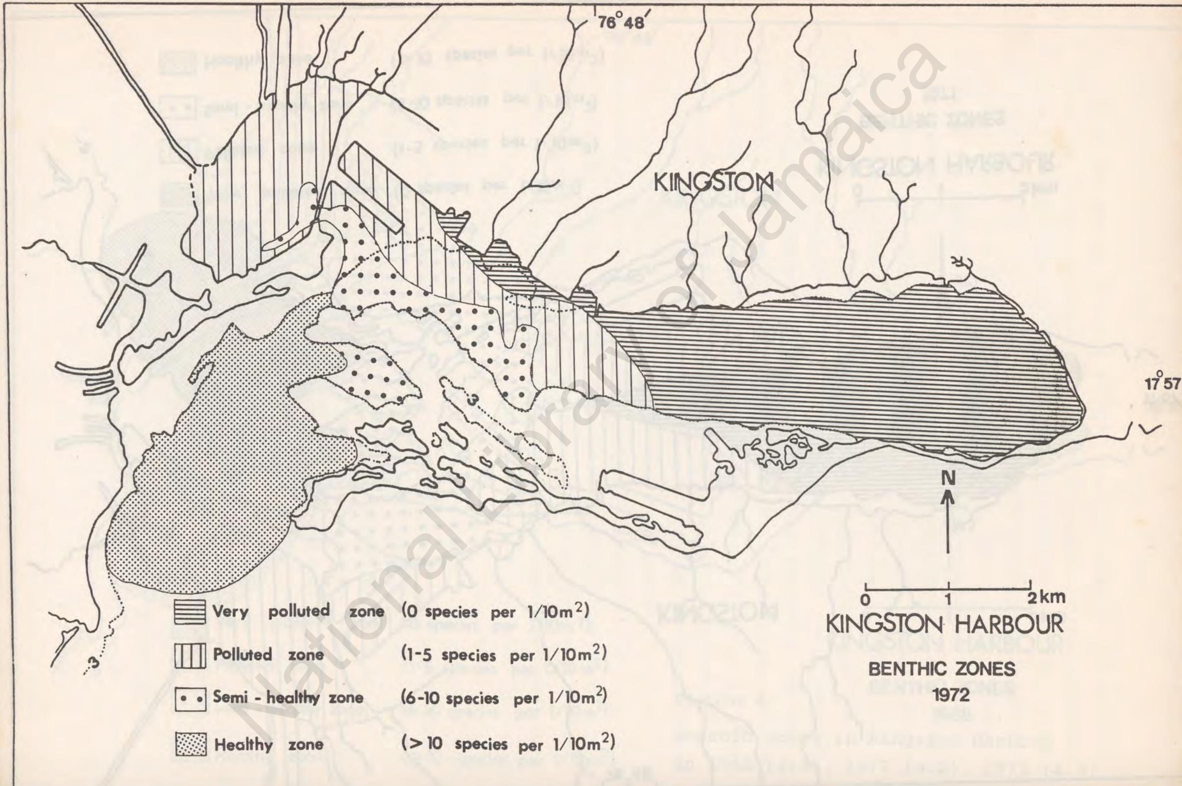
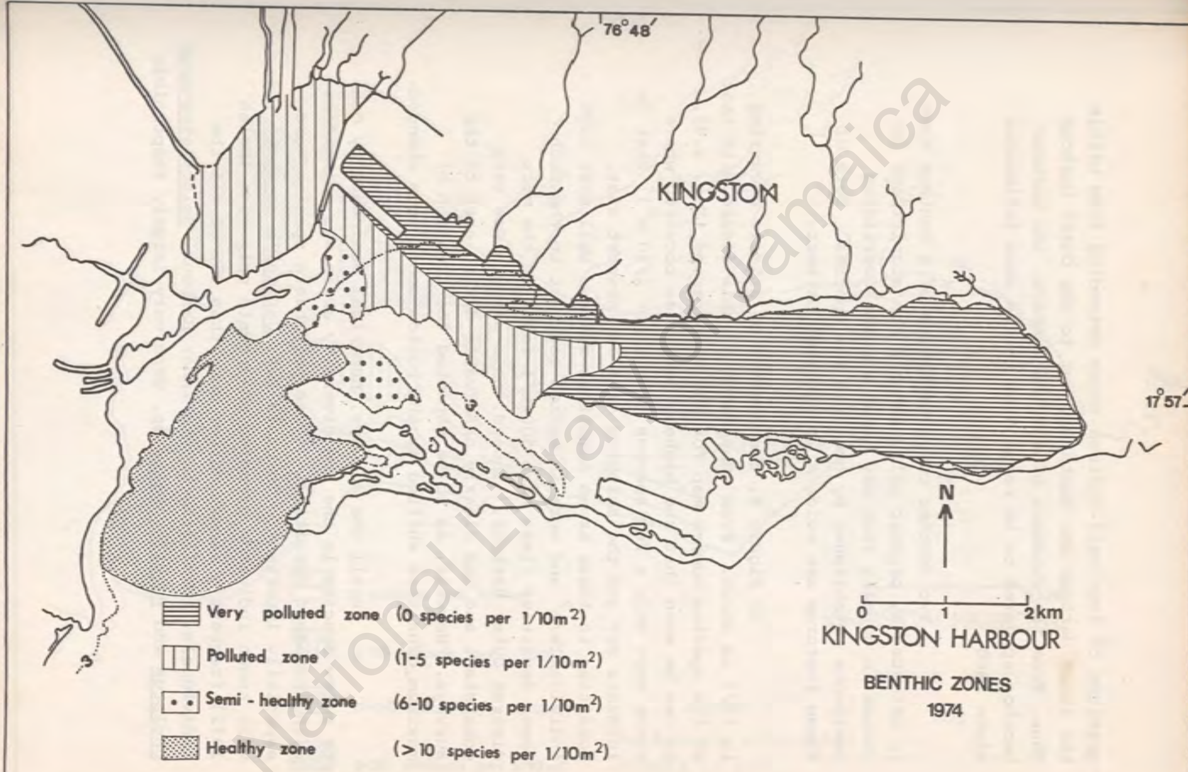
KINGSTON HARBOUR
BENTHIC ZONES
1971
Very polluted zone (0 species per 1/10m²)
Polluted zone (1-5 species per 1/10m²)
Semi - healthy zone (6-10 species per 1/10m²)
Healthy zone (> 10 species per 1/10m²)



KINGSTON HARBOUR

BENTHIC ZONES

1972



KINGSTON HARBOUR

BENTHIC ZONES
1974

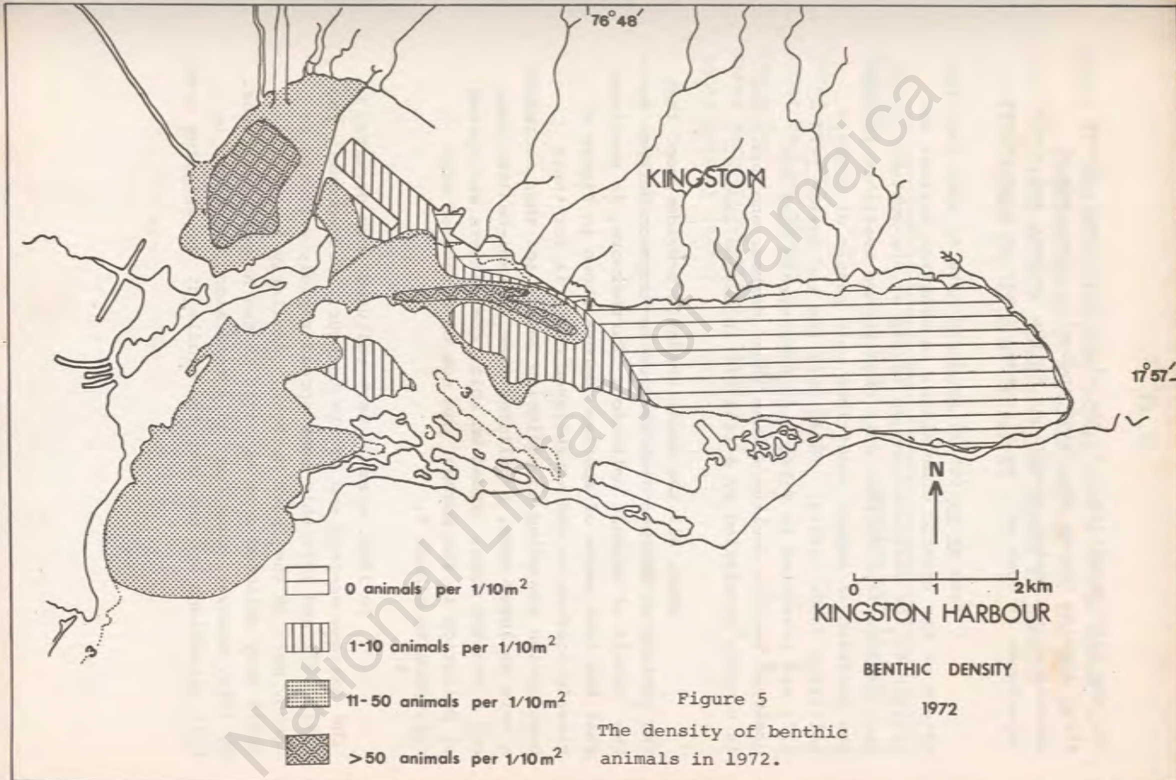


Figure 5
The density of benthic animals in 1972.

gradient of four well-defined zones extending from within the Inner Harbour and Hunts Bay out to the Outer Harbour. Thus, from the evidence of species numbers, the harbour benthos appeared to be responding to the same influences since 1968.

Two further characteristics of a benthos that is affected by organic pollution are the significant increase in density that may occur and the overriding dominance established by one or a few species. Both of these features are evident in Kingston Harbour.

In Figure 5, the density of animals occurring in 1972 is shown. From comparison of this figure with that of the species number map for the same period (Fig. 4.3), it can be seen that the highest densities occurred where there were only a few species (1 - 5 per 1/10 m^2), that is in Hunts Bay and the shipping area off Newport East. Densities in these areas sometimes reached well over 3000 individuals/m^2 and were in marked contrast to the much lower densities (less than 500/m^2) found in the more diverse Outer Harbour. Indeed, this pattern was very consistent and was clearly observable during each of the surveys. However, as to be expected the location of maximum densities shifted as the bottom conditions changed.

In all the surveys, numerical dominance by one or a few species in the low diversity areas was coincident with increased densities. Three polychaete species were especially important. In Hunts Bay, Capitella capitata the well known indicator organism of organic pollution (Reish 1972) frequently accounted for more than 95% of all the individuals. Similarly in the Inner Harbour, Spiochaetopterus oculatus and Poecilochaetus sp. were very largely responsible for the high densities. As the study progressed, these three species became the chief indicator organisms of deteriorating bottom conditions in the harbour and their importance as such will be discussed later in this report.

Wade _et al_ (1972) produced data to show that the nature of the benthic communities in Kingston Harbour was related to the dissolved oxygen levels at the bottom. Since that publication, further data have become available to show the gradient in oxygen conditions as a result of organic pollution (Wade, 1976). These data for the period 1973 - 1975 are presented in Table 2 to demonstrate that the observed benthic decline in the Inner Harbour and Hunts Bay is closely paralleled by a fall-off in oxygen levels.

Thus, all the above evidence provides proof that the pattern of benthic distribution in Kingston Harbour is the result of organic pollution. Furthermore, it confirms that the four zones of species numbers shown in Figure 4 closely conform to the established criteria for their description according to pollution levels and thus represent a very polluted zone, a polluted zone, a semi-healthy zone and a healthy zone. Based on this, the pattern and spread of pollution in the harbour can now be discussed with reference to Figure 4.

In 1968, a small very polluted zone occurred in the extreme eastern end of the harbour. Subsequently in 1971, 1972 and 1974 this zone spread rapidly westward to occupy most of the Inner Harbour. Similarly in 1972, a small very polluted zone appeared in the Newport East area. By 1974, however, this too had spread along the shore in both directions and out into the middle of the shipping area.

Table 2: The mean dissolved oxygen levels at the bottom in various parts of Kingston Harbour for the period 1973 to 1975 along with the number of species found per 1/10 m^2 in 1974.

Station	D.O.	Species per 1/10 m^2
Outer Harbour	5.13 mg/l	>10
Inner Harbour (West)	4.34	1 - 5
Hunts Bay	3.68	1 - 5
Inner Harbour (Central)	3.60	0
Inner Harbour (East)	3.02	0

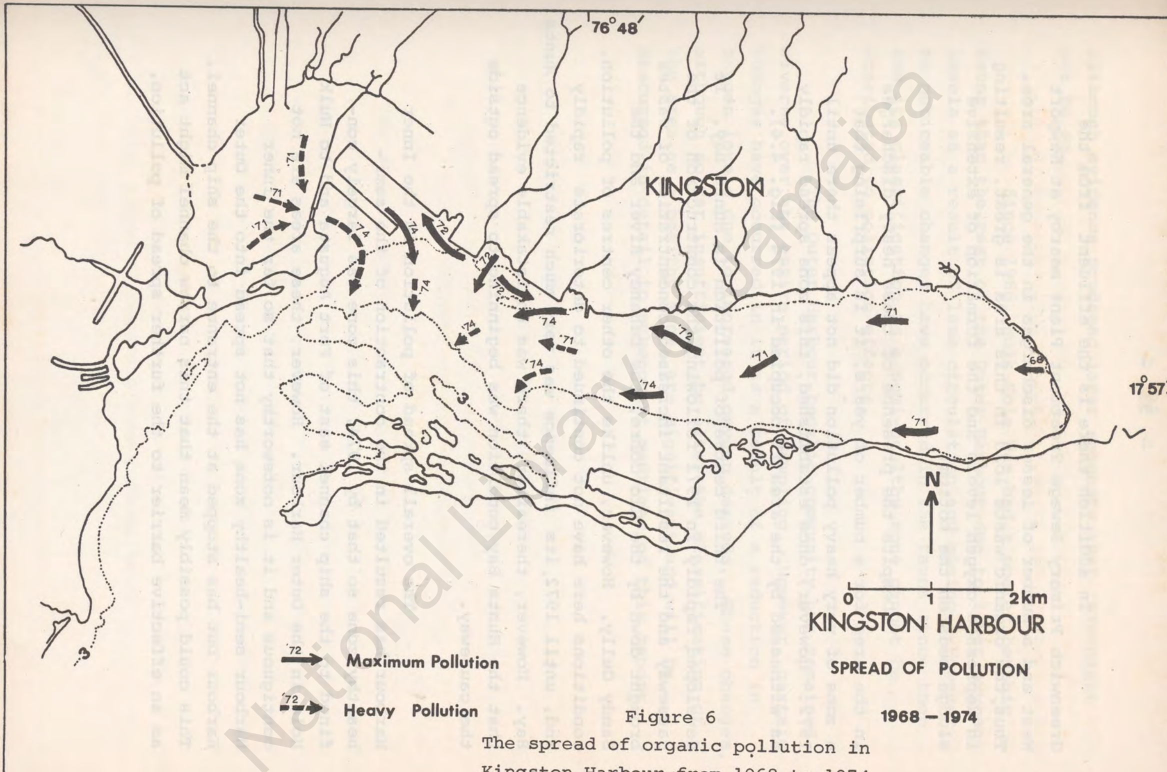


Figure 6
The spread of organic pollution in Kingston Harbour from 1968 to 1974.

Thus, between 1968 and 1974, two clearly discernible centres of very heavy pollution could be observed spreading their influence over the harbour. Similarly, beginning in 1971, a zone of less heavy pollution developed in Hunts Bay. Between 1971 and 1974, this too could be observed extending its effect out of Hunts Bay and into the shipping area.

The appearance and spread of these centres of pollution are illustrated in Figure 6 and the reasons for them are discussed below.

The eastern end of the Inner Harbour has been marked by heavy organic build-up both in the water column and in the sediments. However, this cannot be attributed to a single point source but to the fact that this section of the harbour has acted as a sink for both natural and man-made organic discharges over the years. Thus, under normal conditions and aided by poor tidal circulation and mixing, the oxygen demand exerted by the water and sediments is sufficiently great to cause oxygen depletion at the bottom. Furthermore, due to increasing nutrient levels, the water has become steadily eutrophic and,during plankton blooms, the water column becomes completely anoxic (Wade, 1976). As these conditions have worsened, the area affected has grown with the result that since 1968 this zone of heavy pollution has spread westward to cover the entire eastern end of the Inner Harbour. With its spread, the benthos has declined.

The second centre of very heavy pollution is the Newport East area. This area is marked by heavy organic discharges, as follows:

1) Effluent (3 million gallons a day) from the Western Primary Sewage Treatment Plant;
2) All the untreated wastes and washings from a nearby soap and detergent factory;
3) All the liquid wastes from the city abbattoir; and
4) Various gully discharges.

In addition there is the effluent from the Greenwich Primary Sewage Treatment Plant nearby at Newport West and a number of lesser discharges in the general area. Thus, the organic waste load in this area is great, resulting in depressed oxygen levels and the formation of extensive sludge beds on the bottom.

Despite the presence of these heavy discharges in the area for a number of years, it is surprising that a zone of very heavy pollution did not appear there until 1972. However, once established, this zone spread rapidly as witnessed by the area it occupied in 1974 (Fig. 4.4).

The third centre of pollution is Hunts Bay. It developed rapidly in 1971 following the construction of the causeway and the resultant increased concentration of wastes brought down by the Rio Cobre, the Duhaney River and the Sandy Gully. However, unlike the other centres of pollution, conditions here have not continued to deteriorate rapidly and, until 1972, its influence was very much restricted to Hunts Bay. However, thereafter, there was unmistakable evidence that the Hunts Bay condition was beginning to spread outside the causeway.

The overall spread of pollution in the Inner Harbour has resulted in the contraction of the semi-healthy zone so that by 1974, this zone was largely confined to the ship channel east of Fort Augusta and to Hulk Hole in the Outer Harbour. However, these areas are not contiguous and it is noteworthy that so far the Inner Harbour semi-healthy zone has not spread into the Outer Harbour but has stopped at the entrance to the ship channel. This could possibly mean that this narrow channel might act as an effective barrier to the further spread of pollution, although evidence produced later suggests that this might not be so.

Since 1968, Hulk Hole has had a poorer benthic fauna than the rest of the Outer Harbour due to lower oxygen levels as a result of less circulation and mixing. However, no noticeable changes have occurred in the fauna since then and its classification as a semi-healthy zone cannot be attributed to pollution effects.

The Outer Harbour benthic community has remained diverse over the entire period of sampling. However, certain changes have occurred in it as a result of a reduction in oxygen levels due to increased oxygen demands. These changes, although so far insufficient to alter the classification of the area as a healthy zone, are significant and will be discussed in detail in subsequent sections of this report.

6. EFFECT ON POPULATIONS

Regular sampling of the benthos in Kingston Harbour (Appendices 1, 2 & 3) has provided the opportunity to observe the changes in distribution and density of several species as pollution has spread, and hence to determine the effect that pollution has had on them. In so doing, a number of clearly observable trends have emerged which are described below. These help us not only to understand the nature of the changes which have been taking place in Kingston Harbour, but also to predict what future changes might occur and how they may be recognised with only limited sampling.

In identifying and describing the pattern of effects on populations of individual species, certain criteria for choosing the species have been used. These are:

1) The species must be clearly recognisable and distinct from any other, even though their specific names might not be known;
2) The species must have occurred over the entire period of sampling, i.e. from 1968 to 1974; and
3) The species must be found in sufficient numbers to provide credible data.

Based on these criteria, twelve species have been chosen for description. However, seventeen others of more doubtful status are also mentioned. These together comprise nearly 15% of all the species which were found in Kingston Harbour. They are grouped and discussed below into those found in the polluted zone and those found in the semi-healthy and healty zones.

6.1 Species found in the polluted zone.

Three species were characteristically found in

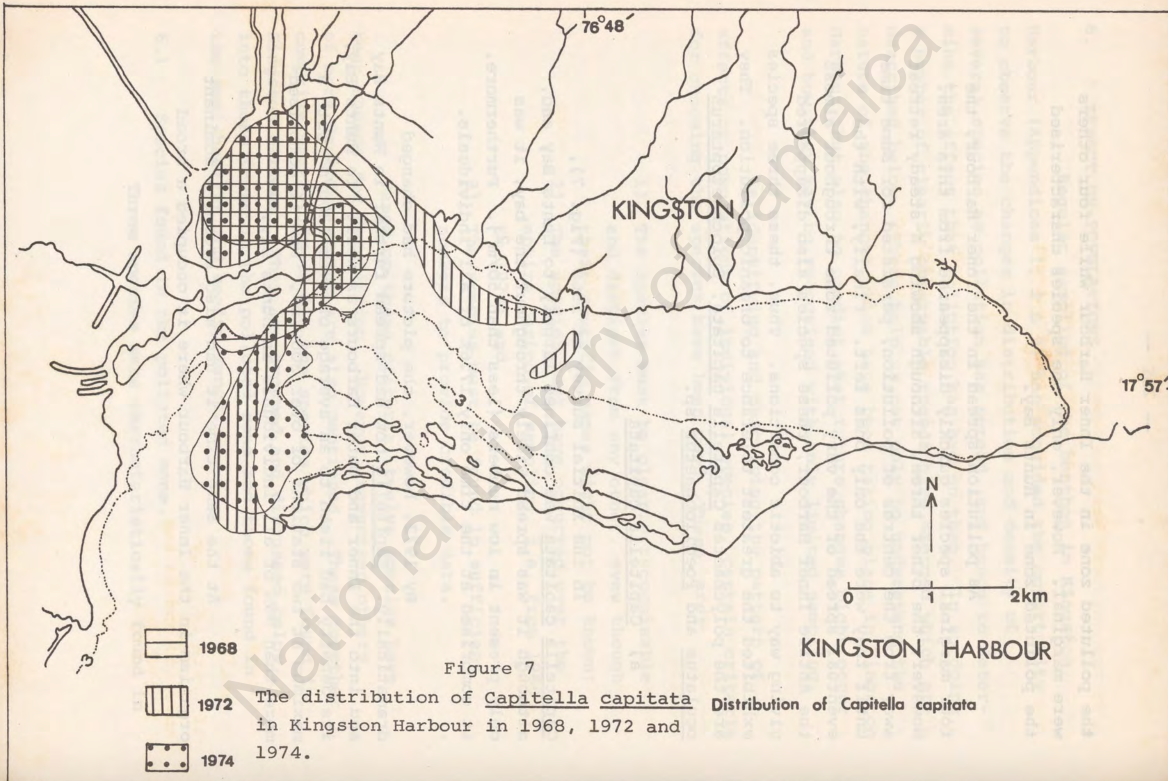


Figure 7

The distribution of _Capitella_ _capitata_ in Kingston Harbour in 1968, 1972 and 1974.

the polluted zone in the Inner Harbour while four others were marginal. However, only one species characterised the polluted zone in Hunts Bay.

As pollution spread in the Inner Harbour, the four marginal species quickly disappeared from this area. However, the other three, although showing a steady retreat away from the centres of pollution, persisted for some time until they were the only ones left. Finally, with the eventual spread of the very polluted zone throughout almost the entire Inner Harbour, these species also disappeared giving way to abiotic conditions. Thus, these three species exhibited the greatest tolerance to organic pollution. They are the polychaetes <u>Capitella capitata</u>, <u>Spiochaetopterus oculatus</u> and <u>Poecilochaetus</u> sp.

a) <u>Capitella capitata</u>

In the initial survey of 1968 (Fig. 7), <u>Capitella capitata</u> was confined largely to Hunts Bay and, although it was spread widely throughout the bay, it was only present in low numbers (less than $50/m^2$). Furthermore, it comprised at the time only 17.6% of all individuals.

By 1972, however, the picture had changed dramatically. <u>Capitella</u> now had spread further in Hunts Bay and into the Inner and Outer Harbours as well. In Hunts Bay, its density had risen to an average of over $1200/m^2$ with a maximum at two stations of over $3000/m^2$. Now it comprised more than 98% of all individuals in Hunts Bay.

At the same time it had also become a dominant organism in the Inner Harbour where it occupied a broad area from Newport West to Newport East and a smaller area east of there. Densities were not more than $350/m^2$ and were greatest near to the Western Treatment Plant sewage outfall.

Extending out of Hunts Bay and into the Outer Harbour was also a narrow band of C.capitata. Although its numbers in the Outer Harbour were very low and the distribution restricted, this marked the first real penetration of the species into the main body of the Outer Harbour.

By 1974, C. capitata had disappeared from the Inner Harbour except for the restricted area of the ship channel, and its distribution and density in the Outer Harbour had increased slightly. In Hunts Bay, however, although it continued to be found throughout the bay, its distribution had become patchy while its maximum density in one area had risen to more than $6500/m^2$. Furthermore, more species had increased and C. capitata now accounted for only 47.2% of all the animals. Thus, there was the suggestion that overall in Hunts Bay, this species had probably reached a peak and was beginning to decline.

Grassle and Grassle (1974) have described the life history of C. capitata and discussed its importance as an indicator of pollution. According to them, C. capitata is present in low numbers in normal estuarine areas. As the environment becomes disturbed by pollution, however, populations of other species become reduced and C. capitata achieves large population sizes, becoming the dominant organisms. However, if the pollution is not too severe or if there is recovery from it, other species will eventually move in, and as the competition increases, the population of C. capitata will decline or disappear.

In many respects, this seems to be what has happened in Hunts Bay as, with the construction of the causeway in 1969 , a new situation developed in which there was a sudden deterioration in oxygen conditions. After some time, however, as the rate of deterioration slowed, less opportunistic species became adjusted to the conditions and C. capitella began to decline. Thus,it no longer had the same high dominance as before (Appendix 3).

This sequence of events does not mean that C. capitata will necessarily disappear from Hunts Bay or that it will never have the same degree of dominance again for, if conditions continue to deteriorate, then the other less tolerant species will eventually disappear and C. capitata may once more take over. Following that, if pollution continues to get worse, C. capitella itself may not be able to survive and the area will become abiotic. Indeed, this is what has happened in the Inner Harbour where, following the rather sudden appearance of C. capitata in 1972, there was an equally rapid disappearance and the creation of a dead area as conditions became intolerable.

Hence, C. capitata in Kingston Harbour has responded in the classical manner to organic pollution and its validity as an indicator organism in this area can therefore be catalogued with the many other cases throughout the world in which it has been recognised and utilised as such (Reish, 1972; Grassle and Grassle, 1974).

b) Spiochaetopterus oculatus

Since 1968, this species has always been found

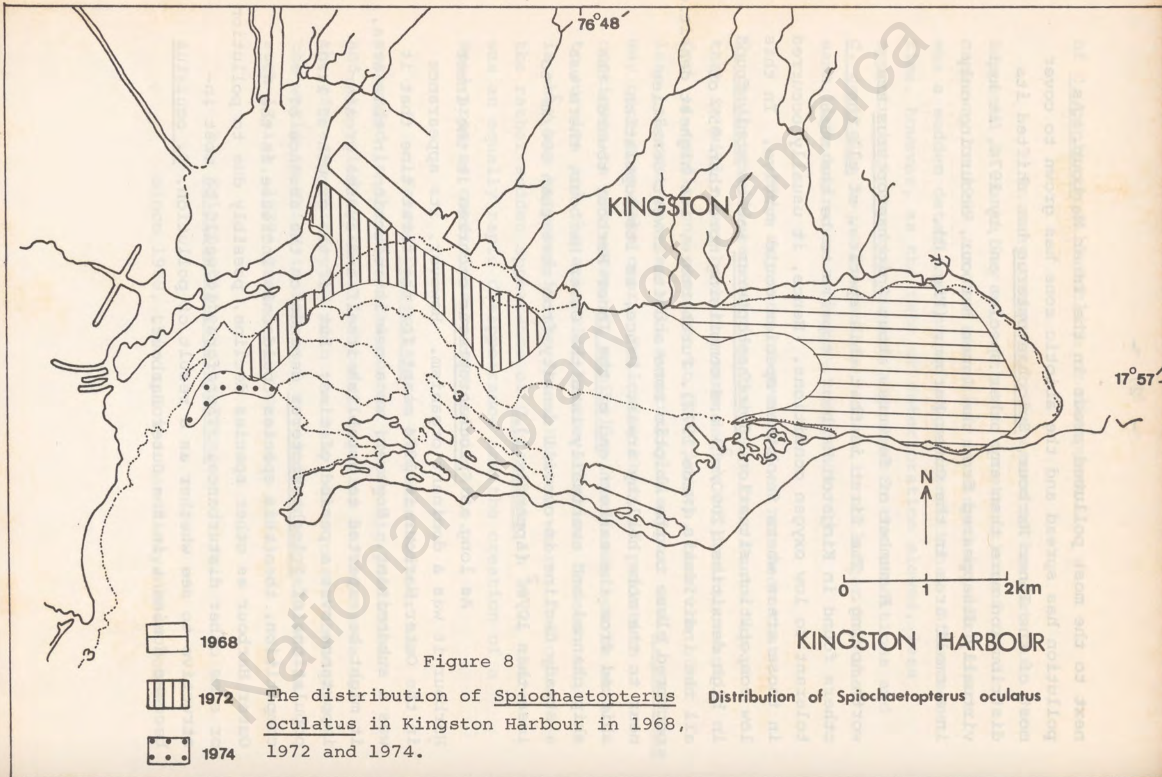


Figure 8

The distribution of <u>Spiochaetopterus oculatus</u> in Kingston Harbour in 1968, 1972 and 1974.

next to the most polluted areas in the Inner Harbour. As pollution has spread and the abiotic zone has grown to cover most of the Inner Harbour, Spiochaetopterus has shifted its distribution more than any other species and,by 1974, it had virtually disappeared from the Inner Harbour, occurring only in a small area in the Outer Harbour (Fig. 8).

A number of features about Spiochaetopterus are worth noting. The first is that this species, of all the others found in Kingston Harbour, appears to be the most tolerant to low oxygen conditions. Hence, it usually occurred in those areas where few other species could survive. In this low competition situation, Spiochaetopterus was commonly found in high densities ($2000/m^2$) and comprising more than 95% of all the individuals (Wade,1972). Furthermore, its highest densities occurred close to the abiotic zone and its lowest densities near to the more healthy areas. Hence, as its population shifted from the eastern end of the Inner Harbour towards the ship channel and eventually into the Outer Harbour, there was a steady decline in overall density from more than $500/m^2$ to less than $10/m^2$ (Appendix 1).

As long as Spiochaetopterus occurred in the Inner Harbour it was a dominant organism. However, its appearance in the Outer Harbour in 1974 meant for the first time that it was a subdominant. However, as a new introduction in this area, it might be expected to establish itself and assume greater importance over a period of time; but if the growth of large populations of Spiochaetopterus depends on the absence of competition, then this species could only increase in the Outer Harbour as other species decline, possibly due to pollution or some other disturbance. Therefore, it would be most instructive to see whether as a result of pollution, S. oculatus becomes dominant in the Outer Harbour.

It is significant that Spiochaetopterus did not occur in Hunts Bay at any time, but the reason for this is not clear. A possible explanation is that this species is unable to tolerate salinity fluctuations, but this suggestion is weakened by the fact that in Biscayne Bay, it occurs where the average salinity is only 27.5 parts per thousand (McNulty, 1961).

Unlike Capitella capitata, S. oculatus is not known as a universal indicator of pollution although McNulty (1961) found it to occur in that part of Biscayne Bay which was affected by sewage pollution. Furthermore, he found that this species only occurred within a narrow range of coliform values (log M.P.N. 3.5 - 5.1) representing fairly high to very high pollution, and hence was a useful indicator organism.

Very little is known about the life history of S. oculatus and it cannot therefore be safely categorised as an opportunistic species according to the criteria of Grassle and Grassle (1974). Instead, it may well be that S. oculatus is a specialist species establishing itself in great numbers only where its own ideal conditions exist; in this case low oxygen conditions. Hence, its status is unclear and more work needs to be done with it. Nevertheless, it has been well established that in Kingston Harbour, S. oculatus for one reason or another is associated with organic pollution and that in this respect, it is similar to Capitella capitata with which it coexisted for some time in the Inner Harbour.

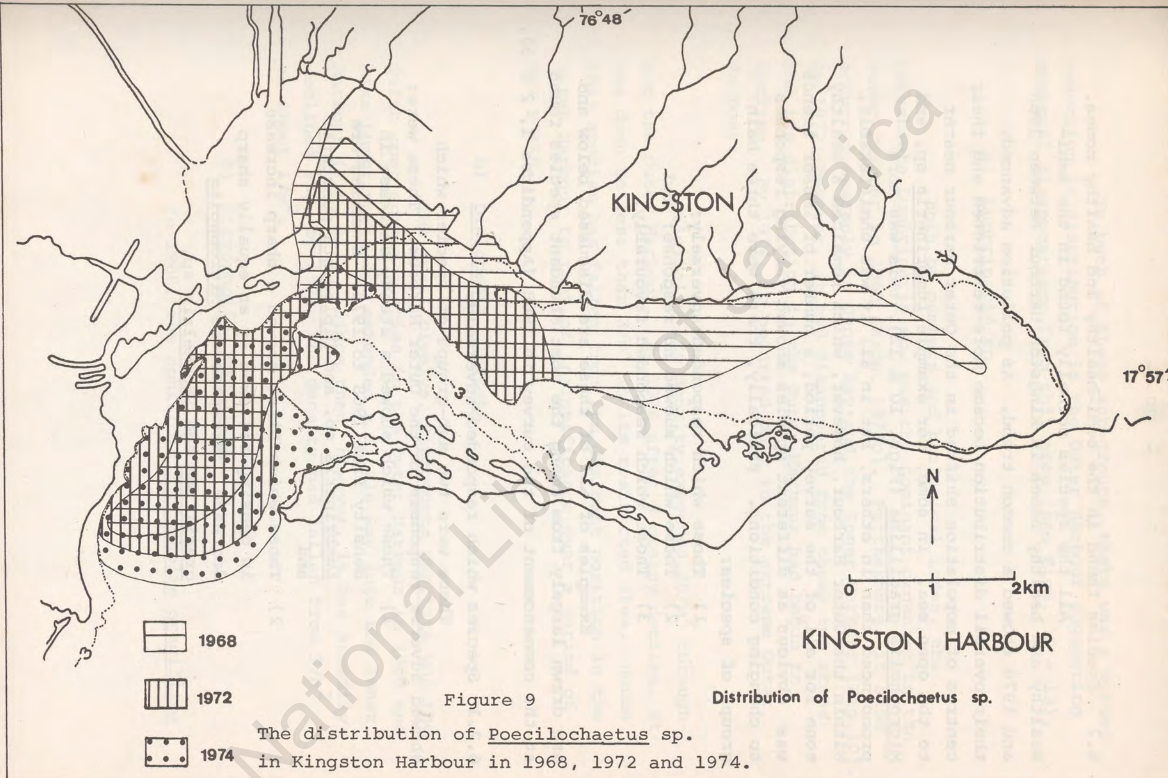


Figure 9

The distribution of <u>Poecilochaetus</u> sp.
in Kingston Harbour in 1968, 1972 and 1974.

c) Poecilochaetus sp.

This polychaete species is outstanding in its ability to tolerate a wide range of conditions. Thus, in 1968, it occurred throughout all sections of the harbour extending from the polluted zone to the healthy zone. The only place where its distribution was restricted was in the inner parts of Hunts Bay (Fig. 9).

From 1968 to 1974, the distribution of Poecilochaetus sp. always overlapped that of Spiochaetopterus oculatus, but differed in that it was more widespread. However, unlike S. oculatus, Poecilochaetus sp. did not achieve the same high densities in the polluted zone. Instead, its highest densities were commonly in the semi-healthy zone where it reached a maximum of $1130/m^2$.

Thus, Poecilochaetus sp. does not seem to favour polluted conditions but is able to tolerate them and, in 1972, together with Capitella capitata and Spiochaetopterus oculatus, it comprised the three dominant organisms in the polluted Inner Harbour. However, as conditions continued to get worse between 1972 and 1974, Poecilochaetus sp. also virtually disappeared from the Inner Harbour.

The fact that this species occurs over such a wide range of conditions does not make its presence a particularly good indication of heavy pollution and, in fact, nowhere in the literature does this species seem to have been associated with a polluted environment. However, as we shall see later on, Poecilochaetus sp. does seem to respond to a fertiliser effect from organic pollution, and the size and growth of its populations may therefore tell us much about the encroachment and spread of deteriorating conditions.

6.2 Species found in the semi-healthy and healthy zones.

All the species normally found in the semi-healthy and healthy zones in Kingston Harbour between 1968 and 1974 showed a common trend. As pollution advanced, their overall distribution became more restricted and their centres of population shifted in the Outer Harbour nearer to the open sea. In some, for example Lumbrineris sp. and Micropholis gracillima (Figs. 10 & 12), this was more pronounced than in others, but in all it was unmistakable. Within the Outer Harbour, however, which remained a healthy zone for all of the survey period, a number of lesser trends was obvious as different species showed varying responses to changing conditions. Basically, there were three main groups of species:

1) Those which responded adversely;
2) Those which showed no response; and
3) Those which responded favourably.

Examples of all of these are discussed below and are drawn largely from among the most abundant species found at the commencement of the survey in 1968 (Appendices 1, 2 & 3).

6.2.1 Species which responded adversely.

There were two sub-groups of species which showed adverse responses in the Outer Harbour. These were:

1) Those which showed a steady decrease in density from 1968 to 1974. Examples are Lumbrineris sp. and Diplodonta punctata; and
2) Those which first showed a sharp increase in density followed by an equally sharp decrease. Examples are Micropholis gracillima and Sthenelais sp.

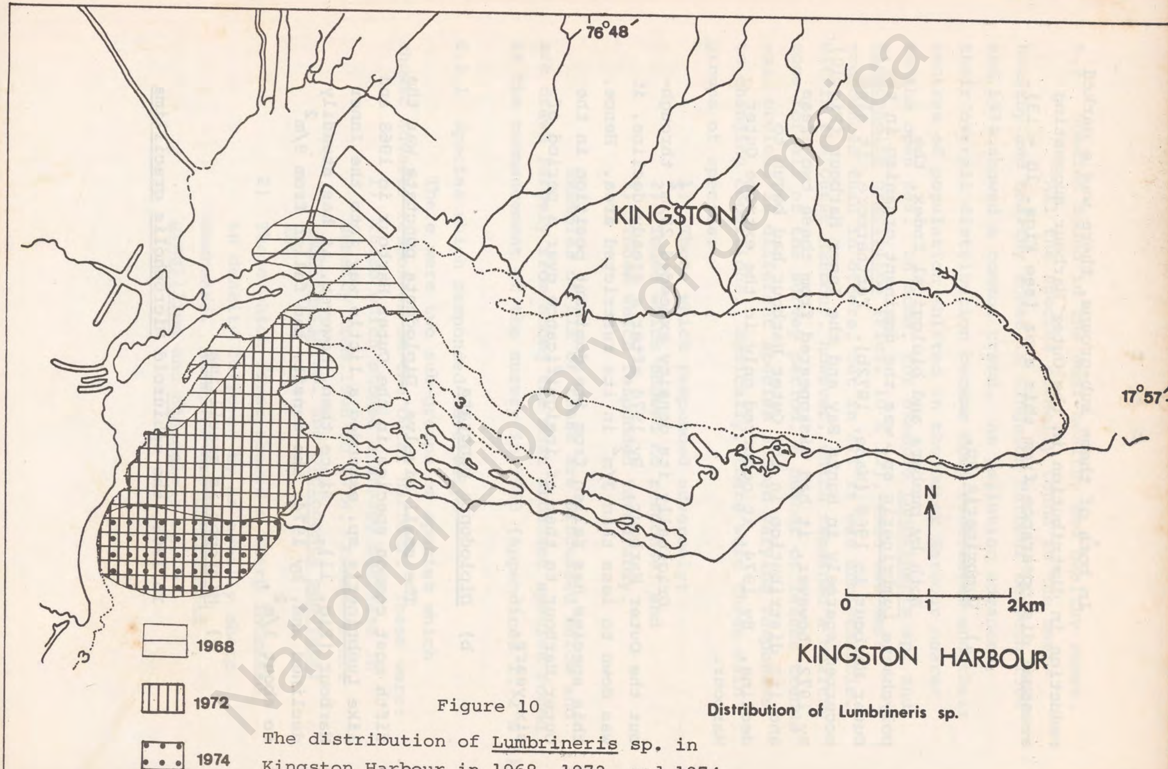


Figure 10

The distribution of <u>Lumbrineris</u> sp. in Kingston Harbour in 1968, 1972, and 1974.

In both of these sub-groups, there was a marked reduction in distribution in the Outer Harbour suggesting eventual disappearance from this area (see Figs. 10 - 13).

a) Lumbrineris sp.

Both by numbers and biological index, the polychaete Lumbrineris sp. was the dominant organism in the Outer Harbour in 1968 (Wade, 1972b). Furthermore, it also occurred sparsely in Hunts Bay and the Inner Harbour (Fig.10). By 1972, however, it had disappeared from these two areas and its distribution in the Outer Harbour had begun to decline. By 1974, it occurred only in the extreme Outer Harbour.

Originally its density exceeded $20/m^2$ throughout the Outer Harbour. By 1974 after a steady decline, it was down to less than $3/m^2$ in its restricted area. Hence, this species has fallen from its dominant position in the Outer Harbour to that of insignificance over a period of six years.

b) Diplodonta punctata

The small bivalve, Diplodonta punctata was the fifth most common species in the Outer Harbour in 1968 and like Lumbrineris sp. extended a little way into the Inner Harbour (Fig. 11). Since then, however, it has steadily declined and, by 1974, the density had fallen from $9/m^2$ to about $1/m^2$.

c) Micropholis gracillima

In 1968, the ophiuroid Micropholis gracillima

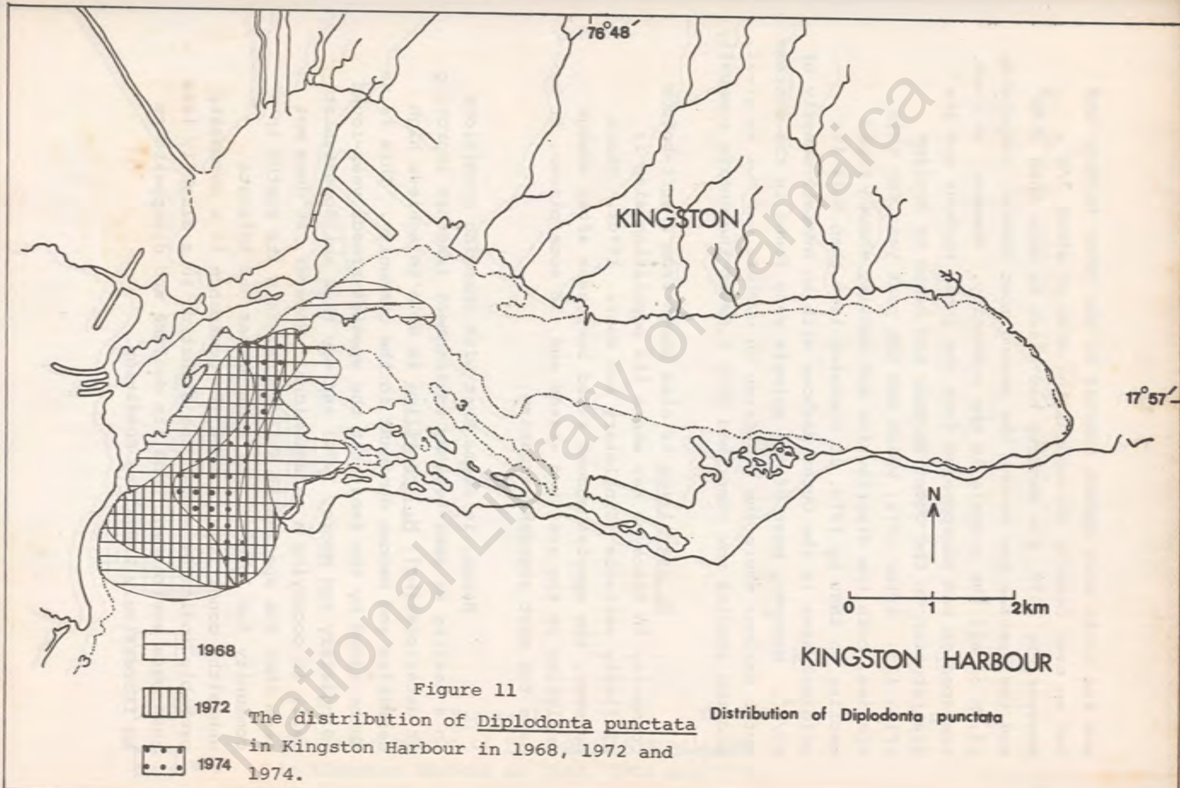


Figure 11
The distribution of _Diplodonta_ _punctata_ in Kingston Harbour in 1968, 1972 and 1974.

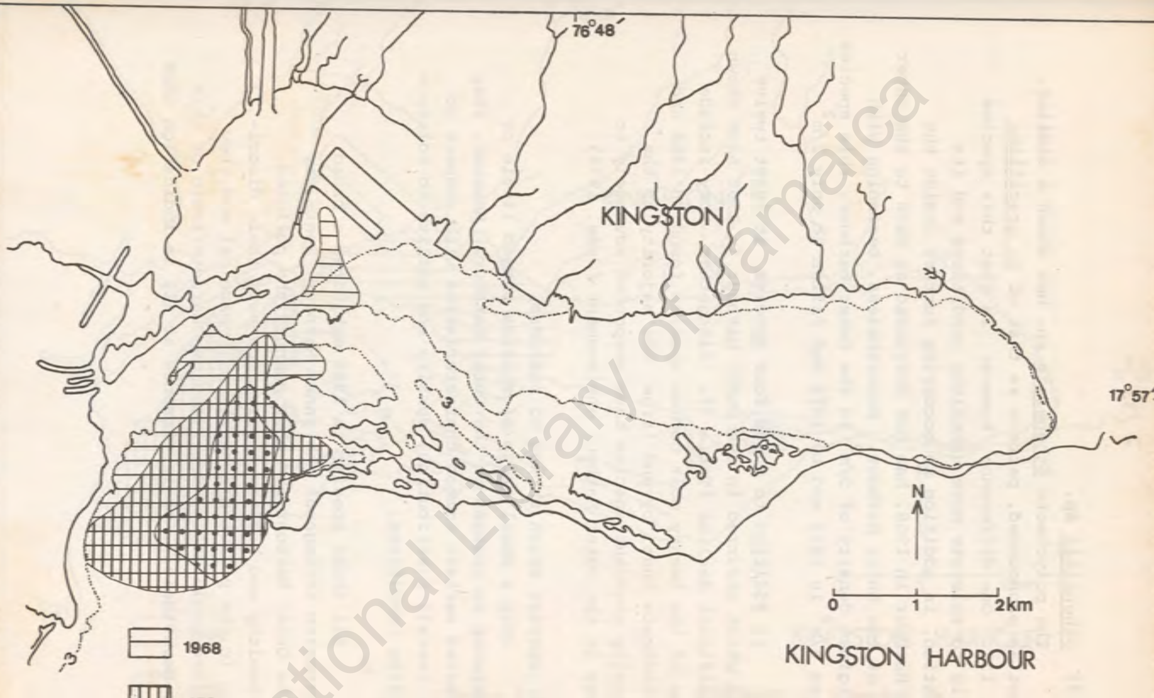


Figure 12

The distribution of Micropholis gracillima in Kingston Harbour in 1968, 1972 and 1974.

was the ninth most common species in the Outer Harbour and had an even density throughout the area of about $7/m^2$. However, by 1972, the density had risen to more than $30/m^2$ and the species had become the second most common, comprising 12.2% of all the animals in the community. However, by then, the species had disappeared from the Inner Harbour and its distribution in the Outer Harbour had begun to decline (Fig. 12). After 1972, which was the peak year for this species, both the distribution and density showed rapid decline so that by 1974, it occupied less than half its original area in the Outer Harbour with an overall density of $10/m^2$. However, most of the animals were found in the extreme Outer Harbour where the reduction in numbers was not as great, and the species now comprised only 2.6% of the entire community.

M. gracillima is also known from a soft-bottom community in Biscayne Bay where its population size is similarly variable (Singletary and Moore, 1974). There, however, the species showed rapid increases after sewage pollution in the area had abated and, in some places, it became the most abundant organism.

Hence, it seems that with changing conditions in a healthy or semi-healthy environment (whether improving or deteriorating), M. gracillima is able to achieve high densities and become dominant in the community. This is no doubt aided by the fact that the species breeds year-round (Singletary and Moore, 1974) and may thus act opportunistically in occupying a vacant niche. However, it does not seem that the species is able to maintain its status in a community for long or, for that matter, to tolerate unhealthy conditions. Hence, its dominance in a community probably indicates a changing situation in a slightly less than pure environment, and its decline and disappearance an increasingly unhealthy condition.

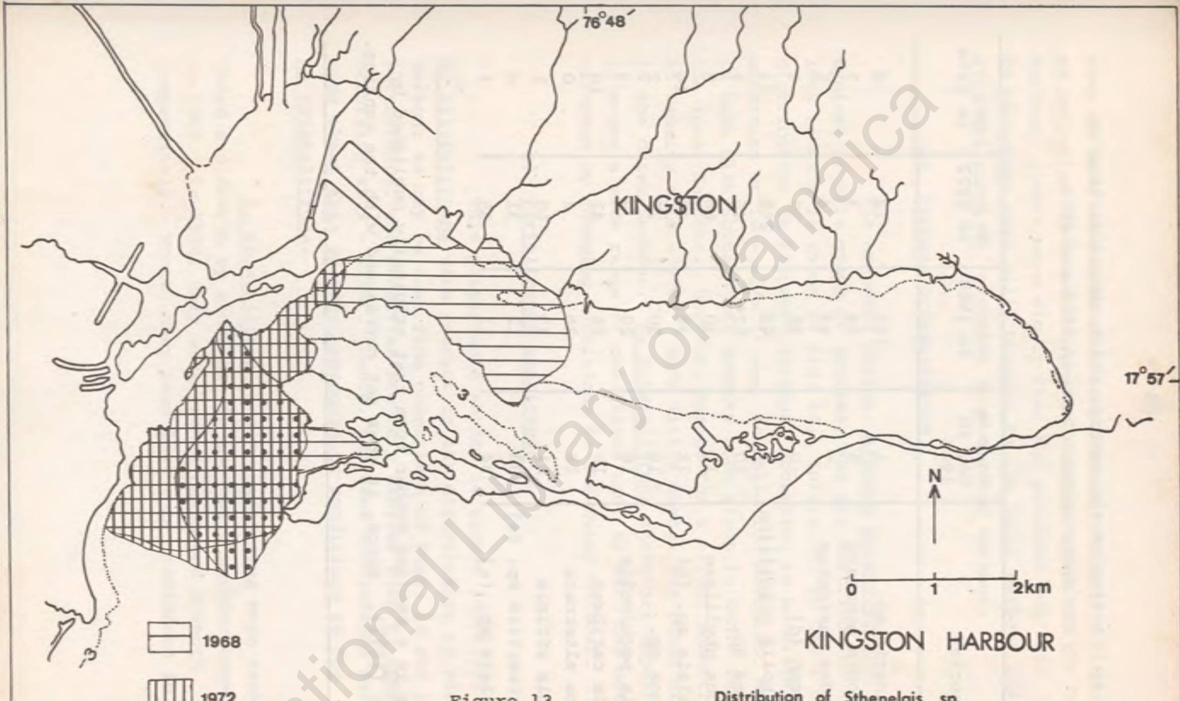


Figure 13

The distribution of Sthenelais sp. in Kingston Harbour in 1968, 1972 and 1974.

d) Sthenelais sp.

The polychaete Sthenelais sp. has shown a similar, but not as pronounced, pattern as that of M. gracillima (Fig. 13). One difference, however, is that this species is able to tolerate more unhealthy conditions and its population, in addition to occurring further inside the Inner Harbour in 1968, has not retreated as much to the outer parts of the Outer Harbour. Nevertheless, beginning with an original density of $5/m^2$ in the Outer Harbour, this species rose to $8/m^2$ in 1972 and by 1974 had fallen to only $2/m^2$.

In addition to these four species, at least twelve others which occurred in the Outer Harbour in 1968 have shown a significant decline (Table 3). Altogether, they include twelve of the twenty most common species found in 1968 and thus indicate that, by and large, the majority of the originally abundant species have responded adversely to changes in the Outer Harbour environment (Wade, 1976).

6.2.2 Species which showed no response.

Only a small group of species showed little or no response to changes in the Outer Harbour. However, they all shared certain common characteristics with respect to their overall distribution, density and ability to tolerate unhealthy conditions.

All these species in 1968 exhibited a broad distribution throughout the Inner Harbour, Hunts Bay and the Outer Harbour and thus spanned the polluted, semi-healthy and healthy zones. However, their distribution in the polluted zone was only marginal and they therefore could not be described as characteristic of this zone. Nevertheless, their presence at all is indication that

Table 3: A list of the species which showed decline in the Outer Harbour between 1968 and 1974.

Species	Rank by No. in 1968	No. in 1968	No. in 1972	No. in 1974
Lumbrineris sp.	1	135	24	4
Diplodonta punctata	5	54	3	7
Phacoides muricatus	7	47	4	5
Nemertean (d)	8	46	30	3
Micropholis gracillima	9	41	248	49
Apseudes sp.	10	52*	46	9
Magelona phyllisae	10	40	66	8
Sthenelais sp. (b)	12	39	43	14
Hipponoa sp.	15	30	27	2
Codakia pectinella	16	29	9	3
Corbula caribaea	18	26	41	10
Tellina alternata	18	26	2	0
Upogebia affinis	21	23	10	1
Ancistrosyllis sp. (a)	33	12	31	4
Sthenelais sp. (a)	34	11	35	7

* This is a revised number from that originally published by Wade (1972). Hence, it does not correspond with the ranking.

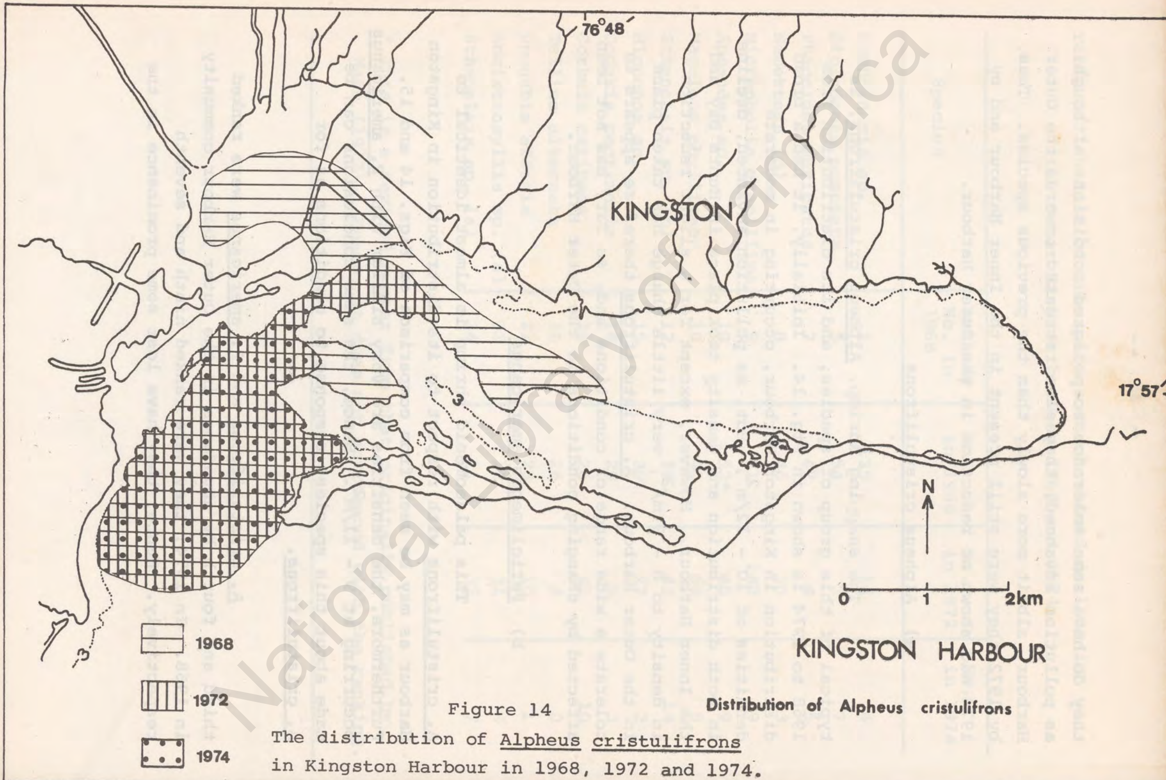


Figure 14

The distribution of Alpheus cristulifrons in Kingston Harbour in 1968, 1972 and 1974.

they do have some tolerance to polluted conditions although, as pollution advanced, they also retreated towards the Outer Harbour, albeit more slowly than the previous species. Thus, by 1972, they were still present in the Inner Harbour and by 1974 had shown no reduction in the Outer Harbour.

a) Alpheus cristulifrons

The snapping shrimp, Alpheus cristulifrons, is typical of this group of species, and its distribution from 1968 to 1974 is shown in Fig. 14. Initially, it had a broad distribution in Kingston Harbour, occurring in moderate densities of 10 - 12/m^2. But, as pollution advanced, decline in both distribution and density took place in Hunts Bay and the Inner Harbour. However, except for a slight reduction in density to 8 - 9 m/^{2}, very little change has taken place in the Outer Harbour. A. cristulifrons therefore appears to tolerate a wide range of conditions and, so far, has not been affected by changing conditions in the Outer Harbour.

b) Periclimenes americanus

This palaeomonid shrimp is almost identical to A. cristulifrons with respect to its distribution in Kingston Harbour as may be seen from comparison of Figs. 14 and 15. Furthermore, the densities are very similar with P. americanus occurring at 9 - 11/m^2. Hence, the same conclusions can be made about this species' response to conditions as for A. cristulifrons.

A. cristulifrons and P. americanus were ranked third and fourth by abundance in the Outer Harbour community in 1968. In 1974, they were ranked ninth and seventh respectively. Hence, they have lost some prominence in the

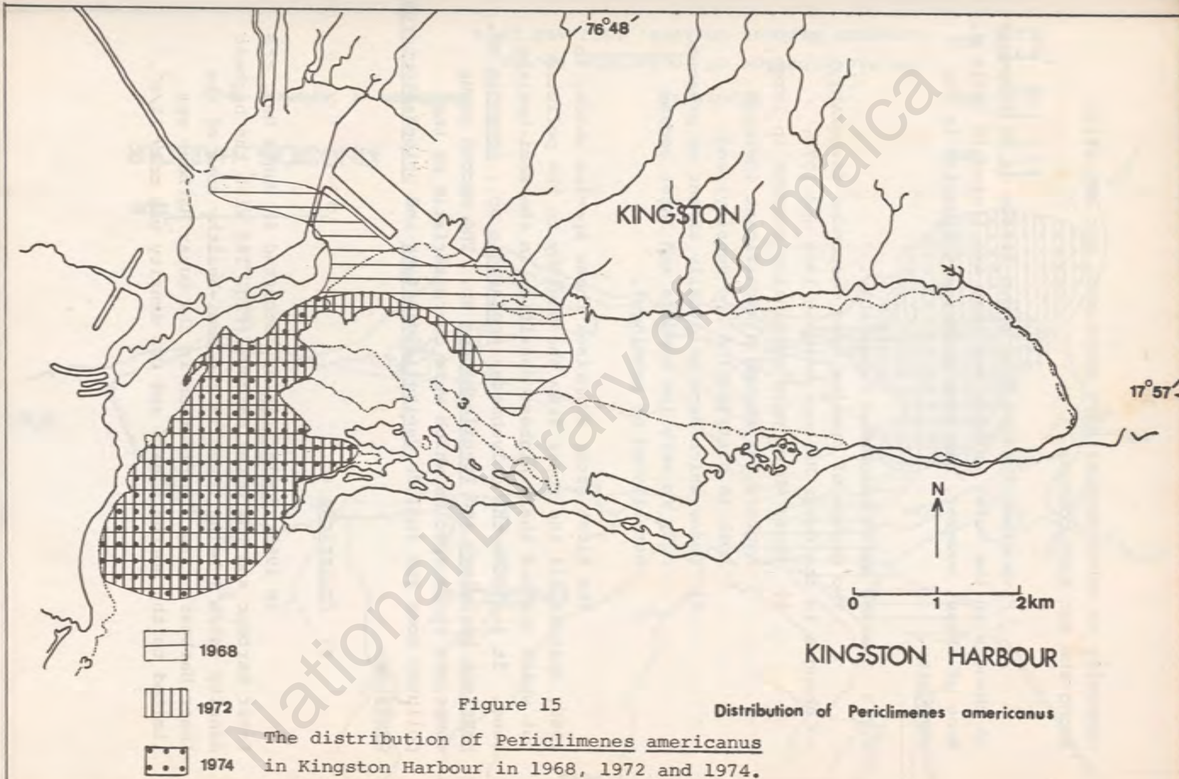


Figure 15
The distribution of Periclimenes americanus in Kingston Harbour in 1968, 1972 and 1974.

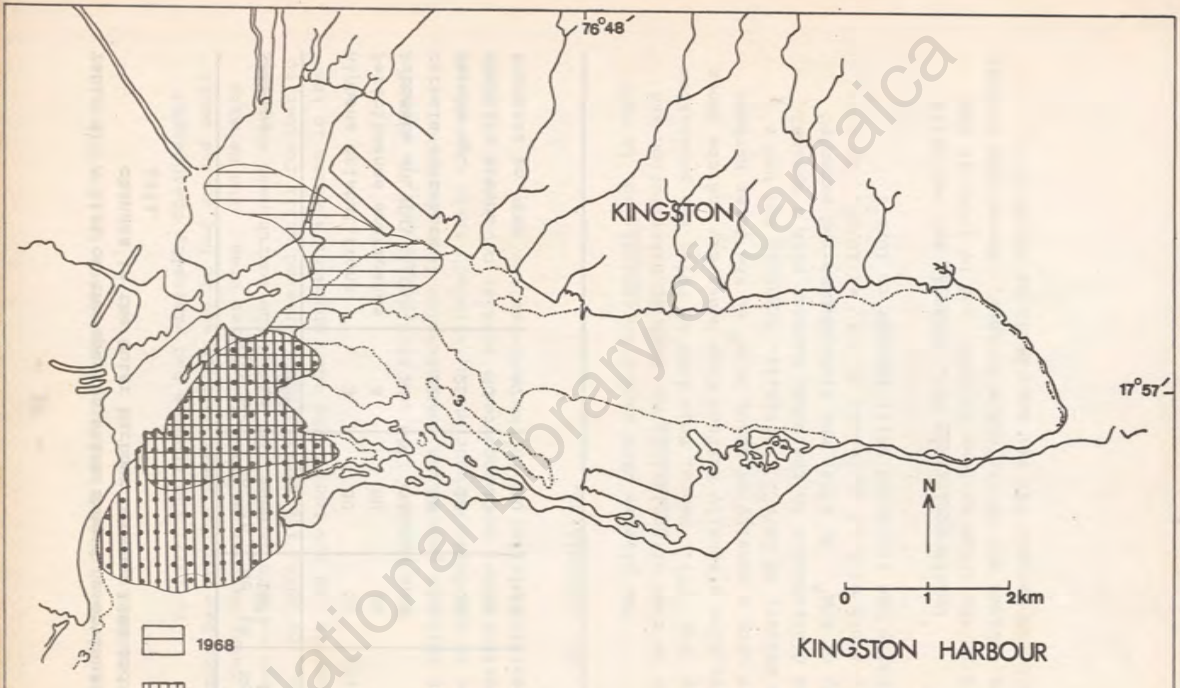


Figure 16

The distribution of Scolaricia sp. in Kingston Harbour in 1968, 1972 and 1974.

community as other species have increased, but are still among the ten most common.

Five other species have shown little or no response to changes in the Outer Harbour and they are listed in Table 4. None of these, however, has been a dominant organism in the community.

6.2.3 Species which responded favourably.

Two groups of species have responded favourably to changes in the Outer Harbour between 1968 and 1974:

1) Those which were originally present in large numbers but showed a significant increase both in distribution and density; and
2) Those which were originally absent or present only in very low numbers and later became established or prominent.

The first group comprises those species which, in 1968, spanned all the zones from the healthy to the polluted but which reached their highest densities in the semi-healthy zone. It includes the polychaetes Scolaricia sp., Armandia sp., Magelona berkeleyi and Poecilochaetus sp. The second group comprises those species which were characteristic of the polluted zone and include Capitella capitata and Spiochaetopterus oculatus.

a) Scolaricia sp.

In 1968, Scolaricia sp. occurred in Hunts Bay, the Inner Harbour and the Outer Harbour (Fig. 16) with the highest density ($40/m^2$) being found in the semi-healthy zone of the Inner Harbour. Its distribution in the Outer Harbour was limited to the northern half and its density was only $11/m^2$.

Table 4: A list of the species which showed no obvious changes in the Outer Harbour between 1968 and 1974.

Species	Rank by No. in 1968	No. in 1968	No. in 1972	No. in 1974
Alpheus cristulifrons	3	80	52	53
Periclimenes americanus	4	60	25	71
Automate sp. (a)	14	34	5	37
Corbula contracta	22	19	16	15
Nereis sp.	25	18	22	28
Mitrella nitens	30	13	23	7
Processa sp. (b)	37	10	34	20

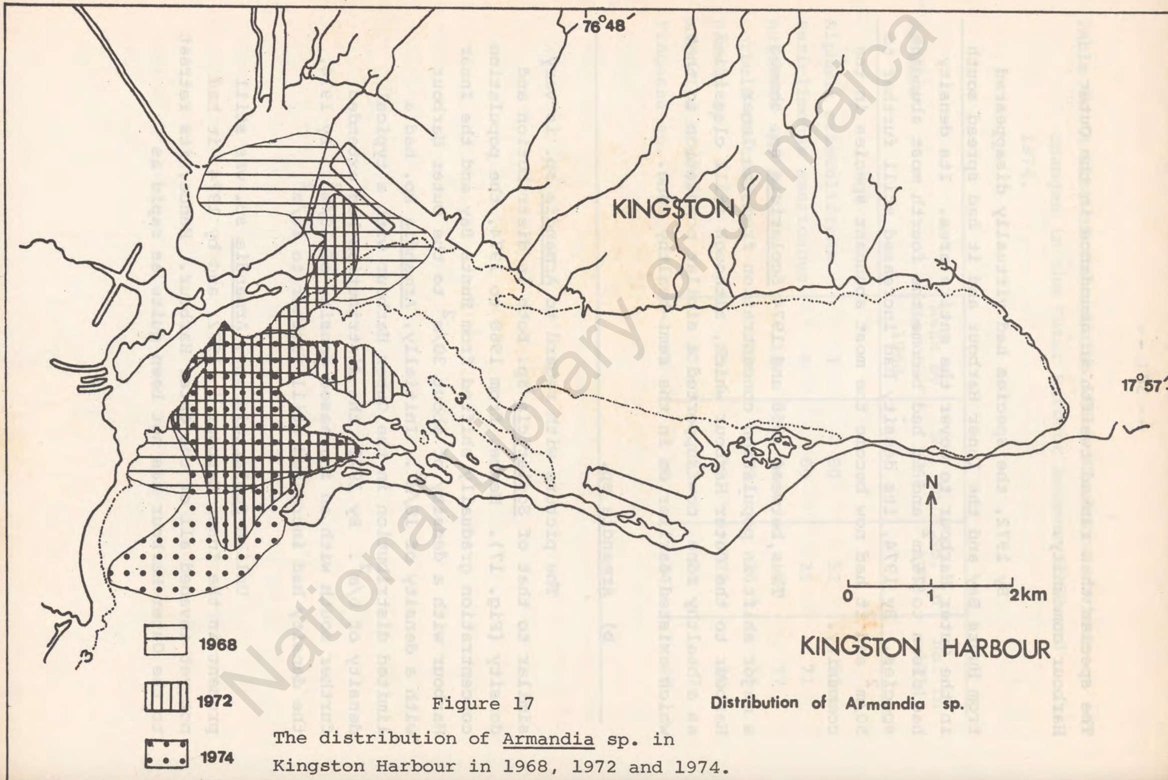


Figure 17

The distribution of <u>Armandia</u> sp. in Kingston Harbour in 1968, 1972 and 1974.

The species then ranked twelfth in abundance in the Outer Harbour community.

By 1972, the species had virtually disappeared from Hunts Bay and the Inner Harbour and it had spread south in the Outer Harbour to cover the entire area. Its density had risen to $26/m^2$ and it had become the fourth most abundant species. By 1974, its density had increased still further to $50/m^2$ and it had now become the most abundant species in the community.

Thus, between 1968 and 1974, Scolaricia sp. showed a major shift in population concentration from the Inner Harbour to the Outer Harbour which, although still classified as a healthy zone, now supported a similar population to that which existed earlier on in the semi-healthy zone.

b) Armandia sp.

The picture with regard to Armandia sp. is very similar to that of Scolaricia sp. both in distribution and density (Fig. 17). Hence, from 1968 to 1974, the population concentration gradually shifted from Hunts Bay and the Inner Harbour with a density of about $30/m^2$ to the Outer Harbour with a density of $18/m^2$. Initially, Armandia sp. had a limited distribution in the Outer Harbour with a typical density of $6/m^2$. By 1972, the distribution had extended further south with an increased density of $10/m^2$. By 1974, the density had increased still further to $18/m^2$.

Unlike Scolaricia sp., Armandia sp. was still present in the Inner Harbour in 1972, and by 1974, it had not yet invaded all of the Outer Harbour. Hence, its retreat to the Outer Harbour has not been quite as rapid as

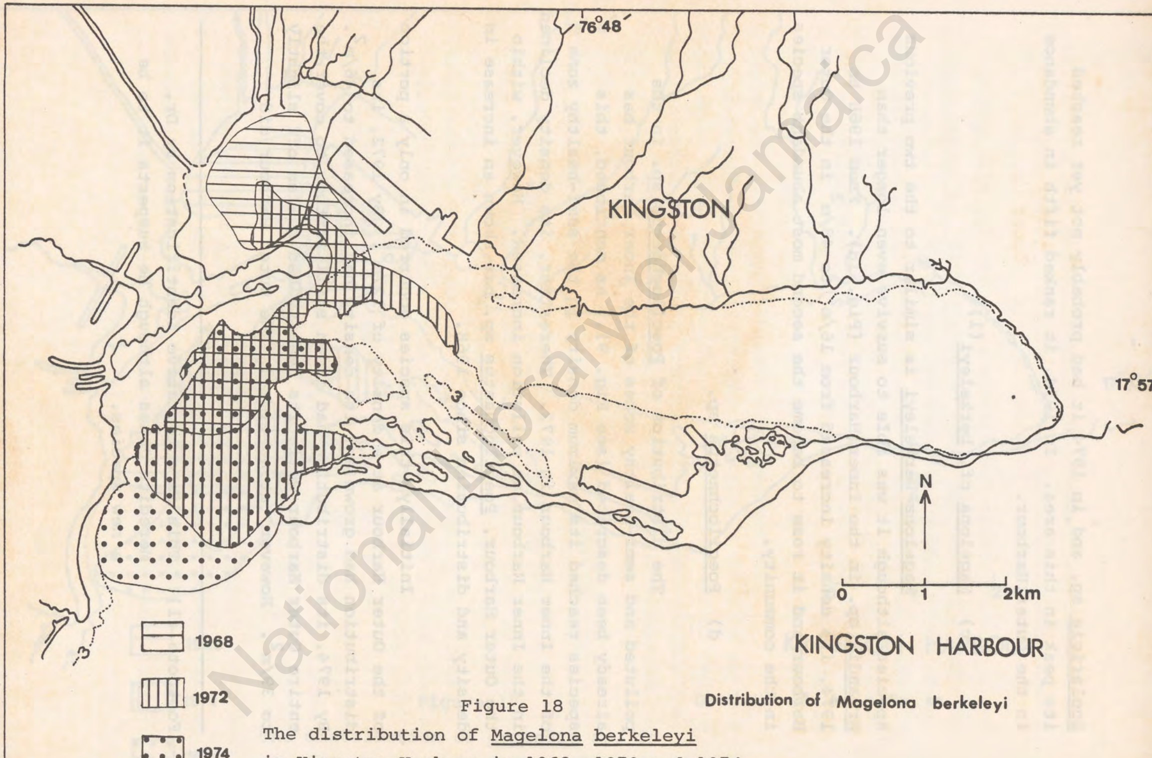


Figure 18
The distribution of Magelona berkeleyi in Kingston Harbour in 1968, 1972 and 1974.

Scolaricia sp. and, in 1974, it had probably not yet reached its peak in this area. In 1974, it ranked fifth in abundance in the Outer Harbour.

c) *Magelona* cf. *berkeleyi*(1)

Magelona berkeleyi is similar to the two previous species although it was able to survive even longer than *Armandia* sp. in the Inner Harbour (Fig. 18). From 1968 to 1974, its density increased from $16/m^2$ to $48/m^2$ in the Outer Harbour and it rose to become the second most abundant species in the community.

d) *Poecilochaetus* sp.

The distribution of *Poecilochaetus* sp. in the polluted and semi-healthy zones of the Inner Harbour has already been described (see Fig. 9). As mentioned, this species reached its maximum density in the semi-healthy zone of the Inner Harbour in 1972. Thereafter, its density declined in the Inner Harbour as pollution increased. However, within the Outer Harbour, *Poecilochaetus* sp. has shown an increase in density and distribution since 1968.

Initially, this species occurred in only a portion of the Outer Harbour at a density of $12/m^2$. By 1972, its distribution had grown and its density had increased to $46/m^2$. By 1974, its distribution had grown still further to cover the entire Outer Harbour while its density had fallen off slightly to $39/m^2$. However, at no time in the Outer Harbour did

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Footnote (1): This is a tentative identification by Dr. Meredith Jones although he suspects it to be a new species.

Poecilochaetus sp. approach the maximum density it attained in the Inner Harbour, and it is therefore likely that this species will continue to increase in the Outer Harbour.

e) Capitella capitata

Capitella capitata has occurred in the Outer Harbour since 1968 (Fig. 7). However, since then, it has become more widespread and its numbers have increased (Table 5). Nevertheless, its density is still very low and it is not prominent in the community.

It will be interesting to see whether this species becomes a dominant organism in the Outer Harbour as a result of further changes in the environment.

f) Spiochaetopterus oculatus

Like C. capitata, this species may be establishing itself in the Outer Harbour. However, its numbers are still very low and its distribution is restricted to a small area near to the ship channel (Fig. 8).

Although the data are still too few to draw any firm conclusions, it is likely that the Outer Harbour environment may be becoming increasingly favourable for the development of a large S. oculatus population.

One species which suddenly established itself throughout the Outer Harbour in 1974 was the polychaete, Cossura sp. However, very little is known of this species in Kingston Harbour since it did not occur in any significant numbers before. Hence, no conclusions can be drawn about its pattern of responses to changing conditions.

A list of the species which showed an increase in the Outer Harbour since 1968 is given in Table 5 together with their numbers and rank in 1968. From this, it can be seen that only four of the twenty most common species in 1968 responded in this way, as against twelve which showed a decrease (Table 3). However in 1974, five of these species were among the seven most common.

6.3 Discussion

The data presented in the preceeding sections show clearly that over the period of surveys from 1968 to 1974 there were significant changes in the benthic populations throughout Kingston Harbour. These changes have been attributed to organic pollution, but what have been the immediate environmental factors causing them? The most obvious one is a reduction in oxygen levels, and Wade (1976) has produced such data. However, these data refer to oxygen levels one metre above the bottom mud, and it is known that there is further reduction at the sediment-water interphase. Hence, the actual oxygen conditions at the level of the benthos are unknown. Similarly, although it has been shown that the greatest reduction in oxygen levels over the past five years has been in the Outer Harbour, the reduction at the sediment-water interphase has quite likely been greater than at one metre above the bottom. Because of these limitations, the oxygen data presented in the earlier parts of this report should only be taken as an indication of the conditions and the degree of changes which the benthos have had to tolerate.

Unfortunately, data on the sediments in the harbour are sparse and it is impossible to describe any changes which might have taken place in them over the survey period. However, from observation and determination of oxygen demand levels, it seems safe to say that the organic content of the sediments has been increasing throughout most of the harbour.

Table 5: A list of the species which showed an increase in the Outer Harbour between 1968 and 1974.

Species	Rank by No. in 1968	No. in 1968	No. in 1972	No. in 1974
Scolaricia sp.	12	39	165	333
Armandia sp.	2	117 (1)	65	116
Magelona berkeleyi	5 (2)	55 (2)	172	319
Poecilochaetus sp.	6	52	292	157
Capitella capitata	-	3	10	30
Spiochaetopterus oculatus	-	1	5	8
Cossura sp.	-	1	0	66

Notes: (1) This number was due largely to a very high density at one station.

(2) Both the number and rank of this species have been revised since Wade (1972b) due to a taxonomic correction.

As this has happened, more and more sediments in the harbour have become anoxic.

One can only speculate on other changes which might have taken place in the immediate environment of the benthos between 1968 and 1974, and the work of various authors (O'Sullivan, 1971; Reish, 1972) can provide a basis for so doing. However, in the absence of proper data, all we can conclude is that certain changes have taken place and the benthos have responded in various ways. All the evidence indicates that these changes have been due to increasing organic pollution.

Because of the varying responses of different species, the structures of the benthic communities in the harbour have undergone changes since their initial description (Wade 1972a). The nature and degree of these changes will be described in the next section of this report; but, for now, we may consider how the major taxa have been affected.

Based on the data in Tables 3, 4 and 5, Table 6 has been prepared to show the responses by the major taxa in the Outer Harbour. It reveals that polychaete and bivalve species responded most to the changes. Six polychaetes declined while seven increased; and five bivalves declined while none increased. Of all groups, the crustaceans showed least response; four species showed no response while two declined. One ophiuroid showed a decline. The overall result of these responses has been the significant reduction of the bivalves as a major component of the Outer Harbour community.

Knowledge of the kinds of responses which certain species show to known environmental conditions is of great

Table 6: The response by major taxa to changes in the Outer Harbour between 1968 and 1974

Response	No. Polychaete Species	No. Bivalve Species	No. Crustacean Species	No. Ophiuroid Species	No. Other Species
Decrease	6	5	2	1	1
None	1	0	4	0	1
Increase	7	0	0	0	0

importance in their designation and use as indicator organisms. Hitherto, only two of the species occurring in Kingston Harbour have been identified as indicator organisms. One is Capitella capitata which is known as a universal indicator of pollution (Reish, 1972; Grassle & Grassle, 1974); the other is Spiochaetopterus oculatus which has previously only been associated with pollution in Biscayne Bay, Florida (McNulty, 1961). However, it is not surprising that more of the species found in Kingston Harbour have not been previously considered since there have been few comparable studies in tropical waters. Hence, it is possible that with more work in these locations, some of these species may become better established in the minds of benthic ecologists as indicator organisms.

With our present knowledge, the following species are being proposed as indicator organisms in tropical mud environments:

(1) Heavy Pollution - Unhealthy
Capitella capitata, Spiochaetopterus oculatus.

(2) Mild Pollution - Semi-healthy
Poecilochaetus sp., Magelona berkeleyi.

(3) No Pollution - Healthy
Lumbrineris sp., Diplodonta punctata.

It is hoped that subsequent investigations will confirm or deny these proposals so that future pollution ecologists may have proven indicators with which to work in the tropics.

The trend of benthic population changes in Kingston Harbour is similar to that indicated by the water quality data except that the Outer Harbour appears to be deteriorating more rapidly than expected. Indeed, the increase of those species which have been proposed as indicators of mild pollution in the Outer Harbour and their growing dominance in the community are strong evidence of this fact.

7. EFFECT ON COMMUNITIES

It should be apparent that with the changes in distribution and density of various species throughout Kingston Harbour, the communities or assemblages of animals with which they were associated were bound to change also. This section describes those changes and relates them to the pattern of pollution spread which has previously been described.

The concept of the community in benthic ecology is imprecise and relates more to a statistical probability of certain species occurring together in relative proportions than to any definite functional biological unit. In discussing the effect that pollution has had on the benthic communities, therefore, attention will be given to how the numbers of species and their distribution within the communities have been affected rather than to their functioning. Nevertheless, it should be borne in mind that since the functioning of a biological community is determined at least in part by the species which comprise it and their relative proportions, it follows that the changes described must also affect how the community works.

Sanders (1968) has discussed how the structure of a benthic community may reflect the kind of environment in which it occurs and has described two extreme kinds of communities. The first, the "physically controlled community" occurs where physical conditions fluctuate widely and the animals are exposed to physiological stress. This kind of community is characterised by a small number of species. The second, the "biologically accomodated community" is present where physical conditions are stable and there is no physiological stress. This community is characterised by a large number of species. However, "there is no such thing as a 'pure' physically controlled or biologically accomodated community. All communities are the result of both their physical and biological components and are therefore somewhat intermediate between these extreme types. What determines the structure of any community is the relative proportions of these two parts" (Sanders, 1968).

It has been shown by many workers that the kinds of stresses caused by pollution lead toward a physically controlled community and that the degree of pollution may determine its structure. One measure of this, and undoubtedly the most powerful, is its diversity and this tool has been used with great success to determine levels of pollution effect on communities. At the same time, several measures of diversity have been devised, each with its own particular merit and applicability to different situations (See Sanders, 1968; Boesch, 1972; Rosenberg, 1973), and different workers have therefore had to choose which measure of diversity best suits their needs. Furthermore, in describing diversity, workers have had to differentiate between what Sanders (1968) has called "Species Diversity" (species richness) and "Dominance Diversity" (species evenness, uniformity or equitability) after Whittaker (1965), although it is generally agreed that the species diversity measure is a much more consistent and reliable tool for describing the relationship between the community and its environment.

Other measures for the determination of community structure also exist such as density, patchiness, faunal homogeneity, feeding types etc. and some of these will be employed in describing the communities in Kingston Harbour and the changes which have occurred since 1968.

The effect of pollution on the benthic communities will be discussed according to the three major regions: the Inner Harbour, Hunts Bay, and the Outer Harbour.

7.1 The Inner Harbour

Wade (1972a) preliminarily described two communities in the Inner Harbour in 1968; one comprising 11 species and dominated by *Spiochaetopterus oculatus* (96.4%), the other comprising 35 species and dominated by *Chaetopterus variopedatus* (47.0%). Between 1968 and 1972, these communities showed rapid decline and there was no opportunity to carefully examine their structure. Indeed, by 1972, *C. variopedatus* had completely disappeared from the Inner Harbour and the original two communities could no longer be recognised as such although *S. oculatus* was still present along with some of the original species. Then, by 1974, *S. oculatus* itself had virtually disappeared along with nearly all the other species and no distinct community could be identified within the Inner Harbour.

Hence, from a position of two communities within the Inner Harbour in 1968, the benthos deteriorated to no community at all in 1974 with almost the entire area except near the ship channel becoming abiotic. Table 7 summarises this decline and virtual destruction of the Inner Harbour benthos.

7.2 Hunts Bay

Unlike the Inner Harbour which showed a decline both in the number of animals and species, Hunts Bay has shown an increase in numbers along with a decrease in species and, indeed, the changes which have occurred there have been of a different nature.

The 1968 community of Hunts Bay contained 37 species with no one species clearly dominant. In fact, the

Table 7: The decline of the benthos in the Inner Harbour from 1968 to 1974.

	1968	1972	1974
No. of Stations sampled	35	35	35
No. of Stations with animals	30	12	6
No. of animals	790	360	48
No. of species	63	26	12
No. of communities	2	1	0
Predominant Organism	S.oc (1)	Poec.sp. (2)	Poec.sp (2)
% Predominant Organism	36.8	47.8	27.1

Notes: (1) S.oc = Spiochaetopterus oculatus

(2) Poec. sp. = Poecilochaetus sp.

most abundant organism comprised only 17.6% of all the individuals and the average density was only $219/m^2$. Between 1968 and 1972, however, this community changed radically both in species composition and numbers, and there was very little similarity between that which existed in 1968 and that in 1972.

From a total of 37 species in 1968, there was a decline to only 8 species in 1972. Furthermore, only 3 of the original species remained. Also from an average density of $219/m^2$ in 1968, the density had risen to $1057/m^2$. Indeed, the faunal index of affinity between the two years, measured by summing the percentage of fauna shared (see Sanders 1960 for procedure), showed such a low figure (18.1%) as to indicate that the original community no longer existed but had been replaced by a new one over the 4-year period.

The only important species carried over from 1968 to 1974 was <u>Capitella capitata</u>. However, whereas it only comprised 17.6% of all the individuals in 1968, in 1972, it comprised 98.48% and was overwhelmingly dominant.

By 1974, the density of animals had risen further to $1555/m^2$ but the number of species had remained constant. However, some of the species which were only present in low numbers in 1972 had increased significantly, the result being that <u>C. capitata</u> no longer dominated the community to the extent it did in 1972. Moreover, its distribution had become more patchy suggesting that as competition increased it began to decline. Nevertheless, the community was essentially the same as in 1972 and shared a reasonably high faunal index of affinity (47.4%). Thus, unlike the 1968-72 period, changes in the community from 1972-1974 could be described as internal and affecting mainly the relative proportion of the species.

These data are summarised in Table 8. They demonstrate that between 1968 and 1972 the benthic community of Hunts Bay suffered a major decline, almost certainly as a result of the construction of the causeway in 1969-1970. With this decline, a new community became established and C. capitata, being an opportunistic species, moved in in vast numbers. However, since 1972, as conditions have stabilised somewhat, other species (especially Paraprionospio sp.) have begun to increase and the community is becoming more uniform. Nevertheless, by all comparison, this community is species poor and most closely resembles Sanders' physically controlled community.

7.3 The Outer Harbour

7.3.1 Introduction

The community of the Outer Harbour in 1968 was described in detail in a paper by Wade (1972b) in which it was shown that the level of diversity was very high and unique to stable tropical environments. Dominance by a few species was reduced and density was surprisingly low. The description was based on data gathered from a total of 64 $1/10m^2$ grab samples taken at 21 stations. Five of these stations (2, 5, 8, 12, 17) occur in a straight line from just south of the ship channel to a point west of Port Royal (see Fig. 1) while the other 16 are fairly evenly distributed throughout the Harbour.

The 1968 description was based on detailed sampling at 8 stations. Since then, four of these stations (2, 5, 8, 12) have been retained for detailed study. Station 14 has been replaced by station 17 with which it bears great similarity while one station (1) was temporarily destroyed by dredging for real estate purposes and another (10) discarded. Moreover, data from all the remaining stations (x) have been lumped

Table 8: Data on the benthos of Hunts Bay from 1968 to 1974.

	1968	1972	1974
No. of Stations sampled	14	10	10
No. of animals	306	1057	1555
Density/m^2	219	1057	1555
No. of species	37	8	8
Predominant organism	C. capitata	C. capitata	C. capitata
% Predominant organism	17.6	98.5	47.3
Index of affinity (%)	(18.1)		(47.4)

together to compare with station 9 in the 1968 study which had the highest faunal index of affinity. Hence, as far as possible, the data gathered since 1968 have been designed to be comparable.

Whereas changes in the benthic communities in the Inner Harbour and Hunts Bay have been striking, those in the Outer Harbour have been far more subtle and a much closer analysis of the data is necessary in order to appreciate them. For, unlike the Inner Harbour where the level of decline has overshadowed every other kind of change and unlike Hunts Bay where the major decline was coincident with a clearly defined event, namely the construction of the causeway, the changes in the Outer Harbour have neither been as great or as sudden. Furthermore, as we shall see, the changes have occurred both in space and time so that different sections of the Outer Harbour community have undergone various degrees of change at different periods of time. In order to investigate this, it will therefore be necessary to consider the community both on a spatial (station 2 to station 17) and temporal (1968 to 1974) basis.

7.3.2 Faunal Homogeneity

In order to discuss the effect of pollution on the Outer Harbour community, it is necessary to establish certain features about it. The first is its homogeneity. The 1968 study showed that the Outer Harbour benthic fauna comprised a single homogeneous community. The average faunal index of affinity[(1)] for all stations was 37.9% with a range per station of 31.6% to 42.6%. This compared favourably with a range of affinities previously established for a number of other homogeneous soft-bottom communities in various locations (see Wade, 1972b). However, the greatest affinities were shown by stations adjacent to one another while distant stations showed

Footnote (1): Faunal index of affinity is a measure of faunal similarity between each possible pair of stations and is calculated by summing the percentage of fauna common to each pair.

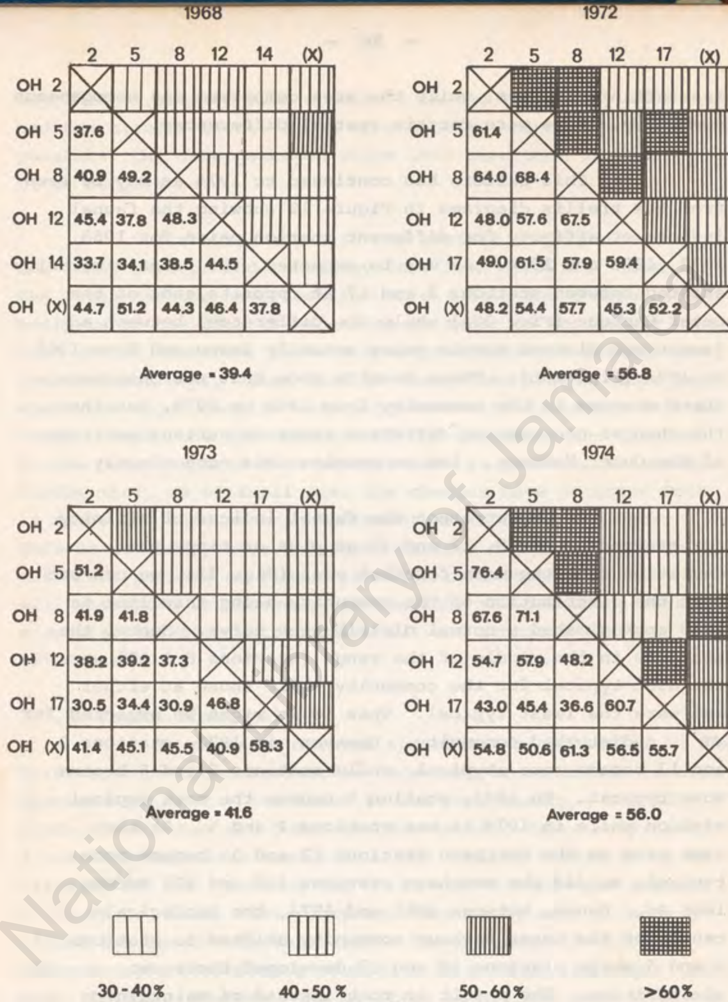

Figure 19

Trellis diagrams showing the faunal indices of affinity between each pair of sampling stations for 1968, 1972, 1973 and 1974. The stations are arranged according to their proximity.

less affinity. Thus, while the area comprised one homogeneous community, there were certain spatial differences.

This pattern has continued to 1974 as may be seen from the trellis diagrams in Figure 19 showing the faunal indices of affinity for different station pairs for 1968, 1972, 1973 and 1974. As may be expected, the least similarity existed between stations 2 and 17 at opposite ends of the Outer Harbour (Fig. 20a) while the differences between adjacent and distant sample pairs actually increased from 1968 to 1974 (Fig. 20b). These results show that not only were there changes in the community from 1968 to 1974, but that the changes occurred at different rates in various sections of the Outer Harbour. Let us examine this more closely.

If we represent the faunal indices of affinity for stations 2, 5, 8, 12 and 17 as plus or minus the deviation from the mean for that year (Fig. 21), we can see that the distribution of the community along this line in 1968 approximated a normal distribution curve. Hence, the stations in the middle of the range (stations 8 & 12) were the most typical for the community while those at either end were the least typical. This is as might be expected for an undisturbed community. However, in 1972, stations 2 and 17 became more atypical while stations 5 and 8 became more typical. In 1973, station 5 became the most typical station while in 1974 it was stations 2 and 5. At the same time as the northern stations (2 and 5) became more typical, so did the southern stations (12 and 17) become less so. Hence, between 1968 and 1974, the biological center of the Outer Harbour community shifted to stations 2 and 5 while stations 12 and 17 developed their own similarities. The result is that instead of maintaining one truly homogeneous set of stations in the Outer Harbour,

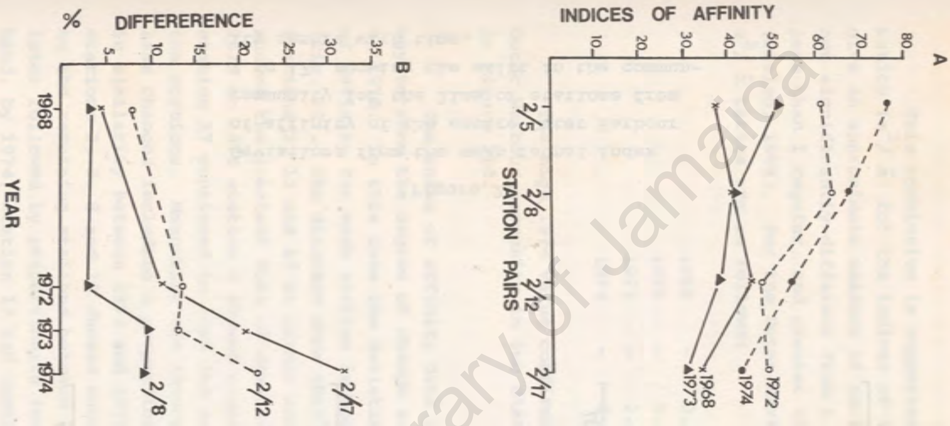

Figure 20

a) The faunal indices of affinity for station pairs along a line from station 2 to station 17. for 1968, 1972 . 1973 and 1974 showing the decreasing similarity with distance.

b) The percentage differences in faunal indices of affinity between the adjacent stations 2 and 5 and the more distant stations 2 and 8, 2 and 12, and 2 and 17, showing the increasing differences with distance and time.

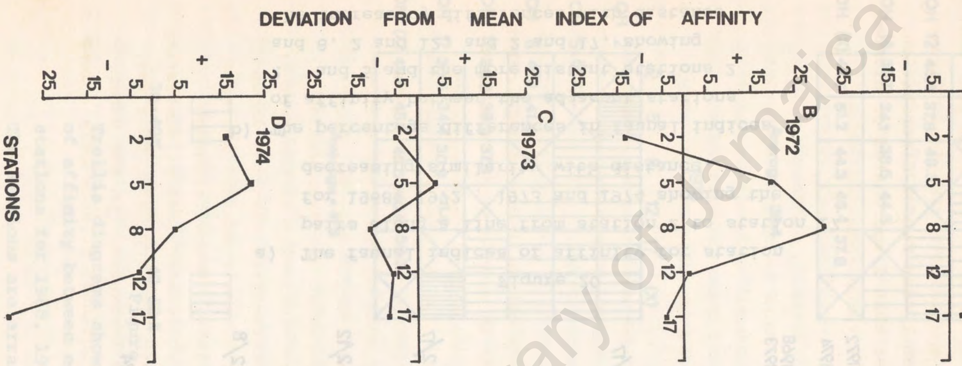

Figure 21

Deviations from the mean faunal index of affinity of the entire Outer Harbour community for the line of stations from 2 to 17, showing the shift in the community centre with time.

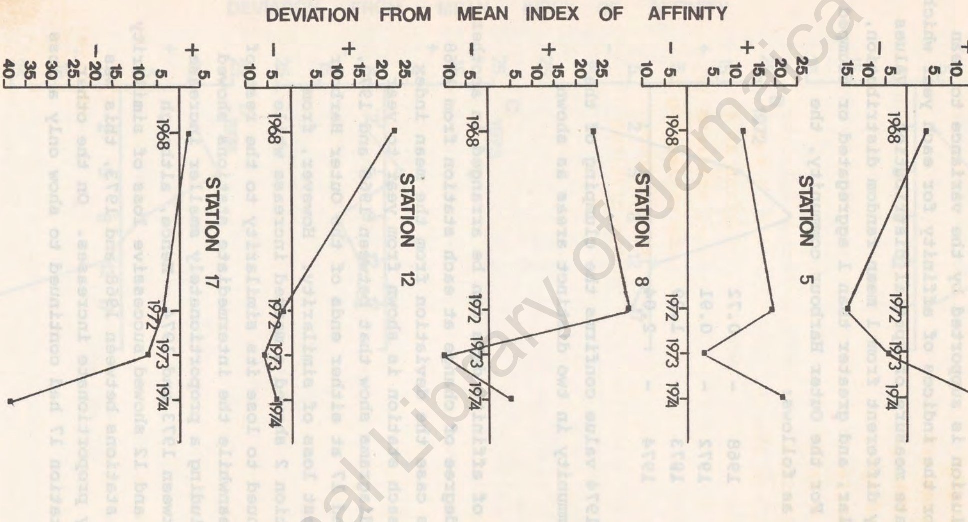

Figure 22

Deviation from the mean faunal index of affinity for each station along a line from station 2 to station 17 for 1968, 1972, 1973 and 1974, showing the degree of change of the community at each station.

two rather different groups of stations developed.

This conclusion is supported by the variance to mean ratios ($s^2/\bar{x}$) for the indices of affinity for each year which give an approximate measure of spatial distribution. Values not significantly different from 1 mean random distribution, less than 1 regular, and greater than 1 aggregated or clumped (Pielou, 1969). For the Outer Harbour community, the $s^2/\bar{x}$ ratios are as follows:

1968	-	0.72
1972	-	0.91
1973	-	1.29
1974	-	2.04

The high 1974 value confirms the clumping of the Outer Harbour community in two distinct areas as shown in Figure 21d.

The index of affinity data can be arranged in another way to show the degree of change at each station from 1968 to 1974. In this case the deviation from the mean index of affinity for each station is shown from year to year (Fig. 22). The diagrams show that between 1968 and 1972, stations 2, 12 and 17 at either ends of the Outer Harbour showed the greatest loss of similarity. However, from 1972 to 1974 station 2 showed a marked increase while station 17 continued to lose its similarity to the rest of the stations. Meanwhile the intermediate stations showed less changes including a proportionately smaller increase in similarity between 1973 and 1974. Hence, although stations 2, 5, 8 and 12 showed successive loss of similarity to the remaining stations between 1968 and 1973, this was later followed by proportionate increases. On the other hand, by 1974, station 17 had continued to show only a loss of similarity.

These data can be interpreted as follows: In 1968, the Outer Harbour community showed an undisturbed distribution. By 1972, however, stations 2, 12 and 17 had become affected by the shift of species southward toward the open sea (see Fig. 12, for example). With this shift of species, the end stations showed the greatest effect while the intermediate stations showed the least. As the shift of species continued between 1972 and 1973, stations 5 and 8 also became affected. However, by 1974, the changes at stations 2, 5 and 8 had gone far enough to establish these stations as the most typical for the community. Meanwhile, stations 12 and 17 to which the sensitive species were retreating now became atypical to the rest of the stations. Thus, by 1974, the community was distributed in two distinct groups of stations.

As stated, these changes in the station similarities can be attributed to the movement of species southward in response to advancing pollution in the Inner Harbour. Stations 2 and 5 being nearest to the Inner Harbour and Hunts Bay have shown the greatest decline while station 17 being furthest away has actually shown a temporary improvement followed by a similar decline (see Fig. 25). Thus, the changes in the Outer Harbour community along a line from the ship channel to Port Royal represent time responses to deteriorating environmental conditions.

It has been shown that by 1974, the Outer Harbour community consisted of two distinct groups of stations. However, the differences in these groups have not been great enough as to distinguish two separate communities, and the range of indices of affinity for all possible pairs of stations in that year is high enough (36.6% - 76.4%) to confirm this. Furthermore, despite the changes, the 1974 community must be regarded to be the same as the 1968 community because of the high index of affinity (38.9%) between the two. Thus, it is clear that since 1968, the Outer Harbour has consisted of only one community although, as a result of certain changes, it has become less homogeneous. So far, we have not yet discussed the nature of these changes, and this must therefore be considered next.

7.3.3 Density

Wade (1972b) showed that in 1968, the Outer Harbour community had a density of 240 individuals/m^2 which was remarkably low in comparison with several other soft-bottom communities cited in that paper. However, the figure compares favourably with that of 115 individuals/m^2 for West Africa (Longhurst, 1959) and 166 individuals/m^2 for Biscayne Bay, Florida (Singletary and Moore, 1974). In his paper, Wade speculated on the reason for such low density and suggested that it might have something to do with an inverse relationship between diversity and density due to reproductive strategies in a stable environment. If this is so, then we might expect the density in the Outer Harbour to increase as the environment becomes less stable and the diversity decreases.

Density data for each station in the Outer Harbour are given in Table 9. They show that by and large the densities continued to remain low in comparison

Table 9: Density data for the benthic sampling stations in the Outer Harbour for 1968, 1972, 1973 and 1974.

Station	1968	1972	1973	1974	AVG.
OH 2	$260/m^2$	$469/m^2$	$267/m^2$	$218/m^2$	$304/m^2$
OH 5	252	265	219	362	275
OH 8	185	324	320	230	230
OH 12	145	389	291	368	299
OH 17	155	270	226	406	264
OH (x)	231	163	312	200	227
Composite	(205)[1]	313	273	297	266

Note: (1) This is an adjusted density for 1968 due to the discarding of one station.

with the majority of other soft-bottom communities although, between 1968 and 1972, there was a definite increase (significant at the 97.5% probability level). From 1972 to 1974, the density remained fairly constant with no statistically significant change. Hence, although the density has increased since 1968, it has neither been large or steady. Nevertheless, a noticeable feature of the density has been the tendency towards increased patchiness as demonstrated by an increase in the variance to mean ($s^2 / \bar{x}$) ratio of from 1.03 to 3.79 between 1968 and 1974.

Both the increased density and patchiness appear to be due to the proliferation of a few very abundant species after 1968. Thus, whereas in 1968 the highest density by a single species along the line of stations from station 2 to station 7 was $30/m^2$ (Poecilochaetus sp.), in 1972 this was $83/m^2$ (Magelona berkeleyi), in 1973 $75/m^2$ (Magelona berkeleyi), and in 1974 $128/m^2$ (Scolaricia sp.). However, despite their high densities at certain stations, these species were patchy in their distribution and occurred in contrasting low densities at other stations of from $1/m^2$ (Magelona berkeleyi, Poecilochaetus sp.) to $14/m^2$ (Scolaricia sp.). This pattern of patchiness is characterisitc of opportunistic species as Grassle and Grassle (1974) have pointed out and points further to the increasing opportunism in the Outer Harbour as the environment has become disturbed.

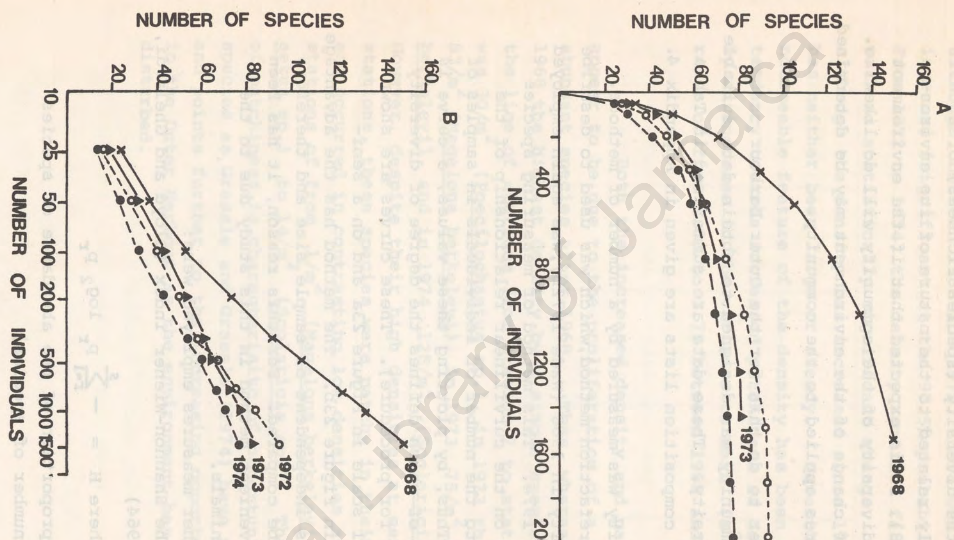

Figure 23

Sanders' rarefaction curves for the entire Outer Harbour community for 1968, 1972, 1973, 1974 on (a) a normal scale, and (b) a semi-logarithmic scale, showing the decrease in diversity.

7.3.4 Diversity

Since the diversity (species richness) of a community is closely related to the nature of its environment (Sanders, 1968), it is expected that if the environment changes, then the diversity of the community will do likewise. Thus, the degree of change of the environment may be determined by diversity measures applied to the community.

In order to do this for the Outer Harbour, sampling of the community was designed to obtain data suitable for measuring diversity. These data are summarised in Table 10 and the species composition lists are given in Appendix 4.

Diversity was measured by a number of methods. Sanders' (1968) rarefaction method,which was used to describe the initial community in 1968 (Wade 1972b),was again employed for 1972, 1973 and 1974. This method of measuring species diversity is based on the curvilinear relationship of the number of species to the number of individuals in samples of different sizes. Thus, by plotting these values, a curve is obtained, the area of which defines the degree of diversity (see Sanders, 1968 for procedure). These curves are shown plotted on a normal scale in Figure 23a and on a semi-logarithmic scale in Figure 23b. The method has the advantage that the measure is independent of sample size and therefore small samples can be compared. For this reason, it has been a particularly convenient method in this study due to the low densities of animals.

The other measures employed were:

(1) The Shannon-Wiener index (Lloyd and Ghelardi, 1964)

where $H = -\sum_{r=1}^{s} p_r \log_2 p_r$

(p_r = proportion of the abundance of species
s = number of species)

Table 10: Summary data of benthic sampling in the Outer Harbour.

Year	Station	No. of grabs	No. of animals	No. of Species
1968	OH 2	4	104	42
	OH 5	10	252	52
	OH 8	10	185	44
	OH 12	10	148	45
	OH 14 ~ 17	4	62	25
	OH (x)	26	797	106
	Composite	64	1548	150
1972	OH 2	10	458	49
	OH 5	10	276	38
	OH 8	10	324	34
	OH 12	10	386	47
	OH 17	10	270	51
	OH (x)	18	307	50
	Composite	68	2021	94
1973	OH 2	3	90	26
	OH 5	10	240	34
	OH 8	10	37	18
	OH 12	10	317	39
	OH 17	10	288	41
	OH (x)	14	481	75
	Composite	57	1453	83
1974	OH 2	10	219	28
	OH 5	10	362	36
	OH 8	10	232	29
	OH 12	10	369	35
	OH 17	10	401	41
	OH (x)	16	360	46
	Composite	66	1943	79

(2) The Margalef index (Margalef, 1957),
where $d = \dfrac{S - 1}{\ln N}$

(S = number of species, ln N = natural logarithm of the number of individuals).

(3) The McIntosh Index (McIntosh, 1967),
where $I = \dfrac{N - \sqrt{n_i^2}}{N - \sqrt{N}}$

(N = number of individuals, n_i is the number of the ith species)

Sanders (1968) found close agreement between the rarefaction measure and the Shannon-Wiener index since the latter is relatively sample-size independent. However, he found little agreement with the Margalef index especially with small samples since this measure is very sample-size dependent. The McIntosh index, which is a fairly new measure, is designed to incorporate a measure of the homogeneity of the samples into the description of diversity. However, in practice, its chief advantage seems to be its ease of computation and, so far, it has not been widely used by benthic ecologists.

The results of all these diversity measures for the Outer Harbour community are given in Table 11 and illustrated in Figure 24 (the rarefaction data are represented as the number of species at the 1000 individuals level). They all show that between 1968 and 1974, there was a significant decline in diversity in the community. However, whereas the Sanders rarefaction measure and the Margalef index show a steady decline, the Shannon-Wiener and the McIntosh indices show a small temporary rise in 1973. Reference to the rarefaction curve in Figure 23 suggests the reason for this discrepancy for, although the height of the 1972 curve is greater than that of the 1973

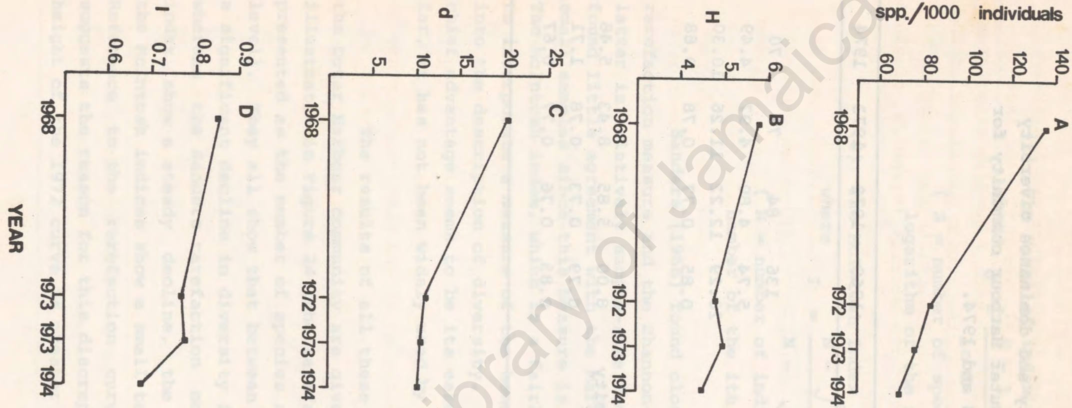

Figure 24

A comparison of four diversity measures for the entire Outer Harbour community for 1968, 1972 , 1973 and 1974.

(a) The Sanders rarefaction measure expressed as the number of species at the 1000 individuals level.
(b) The Shannon-Wiener index (H).
(c) The Margalef index (d).
(d) The McIntosh index (I).

Table 11: Species diversity and dominance diversity values for the Outer Harbour community for 1968, 1972, 1973 and 1974.

Measure	1968	1972	1973	1974
Species Diversity				
Sanders Rarefaction	136	84	77	70
Shannon-Wiener Index	5.74	4.80	4.97	4.49
Margalef Index	20.29	12.22	11.26	10.30
McIntosh Index	0.85	0.77	0.78	0.68
Dominance Diversity				
Sanders Dominance Diversity	8.00	5.85	8.43	5.48
Equitability Function	0.79	0.73	0.78	1.71
McIntosh Evenness	0.83	0.76	0.77	0.67

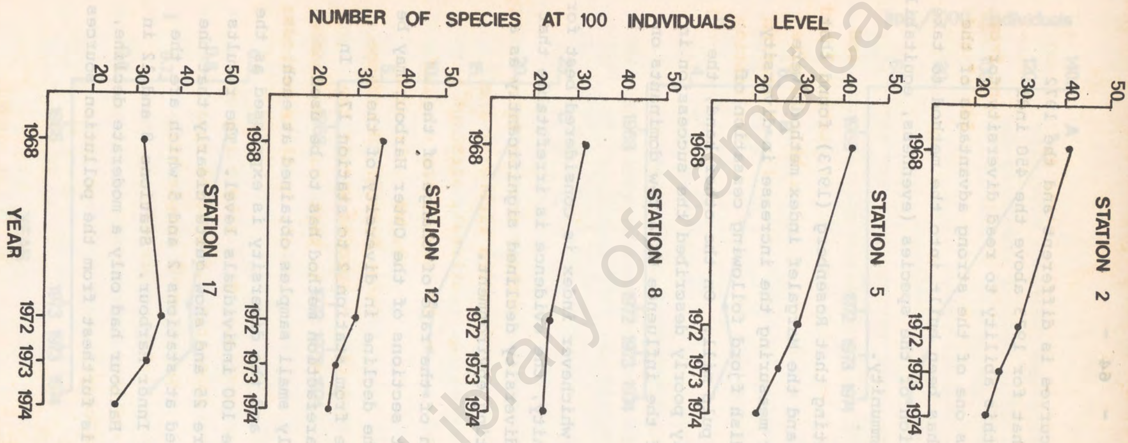

Figure 25

The decrease in diversity in the Outer Harbour community from 1968 to 1974 along a line from station 2 to station 17. Diversity is expressed as the number of species at the 100 individuals level based on Sanders' rarefaction curves.

curve, the shape of the curves is different and the 1972 diversity only exceeds that for 1973 above the 450 individuals level. Indeed, this ability to read diversity for different sample sizes is one of the strong advantages of the rarefaction method, and has been built into the method to take account of the distribution of the species (evenness, equitability, dominance) within the community.

It is interesting that Rosenberg (1973) found that the Sanders rarefaction and the Margalef index methods were the most appropriate for measuring the increase in diversity of a community in a Swedish fjord following cessation of pollution by a sulphite pulp mill. On the other hand, the Shannon-Wiener index only poorly described the succession in the community because of the influence of a few dominants on the measure.

At any rate, whichever index is considered best for the Outer Harbour community, the evidence is irrefutable that from 1968 to 1974, the diversity declined significantly as a result of the deteriorating environment.

An indication of the rate of change of the environment in different sections of the Outer Harbour may be obtained by examining the decline in diversity of the community along the line from station 2 to station 17. In this case the Sanders rarefaction method has to be used because of the relatively small samples obtained at each station (see Table 10), and the diversity is expressed as the number of species at the 100 individuals level. The results are illustrated in Figure 25 and show quite clearly that the greatest decline occurred at stations 2 and 5 which are the stations nearest to the Inner Harbour. Stations 8 and 12 in the middle of the Outer Harbour had only a moderate decline, while station 17 which is furthest from the pollution sources

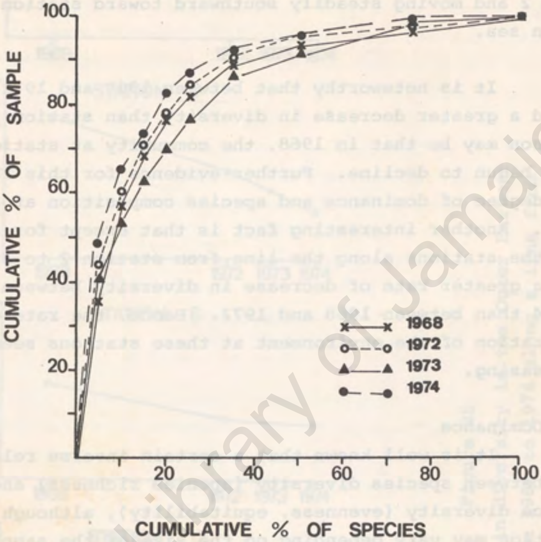

Figure 26

Sanders' dominance diversity curves for the entire Outer Harbour community for 1968,1972, 1973 and 1974.

actually showed an increase in diversity initially followed by a decline after 1972. Hence, from 1968 to 1974, the Outer Harbour environment experienced a deterioration starting from station 2 and moving steadily southward toward station 17 and the open sea.

It is noteworthy that between 1968 and 1972, station 5 showed a greater decrease in diversity than station 2, and the reason may be that in 1968, the community at station 2 had already begun to decline. Further evidence for this is given by the degree of dominance and species composition at station 2 in 1968. Another interesting fact is that except for station 8, all the stations along the line from station 2 to station 17 showed a greater rate of decrease in diversity between 1972 and 1974 than between 1968 and 1972. Hence, the rate of deterioration of the environment at these stations seems to be increasing.

7.3.5 Dominance

It is well known that a certain inverse relationship exists between species diversity (species richness) and dominance diversity (evenness, equitability), although the correlation may vary depending on the size of the samples being considered (Sanders, 1968). Hence, we might expect that as diversity decreased in the Outer Harbour, dominance increased or the distribution of the species within the community became less even. In order to test this, dominance was measured for the Outer Harbour community by three methods:

1) The Sanders dominance diversity curve of percentage composition of species against the percentage composition of sample (Fig. 26); (See Sanders, 1968 for procedure). Dominance has in this case been represented as the percent of species comprising 50% of the sample.

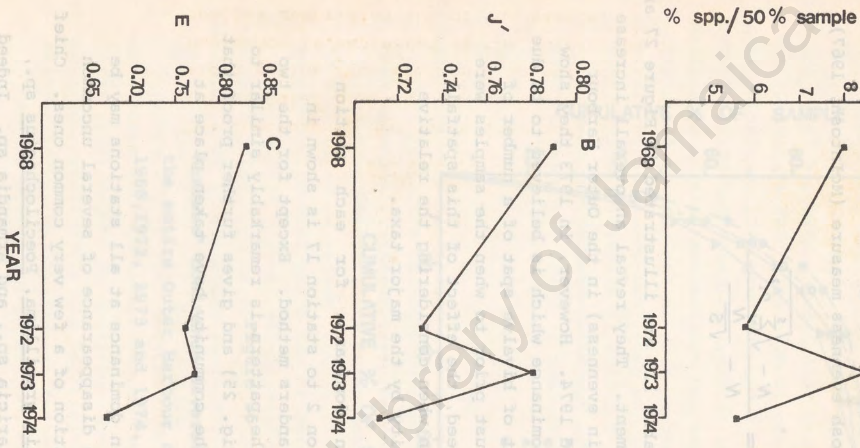

Figure 27

The increase in dominance (decrease in evenness) of the entire Outer Harbour community from 1968 to 1974, expressed by 3 different measures:

(a) Sanders' dominance diversity curve expressed as the percentage of species comprising 50% of the sample.

(b) The equitability function (J') of Lloyd and Ghelardi.

(c) The McIntosh evenness measure.

(2) The equitability function of Lloyd and Ghelardi (1964) based on the Shannon-Wiener index where $J' = \frac{H'}{\log_2 S}$

(3) The McIntosh evenness measure (McIntosh, 1967) where

$$E = \frac{N - \sqrt{\sum_{i=1}^{S} n_i^2}}{N - \frac{N}{\sqrt{S}}}$$

The results (Table 11) are illustrated in Figure 27 and show generally good agreement. They reveal an overall increase in dominance (or decline in evenness) in the Outer Harbour community between 1968 and 1974. However, in 1973 they show a temporary decrease in dominance which is believed to be due to a particular settlement of bivalve spat of a number of species at two stations just prior to when the samples were taken (see Fig. 28). Indeed, the effect of this spatfall in 1973 will show up again when considering the relative composition of the community by the major taxa.

The increase in dominance for each station along the line from station 2 to station 17 is shown in Figure 28, based on the Sanders method. Except for the two anomalous 1973 samples, the pattern is remarkably similar to that for diversity (see Fig. 25) and gives further proof that the greatest changes in the community have taken place at stations 2 and 5.

The increase in dominance at all stations may be attributed largely to the disappearance of several uncommon species and the proliferation of a few very common ones. Chief among these are *Micropholis gracillima*, *Poecilochaetus* sp., *Magelona berkeleyi*, *Scolaricia* sp., and *Armandia* sp. Indeed

(c) The McIntosh evenness measure.

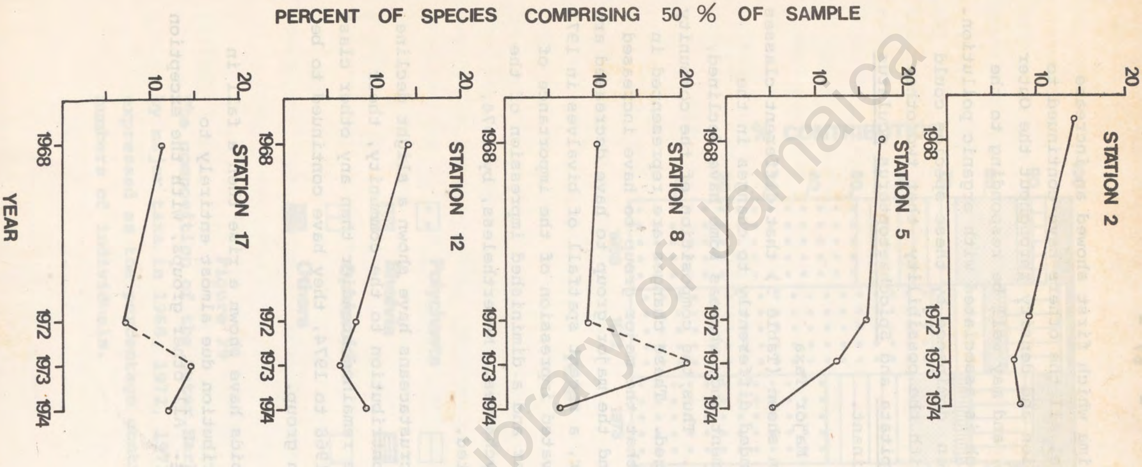

Figure 28

The increase in dominance (decrease in evenness) in the Outer Harbour community from 1968 to 1974 along a line from station 2 to station 17. Dominance is expressed as the percentage of species comprising 50% of the sample.

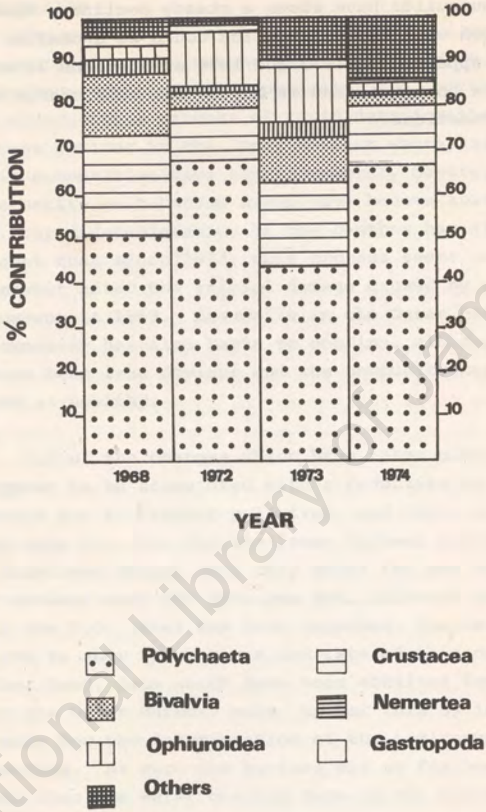

Figure 29

The composition of the Outer Harbour community by major taxa in 1968, 1972, 1973 and 1974, expressed as the percentage contribution by numbers of individuals.

except for M. gracillima which first showed an increase followed by a decrease, all the others have continued to increase in distribution and density throughout the Outer Harbour (see Table 5), and may well be responding to the fertiliser effect which is associated with organic pollution. If this continues, then dominance by these species could become even greater with the possibility that two other species, Capitella capitata and Spiochaetopterus oculatus might also become dominant.

7.3.6 Composition by Major Taxa

It has been shown (Table 5) that different classes of animals have responded differently to changes in the Outer Harbour environment and, whereas some have declined, others have increased. Thus, the composition of the community by taxa has also changed. These changes are represented in Figure 29. It shows that the major group to have increased are the polychaetes and the major group to have decreased are the bivalves. However, a recent spatfall of bivalves in 1973 tended to give an elevated impression of the importance of this group in that year and a diminished impression of the importance of the polychaetes. Nevertheless, by 1974, the picture had reverted.

While the crustaceans have shown a slight decline in their percentage contribution to the community, their population levels have remained steadier than any other class of animals and, from 1968 to 1974, they have continued to be the second most common group.

The ophiuroids have shown a rise then a fall in their percentage contribution due almost entirely to Micropholis gracillima. All other groups, with the exception of the sipunculids have shown a steady decline. However, the position with the sipunculids could be anomalous since they only appeared in 1973 and 1974 at stations 12 and 17 near to the open sea, and it may be due to a chance settlement at these locations.

8. DISCUSSION

The present study of the benthos of Kingston Harbour supports the conclusions made earlier (Wade 1976) that the harbour environment, especially the bottom waters, is undergoing a process of rapid deterioration. This has been most serious in the Inner Harbour where, since 1968, two benthic communities have been completely destroyed and almost the entire soft-bottom areas have become abiotic. In Hunts Bay, rapid deterioration of the benthos has also taken place, except that since 1972, this process seems to have slowed somewhat after the initial damage caused by construction of the causeway in 1969. Meanwhile in the Outer Harbour, the benthic community has also begun to decline, although the changes have been less obvious and the community may still be regarded as healthy.

All of the changes which have taken place in the benthos appear to be associated with a reduction in dissolved oxygen levels due to organic pollution, and there is good supporting data for this for the Inner Harbour and Hunts Bay. However, dissolved oxygen data only exist for one station in the Outer Harbour near the open sea and, although significant decline in the D.O. level has been recorded, the data are insufficient to show the pattern and rate of this decline. On the other hand, data which have been obtained for the benthos in the Outer Harbour make up for this by indicating quite clearly how the deterioration of the environment has been proceeding. As such the benthos has so far been a more useful tool than the water quality data in the Outer Harbour.

While the community of the Outer Harbour has reflected an overall decline in the environment since 1968, different parts of the community have shown different rates of change. Indeed, the information on species diversity and dominance in particular shows that those stations in the Outer Harbour nearest to the Inner Harbour and Hunts Bay where the pollution sources exist have shown the greatest and most rapid deterioration, while the more distant stations have shown the least. However, by 1974, no part of the Outer Harbour was unaffected and even station 17 at the entrance to the open sea showed rapid changes between 1972 and 1974.

In 1968, the Outer Harbour community could be classified as one of the healthiest of its kind in the world (Wade, 1972b), and there was every evidence that it was undisturbed and homogeneous. However, due to the changes emanating from near the Inner Harbour and Hunts Bay, the community had lost much of its homogeneity by 1972 and, in 1974 it exhibited all the usual signs of disturbance such as patchiness and clumping. Hence, instead of being a normally distributed community across the entire Outer Harbour, two separate areas could be identified at either end, one healthier than the other. Moreover, by 1974, the less healthy area occupied most of the Outer Harbour spanning stations 2, 5 and 8, and hence had become more typical of the entire community.

Although in 1974, the entire Outer Harbour could still be classified as a healthy zone according to the criteria established for the demarcation of polluted areas (Pérès and Bellan, 1972), this is not likely to continue for long if the present rate of deterioration is maintained. Indeed, based on an extrapolation of the diversity curves shown for each of the Outer Harbour stations in Figure 25, as well as the species composition and dominance data, it is estimated that parts of the Outer Harbour could become classified as a semi-healthy zone (mildly polluted) by as early as 1976 (stations 2 and 5) or as late as 1978 (stations 12 and 17). If we say 1978 for the entire Outer Harbour, this would put it in the same condition that nearly half of the Inner Harbour was in 1968 (see Fig. 4). If thereafter, deterioration proceeds as it has done in the Inner Harbour, then by 1984-1986 the Outer Harbour could become heavily polluted and, by 1990, abiotic. This is a frightening estimate based on what has happened in the Inner Harbour and, despite certain arguments that the pattern will not be the same as for the Inner Harbour, nothing has happened so far to indicate this.

It should not be difficult to monitor future benthic changes in the Outer Harbour. For one, certain indicator organisms have been identified for heavy and mild pollution in Kingston Harbour, and examining their distribution and density annualy should give a quick indication of how change is proceeding. If the above estimate of deterioration is true, then we can expect Poecilochaetus sp. and Magelona berkeleyi to dominate the entire Outer Harbour in high densities (500-1000/m^2) by 1978. Following that, Capitella capitata and maybe Spiochaetopterus oculatus could take over in even higher densities (more than 1000/m^2) in the mid 1980's. Thereafter, their distribution could become patchy until they eventually disappear and the bottom becomes abiotic. Secondly, a measure of diversity can be used to follow the decline in the number of species. However, this will require a more elaborate sampling program than for the indicator organisms and a more sophisticated analysis of the data. Nevertheless, the information derived from measuring diversity can be related to the information already obtained in this study and should yield more precise knowledge of changes in the environment.

The present study is unique in that it is the first to document the steady decline of one or more benthic communities over a number of years due either to pollution or some other factor. Hence, the results of this study cannot be compared with any previous work although a number of workers have described various communities already affected by pollution. However, whereas decline has not been previously described, recovery from pollution has ,although none in the tropics (Dean and Haskin, 1964; Leppakoski, 1969; McNulty, 1970; Reish, 1971; Rosenberg, 1972, 1973). In most cases recovery of the benthos was rapid once the pollution source was checked, and Rosenberg (1973) has compared the recovery he studied to a logistic population growth process in which an initial colonisation by some pioneer species is followed by a period of rapid increase in maturity. Following that the recovery stabilises although oscillations occur.

It is therefore likely that if pollution were checked in Kingston Harbour, the benthos could recover more quickly than it declined. However, the problem in Kingston Harbour is that instead of having one source of pollution, there are many and abatement can only effectively occur if all or most of these sources are discontinued (Wade, 1976). As this seems unlikely in the foreseeable future, the prospects for benthic recovery in Kingston Harbour are poor and further deterioration must therefore be expected.

9. SUMMARY

(1) The use of the benthos for monitoring environmental conditions in Kingston Harbour has yielded much information on the deterioration of the harbour since 1968.

(2) The first survey identified the presence of 5 distinct level-bottom communities; 4 in mud and one in sand. The mud communities showed a range of diversity from very low diversity in the eastern end of the Inner Harbour to very high diversity in the Outer Harbour.

(3) Between 1968 and 1972, obvious decline in the Inner Harbour and Hunts Bay communities occurred and a large abiotic zone developed and spread in the Inner Harbour. This decline could be correlated with a reduction in dissolved oxygen levels in the bottom water. However, the Outer Harbour community remained diverse.

(4) Based on the number of species occurring in each area, 4 benthic zones were recognised. These were a very polluted zone (maximum pollution), a polluted zone (heavy pollution), a semi-healthy zone (mild pollution) and a healthy zone (no pollution). The pattern of species numbers, the density of animals, and the occurrence of certain dominant organisms indicated that the benthos was being influenced primarily by organic pollution.

(5) Three centres of organic pollution were identified: a) the eastern end of the Inner Harbour which acts as a sink for various natural and man-made organic discharges; (b) the Newport East-Newport West area where large volumes of primary treated sewage effluent and other organic wastes are discharged; and (c) Hunts Bay where a number of rivers and drainage gullies discharge.

(6) The spread of pollution from these three centres

could be observed extending over the Inner Harbour and Hunts Bay from 1968 to 1974. Hence, by 1974, almost the entire Inner Harbour had maximum pollution while Hunts Bay was heavily polluted. Although the Outer Harbour was still healthy, a certain deterioration had taken place.

(7) As pollution spread, various species responded in different ways. Two species, *Capitella capitata* and *Spiochaetopterus oculatus* showed great tolerance to heavy pollution and reached very high densities in the polluted areas. A number of others, especially *Poecilochaetus* sp. and *Magelona berkeleyi*, showed less tolerance but reached their maximum in the mildly polluted areas. However, the majority of species showed no tolerance at all and even in the healthy zone, showed some decline. Chief among these were *Lumbrineris* sp. and *Diplodonta punctata*.

(8) The shift of species away from the polluted areas towards the open sea affected the distribution and structure of the communities. Thus, the two initial communities in the Inner Harbour were eventually destroyed and the Hunts Bay community underwent major changes including a reduction in diversity, an increase in dominance, and an increase in density.

(9) The Outer Harbour community showed more subtle changes. As the pollution effect spread towards the open sea, the community became less homogeneous and patchiness and clumping increased. Density and dominance also increased while diversity decreased.

(10) The greatest and most rapid changes in the Outer Harbour occurred at those stations nearest to the sources of pollution, while the most distant stations showed the least changes.

(11) A change in the composition of the Outer Harbour community has taken place involving especially an increase in the polychaetes and a decrease in the bivalves. The crustaceans have shown the least change.

(12) If the present rate of change in the Outer Harbour community continues, this area could become classified as semi-healthy (mildly polluted) by 1978, heavily polluted by 1986, and possibly very polluted (abiotic) by 1990.

(13) If pollution abatement occurred, the benthos of Kingston Harbour would probably recover more rapidly than it declined. However, this would require the discontinuation of many sources of pollution, and this seems unlikely for now.

(14) Hence, further deterioration of the benthos in Kingston Harbour can be expected.

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APPENDIX 1

List of species collected in the Inner Harbour by use of a $^{1}/10\ m^{2}$ van Veen grab in three surveys: 1968, 1972 and 1974.

Species	No. in 1968	No. in 1972	No. in 1974
Polychaeta			
Spiochaetopterus oculatus	291	57	6
Chaetopterus variopedatus	40		
Poecilochaetus sp.	16	172	13
Scalibregmid	4		
Hipponoa sp.	18	4	
Ophioglycera	3		
Syllid	1		
Ophiodromus sp.	1		
Hesione sp.	1		
Nereis sp. (a)	49	9	6
Nereis sp. (b)	3	1	
Armandia sp.	7	8	
Polynoinae sp.	1		
Sthenelais sp. (a)	67		
Sthenelais sp. (b)	15		
Alentia sp.	2		
Owenia sp.	2		
Terebellid	2		
Lumbrineris sp.	2		
Onuphis sp.	18	5	
Magelona sp.	1	3	

Species	No. in 1968	No. in 1972	No. in 1974
Phyllodoce sp.	13		
Maldanid	2		
Ancistrosyllis sp.	13	3	
Orbiniid (a)	12		
Orbiniid (b)	2		
Cirratulid	1	5	
Scolaricia sp.	16		
Prionospio sp. (a)	1		
Prionospio sp. (b)	6		
Prionospio sp. (c)	2		
Prionospio sp. (f)	13	19	
Spionid	8		
Capitella capitata		37	
Notomastus sp.		1	
Crustacea			
Polyonx sp.	12		
Processa sp. (a)	1	4	
Processa sp. (b)	6		
Alpheus cristulifrons	4		2
Carcinus sp.	4		
Trachypenaeus sp.	3		
Periclimenes americanus	4	1	1
Synalpheus sp.	1		
Upogebia affinis	1		
Leptochela sp.	2		
Amphipod	7	1	
Apseudes sp.	1		
Isopod	5	2	

Species	No. in 1968	No. in 1972	No. in 1974
Cumacea	1	1	
Bivalvia			
Tellina alternata	1	1	1
Corbula contracta	11		
Corbula caribaea	5	4	1
Trigonocardia sp.	2		
Codakia pectinella	1		
Diplodonta punctata	3	1	
Gastropoda			
Mitrella nitens	2		
Anachis sp.		1	
Ophiuroidea			
Micropholis gracillima	11	2	1
Nematoda			
Nematode	1		
Nemertea			
Nemertean (a)	3		
Nemertean (b)	1		1
Nemertean (c)	1		
Sipunculida			
Sipunculid (b)	1		1
Sipunculid (d)	1		2

Species	No. in 1968	No. in 1972	No. in 1974
Oligochaeta			
Oligochaete	2		14
Cephalochorda			
Branchiostoma caribaeum	43	4	
Hemichorda			
Hemichordate (a)	1		
Hemichordate (b)	1		
No. of animals	790	360	48
No. of species	63	26	12
No. of stations	35	35	35
No. of grabs	35	35	35

APPENDIX 2

List of species collected in the Outer Harbour by use of a $^{1}/10\ m^{2}$ van Veen grab in four surveys : 1968, 1972, 1973 and 1974.

Species	No.in 1968	No.in 1972	No.in 1973	No.in 1974
Polychaeta				
Pholoe sp.	1			
Polyodontes sp.	4	11	1	2
Alentia sp. (a)	4	18	12	1
Alentia sp. (b)	4		4	
Sthenelais sp. (a)	11	35	14	7
Harmothoe sp.	1		1	1
Aphroditid (a)			2	
Aphroditid (b)			1	
Hipponoa sp.	30	27		2
Amphinomid			1	
Phyllodoce sp. (a)	2	6	3	3
Phyllodoce sp. (b)		2		
Ancistrosyllis sp. (a)	12	31	9	4
Ancistrosyllis sp. (b)	1		1	
Ancistrosyllis sp. (c)				1
Hesione sp. (a)	5	2		
Hesione sp. (b)		4		
Ophiodromus sp.	1	5		
Syllid (a)	1			1
Syllid (b)	2			
Syllid (c)				1
Lumbrineris sp.	135	24	6	4

Species	No.in 1968	No.in 1972	No.in 1973	No.in 1974
Onuphis sp.	4			
Driloneris sp.			1	
Poecilochaetus sp. (a)	52	292	81	157
Poecilochaetus sp. (b)				2
Orbiniella sp.	1			
Scolaricia sp.	39	165	91	333
Orbiniid	10			
Armandia sp.	117	65	3	116
Capitella capitata	3	10	26	30
Notomastus sp.	5		19	3
Pectinaria sp.	1			
Megalomma sp.	1			
Branchiomma sp.	1			
Aglaophamus sp. (a)	9		12	
Aglaophamus sp. (b)	6			
Cirratulid	1			7
Sternaspis sp.	1	1	4	8
Arabella sp.			1	
Chaetopterus variopedatus	1	1		
Spiochaetopterus oculatus	1	5	4	8
Ophioglycera sp.	3	1		
Glycera sp.		1		
Terrebellid (a)	1	1		
Terrebellid (b)	1	1		
Terrebellid (c)	1			
Terrebellid (d)	1			
Terrebellid (e)		1		
Cossura sp. (a)	1		2	66
Cossura sp. (b)	1			

Species	No.in 1968	No.in 1972	No.in 1973	No.in 1974
Cossura sp. (e)	1			
Cossura sp. (d)	1			
Cossura sp. (e)		5		
Spionid				3
Malacoceros sp.	7	2		
Laonice sp.	5	23		
Aonides	1			
Paraprionospio sp.	19	105	7	44
Prionospio sp. (a)	18	13		3
Prionospio sp. (b)	10	2		
Prionospio sp. (c)	11	18		3
Prionospio sp. (d)	2	2		
Prionospio sp. (f)	5			1
Prionospio sp. (g)	5			
Prionospio sp. (h)	3			6
Prionospio sp. (i)	10	27		6
Prionospio sp. (j)				3
Prionospio sp. (k)				14
Nereis sp. (a)	19	44	33	56
Nereis sp. (b)	18	43	32	56
Nereis sp. (c)	18			
Nereis sp. (d)	18			
Cheilonereis sp.		2		
Magelona berkeleyi	55	172	231	319
Magelona phyllisae	40	166	6	8
Magelona polydentata	4			
Magelona pettiboneae	2			
Arenicola sp.		47		
Scalibregmid		1		

Species	No.in 1968	No.in 1972	No.in 1973	No.in 1974
Flabelligerid		1		
Unid. Polychaete		2		
Unid. Polychaete		1		
Maldanid			1	
Sabelariid			1	
Paraonis sp.			1	
Bivalvia				
Diplodonta punctata	54	3	12	7
Phacoides muricatus	47	4	3	5
Codakia pectinella	29	9	49	3
Corbula aequivalvis	3		14	1
Corbula caribaea	26	31	9	10
Corbula contracta	19	16	18	15
Tellina alternata	26	2	36	
Tellina sybaritica	2	3	1	
Tellina aequistriata	3			
Macoma tenta	3			
Transennella sp.	1		2	
Trigonocardia sp.	1	1	2	
Tagelus sp.	1	2		2
Asaphis deflorata			1	
Trachycardium muricatum	1			
Pitar aresta			1	
Laevicardium symbaritica			5	
Gastropoda				
Mitrella nitens	13	23	20	7
Crassispira sp.	2			
Murex sp.	1			
Haminoea succinea	11			

Species	No.in 1968	No.in 1972	No.in 1973	No.in 1974
Nassarina sp.	1			
Eulima bifasciata	1	1	1	
Scaphopoda				
Cadulus acus	14		12	
Dentalium gouldi	1	2		
Crustacea				
Alpheus cristulifrons	80	52	52	53
Automate sp. (a)	34	5	28	37
Automate sp. (b)	3			
Synalpheus sp. (a)	1			1
Synalpheus sp. (b)	1	7		
Upogebia affinis	23	10	8	1
Periclimenes sp. (b)	2	2	5	
Periclimenes americanus	60	25	54	71
Processa sp. (a)	8	7	35	
Processa sp. (b)	10	34	20	20
Processa sp. (c)	3		1	8
Trachypenaeus sp.	4		6	6
Callianidea sp.	1	1		
Axius sp.	2			2
Acetes sp.	1		1	
Squilla sp. (a)		2		
Squilla sp. (b)		1	1	
Squilla sp. (c)	1			1
Talorchestia sp.	10			
Amphipod (a)	1			

Species	No.in 1968	No.in 1972	No.in 1973	No.in 1974
Amphipod (b)	8		29	6
Amphipod (c)	1		2	4
Gammarus sp.		19		
Cirripedia	2			
Paracerceis sp.	1			
Cirolana sp.	1			
Cumacea	1			
Apseudes sp.	52	46	24	9
Leucozonia wadeii	1			
Tanaid			1	
Pachycheles sp.	3			
Pagurus sp.	1	1		
Petrolisthes sp.	1			
Pilumnus sp. (a)	2			
Hepatus sp.	1			
Micropanope sp.	2			
Pinnixa sp.	1			
Pilumnus sp. (b)	1			
Speocarcinus sp.				2
Xanthid		4	1	
Unid. brachyuran		1		
Isopod (a)				1
Isopod (b)		1		
Euchirograpsus sp.			1	1
Ophiuroidea				
Micropholis gracillima	41	248	179	49
Ophiophragmus septus	1	1		
Hemipholis elongata	1			

Species	No.in 1968	No.in 1972	No.in 1973	No.in 1974
Amphioplus sp.	1	2		1
Amphioplus coniortodes	1			
Holothuroidea				
Synaptulid (a)	13	40	27	
Synaptulid (b)		1	18	3
Echinoidea				
Moira atropus	5	1	1	
Sipunculida				
Sipunculid (a)	4	2		2
Sipunculid (b)	11	10	11	129
Sipunculid (c)	2			74
Sipunculid (d)	1			40
Sipunculid (e)	1	1		1
Sipunculid (f)		1		
Sipunculus sp.	1	1		1
Cnidaria				
Anemone (a)	1		1	
Anemone (b)	1			
Nemertea				
Nemertean (a)	2	1		5
Nemertean (b)	1			6
Nemertean (c)	1		9	
Nemertean (d)	46	30	27	3
Nemertean (e)			19	

Species	No.in 1968	No.in 1972	No.in 1973	No.in 1974
Hemichorda				
Hemichordate (a)	1			
Hemichordata (b)	2			
Enteropneusta sp			8	2
Glossobalanus sp.		13		
Cephalochorda				
Branchiostoma caribaeum	6	3	2	2
Urochorda				
Ascidian			2	
Echiurida				
Echiurid		3	24	
Nematoda				
Nematode		2	1	
Phoronida				
Phoronis sp.		1	20	
Pisces				
Gobiid	7	8	4	11
Pisces (b)	2	2		
Pisces (c)	1			
Pisces (d)	1			
Pisces (e)	1			
Pisces (f)	1			
Pisces (g)	1			

Species	No.in 1968	No.in 1972	No.in 1973	No.in 1974
Ophicthid			1	
No. of animals	1548	2021	1453	1943
No. of species	150	94	83	79
No. of stations	21	19	20	20
No. of grabs	64	68	57	66

APPENDIX 3

List of species collected in Hunts Bay by use of a $^{1}/10\ m^{2}$ van Veen grab in three surveys: 1968, 1972 and 1974.

Species	No.in 1968	No.in 1972	No.in 1974
Polychaeta			
Magelona berkeleyi	34	1	1
Capitella capitata	54	1042	735
Armandia sp.	33	1	
Ancistrosyllis sp.	3		
Scolaricia sp.	12		
Onuphis sp.	5		
Lumbrineris sp.	1		
Eunicid	5		
Nereid sp.	6		
Hipponoa sp.	4		
Prionospio sp. (c)	21		
Sabellid	1		
Phyllodoce sp.	1		22
Orbiniid	2		
Hesionid	2		
Notomastus sp.	1		
Paraprionospio sp.	1		719
Spiochaetopterus oculatus	1		
Cirratulid		1	1
Crustacea			
Pagurus sp.	2		
Leptochela sp.		1	

Species	No.in 1968	No.in 1972	No.in 1974
Xanthid	10		
Polyonyx sp.	8		
Alpheus cristulifrons	7		
Periclimenes americanus	9		
Processa sp.	1		
Apseudes sp.	5		
Isopod	3		
Amphipod	1		
Cumacean	2		
Bivalvia			
Phacoides muricatus	1		
Lyonsia sp.	1		
Tellina sybaritica	3		
Tagelus sp.	7		8
Macoma tenta		6	
Nemertea			
Nemertean (d)	1		
Oligochaeta			
Oligochaete		4	64
Nematoda			
Nematode		1	5
Cephalochorda			
Branchiostoma caribaeum	54		

Species	No.in 1968	No.in 1972	No.in 1974
No. of animals	306	1057	1555
No. of species	37	8	8
No. of stations	14	10	10
No. of grabs	14	10	10

APPENDIX 4

Data on the composition of the Outer Harbour community for 1968, 1972, 1973 and 1974.

a) 1968

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Lumbrineris sp.	135	1	8.72	8.72
Armandia sp.	117	2	7.56	16.28
Alpheus cristulifrons	80	3	5.17	21.45
Periclimenes americanus	60	4	3.88	25.33
Magelona berkeleyi	55	5	3.55	28.88
Diplodonta punctata	54	6	3.49	32.37
Poecilochaetus sp. (a)	52	7	3.36	35.73
Apseudes sp.	52	7	3.36	39.09
Phacoides muricatus	47	9	3.04	42.13
Nemertean (d)	46	10	2.97	45.10
Micropholis gracillima	41	11	2.64	47.74
Magelona phyllisae	40	12	2.58	50.32
Sthenelais sp. (b)	39	13	2.52	52.84
Scolaricia sp.	39	13	2.52	55.36
Automate sp. (a)	34	15	2.20	57.56
Hipponoa sp.	30	16	1.94	59.50
Codakia pectinella	29	17	1.87	61.37
Corbula caribaea	26	18	1.68	63.05
Tellina alternata	26	18	1.68	64.76
Upogebia affinis	23	20	1.48	66.21
Corbula contracta	19	21	1.23	67.44
Paraprionospio sp.	19	21	1.23	68.67

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Nereis sp. (a)	19	21	1.23	69.90
Nereis sp. (b)	18	24	1.16	71.06
Nereis sp. (c)	18	24	1.16	72.22
Nereis sp. (d)	18	24	1.16	73.38
Prionospio sp. (a)	18	24	1.16	74.54
Cadulus acus	14	28	0.90	75.44
Synaptulid (a)	13	29	0.84	76.28
Mitrella nitens	13	29	0.84	77.12
Ancistrosyllis sp. (a)	12	31	0.77	77.89
Sthenelais sp. (a)	11	32	0.71	78.60
Prionospio sp. (c)	11	32	0.71	79.31
Haminoea succinea	11	32	0.71	80.02
Talorchestia sp.	10	35	0.65	80.67
Prionospio sp. (i)	10	35	0.65	81.32
Prionospio sp. (b)	10	35	0.65	81.97
Processa sp. (b)	10	35	0.65	82.62
Orbiniid sp.	10	35	0.65	83.27
Aglaophamus sp. (a)	9	40	0.58	83.85
Processa sp. (a)	8	41	0.52	84.37
Amphipod (b)	8	41	0.52	84.89
Gobiid	7	43	0.45	85.34
Automate sp. (b)	7	43	0.45	85.79
Malacoceros sp.	7	43	0.45	86.24
Agloaphamus sp. (b)	6	46	0.39	86.63
Branchiostoma caribaeum	6	46	0.39	87.02
Calianassa sp.	5	48	0.32	87.34
Hesione sp.	5	48	0.32	87.66
Prionospio sp. (f)	5	48	0.32	87.98
Laonice sp.	5	48	0.32	88.30
Prionospio sp. (g)	5	48	0.32	88.62
Moira atropus	5	48	0.32	88.94

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Polyodontes sp.	4	54	0.26	89.20
Alentia sp. (a)	4	54	0.26	89.46
Alentia sp. (b)	4	54	0.26	89.72
Magelona polydentata	4	54	0.26	89.98
Trachypeneus sp.	4	54	0.26	90.24
Sipunculid (a)	4	54	0.26	90.50
Sipunculid (b)	4	54	0.26	90.76
Onuphis sp.	4	54	0.26	91.02
Ophioglycera sp.	3	62	0.19	91.21
Capitella capitata	3	62	0.19	91.40
Prionospio sp. (h)	3	62	0.19	91.59
Macoma tenta	3	62	0.19	91.78
Corbula aequivalvis	3	62	0.19	91.97
Processa sp. (c)	3	62	0.19	92.16
Tellina equistriata	3	62	0.19	92.35
Alpheus sp.	3	62	0.19	92.54
Leptochela sp.	3	62	0.19	92.73
Pachycheles sp.	3	62	0.19	92.92
Cumacean	3	62	0.19	93.11
Syllid (b)	2	73	0.13	93.24
Capitobranchus sp.	2	73	0.13	93.37
Prionospio sp. (d)	2	73	0.13	93.50
Magelona pettibonae	2	73	0.13	93.63
Tellina sybaritica	2	73	0.13	93.76
Crassispira sp.	2	73	0.13	93.89
Axius sp.	2	73	0.13	94.02
Periclimenes sp.	2	73	0.13	94.15
Cirripedia	2	73	0.13	94.28
Pilumnus sp. (a)	2	73	0.13	94.41
Micrapanope sp.	2	73	0.13	94.54

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Sipunculid (c)	2	73	0.13	94.67
Nemertean (a)	2	73	0.13	94.80
Hemichordate (b)	2	73	0.13	94.93
Pisces (b)	2	73	0.13	95.06
Phyllodoce sp. (a)	2	73	0.13	95.19
62 Others	1	89-150	0.06	100.00
Total	1548	150		
b) <u>1972</u>				
Poecilochaetus sp. (a)	292	1	14.45	14.45
Micropholis gracillima	248	2	12.27	26.72
Magelona berkeleyi	172	3	8.51	35.23
Scolaricia sp.	165	4	8.16	43.39
Paraprionospio sp.	105	5	5.19	48.58
Magelona phyllisae	66	6	3.27	51.85
Armandia sp.	65	7	3.22	55.07
Alpheus cristulifrons	52	8	2.57	57.64
Arenicola sp.	47	9	2.33	59.97
Apseudes sp.	46	10	2.28	62.25
Nereid (a)	44	11	2.18	64.43
Nereid (b)	43	12	2.13	66.56
Sthenelais sp. (b)	43	12	2.13	68.69
Synaptulid (a)	40	14	1.98	70.67
Sthenelais sp. (a)	35	15	1.73	72.40
Processa sp. (b)	34	16	1.68	74.08
Corbula caribaea	31	17	1.53	75.61
Ancistrosyllis sp. (a)	31	17	1.53	77.14
Nemertean (d)	30	19	1.48	78.62

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Hipponoa sp.	27	20	1.34	79.96
Prionospio sp. (i)	27	20	1.34	81.30
Periclimenes americanus	25	22	1.24	82.54
Lumbrineris sp.	24	23	1.19	83.73
Mitrella nitens	23	24	1.14	84.87
Laonice sp.	23	24	1.14	86.01
Gammarus sp.	19	26	0.94	86.95
Alentia sp. (a)	18	27	0.89	87.84
Prionospio sp. (a)	18	27	0.89	88.73
Corbula contracta	16	29	0.79	89.52
Glossobalanus sp.	13	30	0.64	90.16
Prionospio sp. (a)	13	30	0.64	90.80
Polyodontes sp.	11	32	0.54	91.44
Capitella capitata	10	33	0.49	91.93
Sipunculid (b)	10	33	0.49	92.42
Upogebia affinis	10	33	0.49	92.91
Codakia pectinella	9	36	0.45	93.36
Processa sp. (a)	7	37	0.35	93.71
Leptochela sp.	7	37	0.35	94.06
Synalpheus sp. (b)	7	37	0.35	94.41
Phyllodoce sp. (a)	6	40	0.30	94.71
Ophiodromus sp.	5	41	0.25	94.96
Spiochaetopterus oculatus	5	41	0.25	95.21
Hesione sp. (b)	4	43	0.20	95.41
Phacoides muricatus	4	43	0.20	95.61
Xanthid	4	43	0.20	95.81
Echiurid	3	46	0.15	95.96
Diplodonta punctata	3	46	0.15	96.11
Tellina sybaritica	3	46	0.15	96.26
Branchiostoma caribaeum	3	46	0.15	96.41

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Pisces (b)	2	50	0.10	96.51
Hesione sp. (a)	2	50	0.10	96.61
Malacoceros sp.	2	50	0.10	96.71
Prionospio sp. (b)	2	50	0.10	96.81
Prionospio sp. (d)	2	50	0.10	96.91
Cheilonereis cyclurus	2	50	0.10	97.01
Polychaete unid.	2	50	0.10	97.11
Tellina alternata	2	50	0.10	97.21
Tagelus sp.	2	50	0.10	97.31
Dentalium gouldi	2	50	0.10	97.41
Periclimenes sp. (b)	2	50	0.10	97.51
Squilla sp. (a)	2	50	0.10	97.61
Amphioplus sp. (a)	2	50	0.10	97.71
Sipunculid (a)	2	50	0.10	97.81
Nematoda	2	50	0.10	97.91
Phyllodoce sp. (b)	2	50	0.10	98.01
29 Others	1	66-94	0.05	100.00
Total	2021	94 spp.		

c) 1973

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Magelona berkeleyi	231	1	15.90	15.90
Micropholis gracillima	179	2	12.32	28.22
Scolaricia sp.	91	3	6.26	34.48
Poecilochaetus sp. (a)	81	4	5.57	40.05
Periclimenes americanus	54	5	3.72	43.77
Alpheus cristulifrons	52	6	3.58	47.35
Codaka pectinella	49	7	3.37	50.72
Tellina alternata	36	8	2.48	53.20

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Processa sp. (a)	35	9	2.41	55.61
Nereis sp. (a)	33	10	2.27	67.88
Nereis sp. (b)	32	11	2.20	60.08
Amphipod (b)	29	12	2.00	62.08
Automate sp. (a)	28	13	1.93	64.01
Synaptulid (a)	27	14	1.86	65.87
Sthenelais sp. (b)	27	14	1.86	67.73
Nemertean (d)	27	14	1.86	69.59
Capitella capitata	26	17	1.79	71.38
Echiurid	24	18	1.65	73.03
Apseudes sp.	24	18	1.65	74.68
Mitrella nitens	20	20	1.38	76.06
Processa sp. (b)	20	20	1.38	77.44
Phoronis sp.	20	20	1.38	78.82
Notomastus sp.	19	23	1.31	80.13
Nemertean (e)	19	23	1.31	81.44
Synaptulid (b)	18	25	1.24	82.68
Corbula contracta	18	25	1.24	83.92
Sthenelais sp. (a)	14	27	0.96	84.88
Corbula aequivalvis	14	27	0.96	85.84
Cadulus acus	12	29	0.83	86.67
Diplodonta punctata	12	29	0.83	87.50
Aglaophamus sp. (a)	12	29	0.83	88.33
Alentia sp. (a)	12	29	0.83	89.16
Sipunculid (b)	11	33	0.76	89.92
Ancistrosyllis sp. (a)	10	34	0.70	90.62
Corbula caribaea	9	35	0.62	91.24
Nemertean (c)	9	35	0.62	91.86
Enteropneusta sp.	8	37	0.55	92.41
Upogebia affinis	8	37	0.55	92.96

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Paraprionospio sp.	7	39	0.48	93.44
Trachypeneus sp.	6	40	0.41	93.85
Lumbrineris sp.	6	40	0.41	94.26
Magelona phyllisae	6	40	0.41	94.67
Periclimenes sp. (b)	5	43	0.34	95.01
Laevicardium symbaritica	5	43	0.34	95.35
Alentia sp. (b)	4	45	0.28	95.63
Sternaspis sp.	4	45	0.28	96.19
Gobiidae	4	45	0.28	96.47
Phacoides muricatus	3	49	0.21	96.68
Armandia sp.	3	49	0.21	96.89
Phyllodoce sp. (a)	3	49	0.21	97.10
Aphroditid (a)	2	52	0.14	97.24
Cossura sp. (a)	2	52	0.14	97.38
Transennella sp.	2	52	0.14	97.52
Trigonocardia antillarum	2	52	0.14	96.66
Amphipod (c)	2	52	0.14	97.80
Branchiostoma caribaeum	2	52	0.14	97.94
Ascidian	2	52	0.14	98.28
25 Others	1	59-83	0.07	100.00
Total	1453	83 spp.		
d) <u>1974</u>				
Scolaricia sp.	333	1	17.14	17.14
Magelona berkeleyi	319	2	16.42	33.56
Poecilochaetus sp. (a)	157	3	8.08	41.64
Sipunculid (b)	129	4	6.64	48.28
Armandia sp.	116	5	5.97	54.25

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Sipunculid (c)	74	6	3.81	58.06
Periclimenes americanus	71	7	3.65	61.71
Cossura sp. (a)	66	8	3.40	65.11
Nereis sp. (a)	56	9	2.88	67.99
Nereis sp. (b)	56	9	2.88	70.87
Alpheus cristulifrons	53	11	2.73	73.60
Micropholis gracillima	49	12	2.52	76.12
Paraprionospio sp.	44	13	2.26	78.38
Sipunculid (d)	40	14	2.06	80.44
Automate sp. (a)	37	15	1.90	82.34
Capitella capitata	30	16	1.54	83.88
Amphipod (b)	26	17	1.34	85.22
Processa sp. (b)	20	18	1.03	86.25
Corbula contracta	15	19	0.77	87.02
Sthenelais sp. (b)	14	20	0.72	87.74
Prionospio sp. (k)	14	20	0.72	88.46
Leptochela sp.	14	20	0.72	89.18
Gobiid	11	23	0.57	89.75
Corbula caribaea	10	24	0.51	90.26
Apseudes sp.	9	25	0.46	90.72
Ophiuroid	8	26	0.41	91.13
Processa sp. (c)	8	26	0.41	91.54
Magelona phyllisae	8	26	0.41	91.95
Spiochaetopterus oculatus	8	26	0.41	92.36
Sternaspis sp.	8	26	0.41	92.77
Sthenelais sp. (a)	7	31	0.36	93.13
Cirratulid	7	31	0.36	93.49
Diplodonta punctata	7	31	0.36	93.85
Mitrella nitens	7	31	0.36	94.21
Nemertean (b)	6	35	0.31	94.52

Species	No.	Rank by No.	% by No.	Cumul. % by No.
Trachypeneus sp.	6	35	0.31	94.83
Prionospio sp. (i)	6	35	0.31	95.14
Prionospio sp. (h)	6	35	0.31	95.45
Phacoides muricatus	5	39	0.26	95.71
Automate sp. (b)	5	39	0.26	95.97
Nemertean (a)	5	39	0.26	96.26
Amphipod (b)	4	42	0.21	96.44
Lumbrineris sp.	4	42	0.21	96.65
Ancistrosyllis sp. (a)	4	42	0.21	96.86
Phyllodoce sp. (a)	3	45	0.15	97.01
Notomastus sp.	3	45	0.15	97.16
Spionid	3	45	0.15	97.31
Prionospio sp. (a)	3	45	0.15	97.46
Prionospio sp. (c)	3	45	0.15	97.61
Prionospio sp. (j)	3	45	0.15	97.76
Codaka pectinella	3	45	0.15	97.91
Synaptulid (b)	3	45	0.15	98.06
Nemertean (d)	3	45	0.15	98.21
Branchiostoma caribaeum	2	54	0.10	98.31
Enteropneusta sp.	2	54	0.10	98.41
Sipunculid (a)	2	54	0.10	98.51
Speocarcinus sp.	2	54	0.10	98.61
Axius sp.	2	54	0.10	98.71
Tagelus sp.	2	54	0.10	98.81
Poecilochaetus sp. (b)	2	54	0.10	98.91
Hipponoa sp.	2	54	0.10	99.01
Polyodontes sp.	2	54	0.10	99.11
17 Others	1	63-79	0.05	100.00
Total	1943	79 spp.		