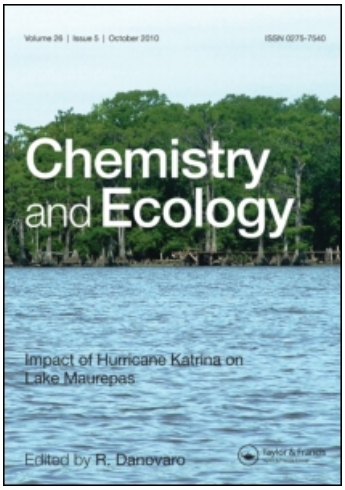

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

The Water Quality of Kingston Harbour: Evaluating the Use of the Planktonic Community and Traditional Water Quality Indices

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To cite this Article Webber, Dale F. and Webber, Mona K.(1998) 'The Water Quality of Kingston Harbour: Evaluating the Use of the Planktonic Community and Traditional Water Quality Indices', Chemistry and Ecology, 14: 3, 357 — 374
To link to this Article: DOI: 10.1080/02757549808037614
URL: http://dx.doi.org/10.1080/02757549808037614

Chemistry and Ecology, 1998, Vol. 14, pp. 357–374
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THE WATER QUALITY OF KINGSTON HARBOUR: EVALUATING THE USE OF THE PLANKTONIC COMMUNITY AND TRADITIONAL WATER QUALITY INDICES

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(Received 10 April 1997; In final form 6 February 1998)

Kingston Harbour has been experiencing increased levels of organic pollution since initial ecological assessments in 1971. To develop a new baseline of eutrophication in the Harbour 20 years later, and determine the most appropriate indices to be used in the continued monitoring the area, the water quality of Kingston Harbour was reassessed between December 1992 and 1993, by contemporaneous sampling of traditional water column parameters and planktonic communities at 28 stations within the Harbour. Indices used for water quality assessment were temperature, salinity, light penetration, dissolved oxygen, BOD and nutrients (nitrates–N, phosphate–P and ammonia–N). Results indicated that the planktonic community provided the most reliable index of increased eutrophication and changes in water quality. While physical variables indicated little change in Harbour waters and chemical variables indicated significant but erratic changes, the planktonic community displayed the classic characteristics of eutrophication. Phytoplankton biomass (a maximum of 148 mg m^{-3} chlorophyll *a*) was 5 to 10 times greater than in 1971 while zooplankton abundances (maximum of 80,000 animals m^{-3}) were 4 times greater. In both cases the community composition had altered and there were fewer taxa than previously found.

Keywords: Water quality; eutrophication; plankton; Jamaica

INTRODUCTION

Kingston Harbour, located on the south coast of Jamaica, is one of the most polluted harbours in the Caribbean. Metropolitan Kingston situated on the north shore of the Harbour (Fig. 1) now has a

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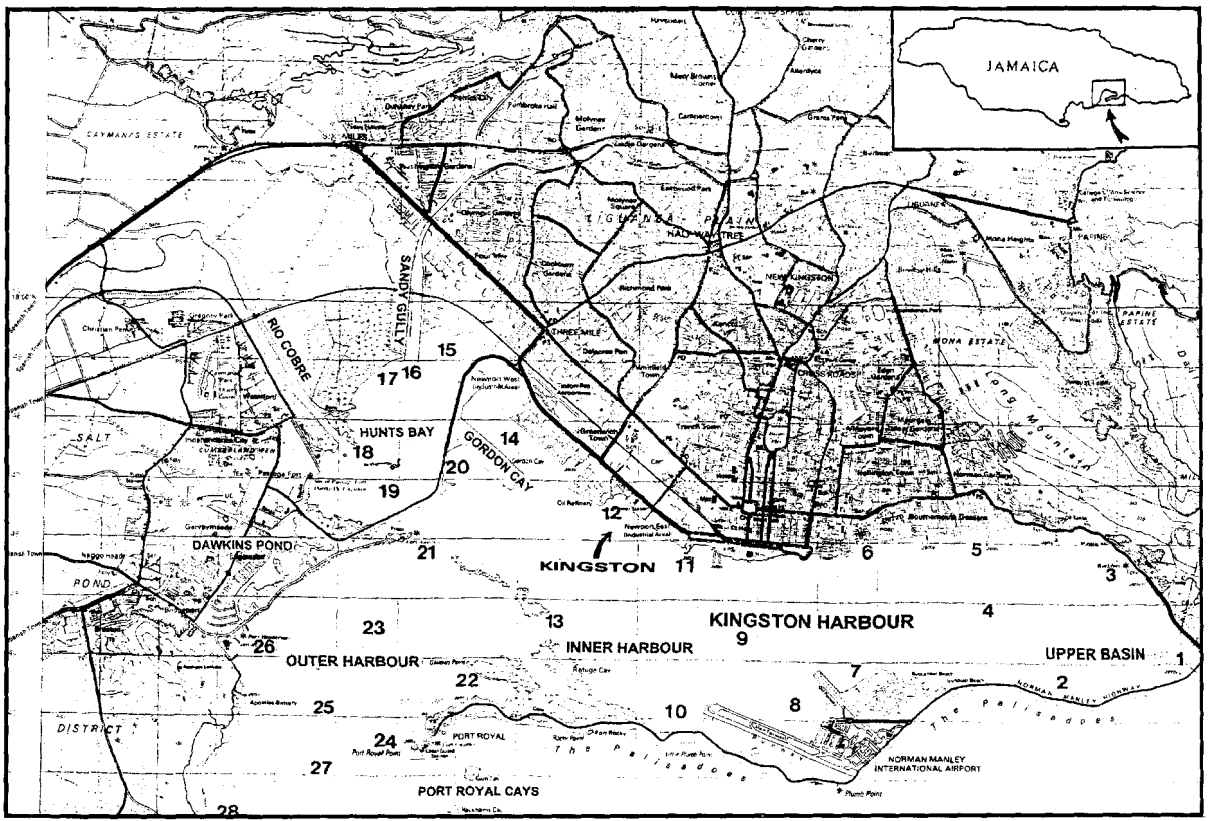

FIGURE 1 Map of Kingston Harbour showing sampling stations, Hunts Bay and the City of Kingston.

population of approximately 750,000, rising from 480,000 in the 1970's, and is expected to increase by another 10% by the year 2000. Several manufacturing complexes are located on the shores of the Harbour. It houses major trans-shipment ports (Newport East and West) and as such plays a significant role in the supply of goods for the island as well as the earning of foreign exchange. The degree of pollution suffered by Kingston Harbour has important consequences for those using the Harbour, and as pollution levels increase, discharge from Kingston Harbour has affected the nearby Port Royal Cays (Webber *et al.*, 1996) and Hellshire Coastline (Lindo, 1991; Webber and Roff, 1996) under normal conditions and especially in response to extreme flooding (Webber *et al.*, 1992).

Kingston Harbour has been reported as an area of very high biological productivity (Steven, 1965; Grahame, 1976 and 1977) and the site of several confirmed and unconfirmed plankton blooms (Steven, 1966; Goodbody, 1970; Wade, 1971). Moore and Sander (1982) also reported Kingston Harbour as being a highly eutrophic area. Almost twenty years have elapsed since the last detailed investigation of the waters of Kingston Harbour. During this time the quantities and sources of eutrophication have increased with increased urbanization and population growth in and around the city of Kingston. The discharge of untreated sewage, which is the major source of contamination, has increased from 12 to 21 mgd (million gallon per day), with significant increase in BOD and an alarming 240% increase in coliform bacteria in some parts of the Harbour (Wade, 1972; Sidrak, 1993). Hunts Bay (Fig. 1) receives agricultural runoff from the Rio Cobre drainage basin which covers an area of 770 km^2. Formally this drainage basin was completely forested, but large areas are currently under cultivation employing agricultural practices which result in increasing levels of nutrient loading and particulates in the discharge. The present study will attempt to determine the present levels of eutrophication in Kingston Harbour in light of the continued and increasing organic pollution.

The Harbour is described as a bar-built estuary (Wade, 1972) bordered on the south by the Palisadoes spit and on the north, east and west by the mainland coast (Fig. 1). It extends 16.7 km in a east-west direction and between 2.8 and 6.5 km in a north-south direction; covering an area of $\sim 50\,km^2$. There are two main basins (Inner and

Outer) which range in depth from 9.7 to 18.3 m, the deepest portions being at the entrance and the eastern ends. The Harbour has been previously zoned according to pollution levels and bathymetry (Wade, 1976) into the Upper Basin, Inner Harbour, Outer Harbour and Hunt's Bay (Fig. 1). The present study will also seek to validate these zones or suggest a new zoning in relation to pollution levels.

The main objective of this study was to evaluate the importance of phytoplankton and zooplankton as indicators of water quality, while assessing the existing water quality of Kingston Harbour, thus producing a new baseline of conditions.

METHODS

Sampling was conducted on six occasions between December 1992 and 1993. Collections were made from twenty-eight (28) stations throughout the Harbour (Fig. 1). Samples collected were processed for nutrients (NH_3-N, NO_3-N+NO_2-N and PO_4-P), phytoplankton biomass and abundance, and biochemical oxygen demand (BOD) while measurements of light penetration, temperature, salinity and dissolved oxygen were made *in situ*.

Light penetration was determined at each station using a Licor integrating quantum radiometer/photometer (model no. LI 188 B). Temperature, and dissolved oxygen were recorded using a YSI dissolved oxygen/temperature meter $\pm 0.5°C$; $\pm 0.1\ mg\ l^{-1}$ DO, and a Kahl Scientific Instruments temperature meter $\pm 0.1°C$. The average temperature was taken as the mean from the two instruments. Salinity was determined using a YSI Temperature/Salinity meter ± 0.5 ppt with confirmation of random samples determined by the silver nitrate titration method (Strickland and Parsons, 1972).

The biological demand (BOD_5) was determined from differential dissolved oxygen readings before and after a 300 ml volume of sample water was incubated at 20°C as described in Standard Methods for the Examination of Water and Waste Water.

Ammonia nitrogen (NH_3-N) was determined using a Pulse Instruments Auto-Analyzer with accuracy $\pm 0.05\ \mu g\ at\ l^{-1}$. Nitrate nitrogen ($NO_3-N$), was determined using the cadmium reduction column with accuracy $\pm 0.5\ \mu g\ at\ l^{-1}$ and a micro-reduction column in

an Auto-Analyzer with accuracy $\pm 0.05\,\mu g\,at\,l^{-1}$. Phosphate phosphorus ($PO_4-P$) was determined using two methods, the colourimetric Vanado molybdic acid method and the ascorbic acid method with colourimetric determination on the Auto-Analyzer.

Phytoplankton samples were collected in a six litre Niskin whole water bottle sampler. Samples were kept in a dark cool place to prevent light shock before filtration was possible, maximum holding time being five hours (Parsons *et al.*, 1984). One litre of the whole water sample was filtered through a nalgene size fractionating tower, which separated the phytoplankton into three sizes. Each size was trapped on the appropriate filter using a millepore vacuum pump with 10 to 20 cm Hg pressure (Li and Dickie, 1985). The pore size of each filter used were: Nitex screening – 20 μm (net plankton); Whatman glass fibre filters, GFD – 2.7 μm (nanoplankton); Whatman glass fibre filters, GFF – 0.7 μm (picoplankton). Chlorophyll-*a* present was determined from 90% v/w acetone extractions (Lorenzen and Jeffery, 1978) using a Turner fluorometer (model no. 111A). Corrections were made to compensate for the residual water content of the GFD and GFF filters (Hopcroft, 1988). A 230 ml aliquots of the water sample were fixed immediately upon collection with 3 ml additions of Lugol's iodine solution for later identification (Steidinger, 1979). Samples were homogenised and 100 ml volumes poured into settling chambers which were allowed to stand for three to five hours before examination. Examinations were carried out using a Leitz Labovert (model no. 020-435.025) inverted microscope (Utermohl, 1958). Phytoplankton cells were identified from forty random fields of view to remove edge effect with the objective of recording the presence of indicators.

Zooplankton collections were made with a 200 μm mesh plankton net with a hoop diameter of 0.5 m (SCOR, WP2 pattern). Vertical hauls were conducted throughout the water column at all except the stations inside Hunts Bay where horizontal surface (~ 0.5 m depth) tows in a circular path were used. The filtering efficiency of the net throughout the sampling area was determined and applied to the calculations of numbers per volume of sea water filtered. Samples were immediately fixed in the field using 10 ml of full strength formalin which was later made up to 10% formalin.

Identification and counting of the zooplankton were conducted on a sub-sample obtained using the beaker split method. The sub-sample

was transferred to a Bogorov tray (Wickstead, 1976) and counted on a Wild binocular microscope. Sampling and sub-sampling techniques were assessed by determining a coefficient of variation (% CV). Sampling % CV throughout the area ranged from 2.2 to 25.9 ($n = 5$) while the mean sub-sampling variability ($n = 5$) was 7.5%. Biomass determinations were made from distilled water washed portions of the sample dried to constant weight at 60°C.

RESULTS AND DISCUSSION

The assessment of water quality has been conducted for some time using a variety of indices. Nutrients, water clarity, biochemical oxygen demand, chemical contaminants and bacteria are the indices frequently employed. Although tedious to analyse, the planktonic communities are perhaps the most reliable tool in the assessment of water quality and possible changes due to eutrophication. This can be attributed to the rapid nutrient uptake kinetics of the phytoplankton (Satsmadjis, 1985), short generation times, motile existence and reaction with pollutants such as oils and toxins. Numerous studies have used the planktonic community to indicate changes in water quality due to eutrophication (Youngbluth, 1976; Miki, 1985) but few, if any, have conducted a systematic evaluation of the plankton and other indices as pollution indicators.

The highest dissolved oxygen (DO) values were recorded at station 16 at the mouth of the Sandy Gully, station 15 in Hunts Bay and station 14 between Gordon Cay and Newport West (Fig. 2). These supersaturation values ($> 7.56\,mg\,l^{-1}$) were not surprising since these stations were also observed to support high phytoplankton biomass (see below). The lowest surface DO was in excess of $4.0\,mg\,l^{-1}$ but this value decreased rapidly with increasing depth to anoxia especially in Hunts Bay. During the present study dissolved oxygen values in surface waters indicated that there was no distinct difference between Inner Harbour, Upper Basin and Outer Harbour (ANOVA, $p = 0.017$), while these distinctions were clearly made in the Wade (1976) study. It should be noted that the climatic conditions over the months of sampling were such that strong winds produced choppy seas and

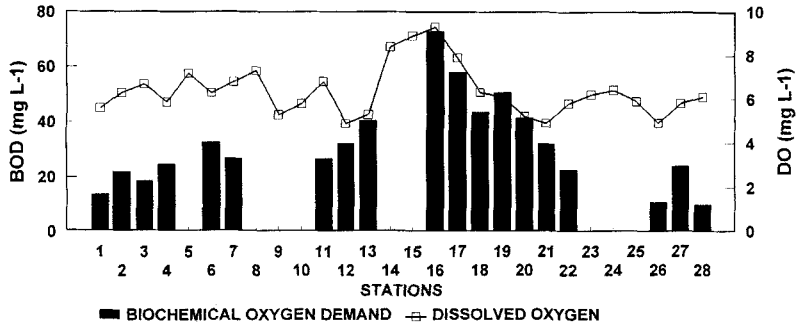

FIGURE 2 Mean values of biochemical oxygen demand, and dissolved oxygen sampled in Kingston Harbour.

significant mixing within the Harbour. This perhaps accounted for the lack of spatial variation in DO in the Harbour waters.

Biochemical oxygen demand (BOD_5) was greatest in Hunts Bay especially at the outflow of Sandy Gully (Fig. 2). While values during Wade's study ranged from 3.51 (Outer Harbour) to 48 $mg\,l^{-1}$ at New Port East, during the present study values ranged from 5.5 to 75.2 $mg\,l^{-1}$ in the Outer Harbour and Hunts Bay, respectively. It is widely accepted that BOD_5 values greater than 70 $mg\,l^{-1}$ are indicative of high organic pollution, usually due to introduction of untreated sewage.

Salinities were significantly different across the Harbour (ANOVA, $p = 0.003$) with stations in and near Hunts Bay having consistently lower salinities than the rest of the Harbour (Fig. 3), as expected since Hunts Bay receives significant fluvial input from Rio Cobre and Sandy Gully. Wade (1976) similarly recorded lowered salinities in Hunts Bay and also attributed this to fluvial inputs. There was little horizontal spatial variation in temperature over the entire Harbour (Fig. 3), as is typical of tropical coastal systems. Wade (1976) also recorded similar small temperature variations.

Throughout the Harbour, light penetration values were significantly different (ANOVA, $p = 0.0026$). Again, areas with the worst water clarity (low light penetration) were inside Hunts Bay and at the mouth of Dawkins Pond, as was reported by Wade in 1976. The highest light penetration values, indicating the best water clarity, were recorded at stations 6 and 7 ("Inner Harbour" region) and stations 25 and 28

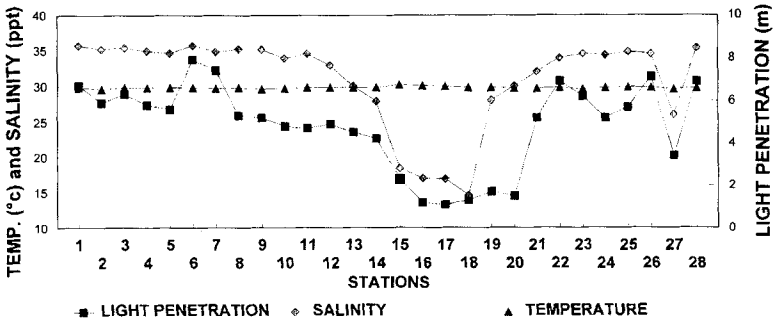

FIGURE 3 Mean values of temperature, salinity and light penetration sampled in Kingston Harbour.

located at the Harbour mouth (Fig. 3). These results further suggested that the water clarity of the "Inner Harbour" had improved over the 20 year period since Wade (1976) and Grahame (1976 and 1977) reported, but that of Hunts Bay had worsened. This reduction in water clarity at Hunts Bay was perhaps attributable to high planktonic turbidity.

The determination of water quality by a reduction in water clarity may be inconclusive if conducted in the absence of the plankton. Water clarity may be affected by sediment load or silting (non-biological turbidity) usually associated with surface run off, or by the presence of phytoplankton and zooplankton (biological turbidity). While non-biological turbidity may be a temporary feature associated with wind or wave action, biological turbidity is a feature of increased eutrophication. Thus, an index such as water clarity would be interpreted best when associated with plankton data collection. Water quality should therefore be assessed best by the pooling of a number indices and the integrated interpretation of contemporaneously collected data.

There was no significant spatial variation in nutrient concentrations throughout the Harbour (ANOVA, $p = 0.13$). Hunts Bay and Gordon Cay did not show the expected maximum nutrient values when compared to the rest of the Harbour. These areas were expected to have maximum nutrient values since the waters there receive major nutrient inputs (Station 14 receives more than 12 mgd from Greenwich sewage treatment plant and Stations 15 to 20 receive agricultural

runoff from the Rio Cobre and the Fresh River as well as domestic and industrial waste from Sandy Gully). The highest ammonia and phosphate values were in areas affected by Dawkins Pond. The highest nitrate value was recorded in the upper basin (Fig. 4). Ammonia concentrations were low throughout the Harbour, which is similar to Wade (1976) who reported ammonia concentrations being below detection limits of his method and thus not determined. Nitrates were alarmingly high, and in some areas 10 times greater than that reported during Wade's study but not in areas where maximum values were expected, *i.e.*, associated with known sewage outfalls. However, phosphates occurred in similar quantities to those found by Wade and in some areas were lower. This may have provided the limiting factor preventing constant plankton blooms over the entire Harbour, considering the high nitrate values (Hecky and Kilham, 1988).

Nutrient inputs are accurately detected in aquatic environments only if present in a sufficiently high concentration (greater than the detection limits of standard techniques) and if sampling is conducted at the exact moment of nutrient release. This is especially relevant in waters where nutrient release is sporadic and ranges from intermittent torrents to constant trickles. Moreover, the nutrients detected in the water column may not reflect the quantities released since these are residual nutrients after algal absorption. Thus, as an index of water quality, nutrient sampling should be associated with phytoplankton data collection or interpreted with caution.

Surprisingly, areas with lowered salinity and water clarity, evidently receiving fresh water inputs, were not recorded as having high nutrient

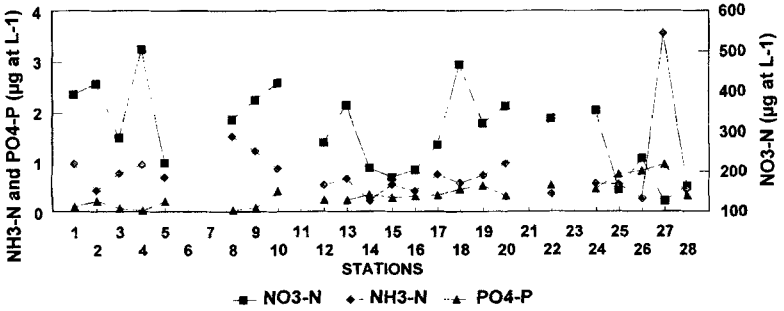

FIGURE 4 Mean values of nitrate – N, ammonia – N and phosphate – P sampled in Kingston Harbour.

inputs, but, they were recorded as having very high phytoplankton biomass and low fluctuation (see below). It may be concluded that high nutrient input does occur regularly in these areas but the nutrients are rapidly absorbed and utilised by the phytoplankton and removed from the water column (Fichez *et al.*, 1992; Gallegos *et al.*, 1992).

Size fractionated phytoplankton biomass (chlorophyll-*a*) in surface waters of the Harbour (Fig. 5) varied from a minimum value of $0.453\,mg\,m^{-3}$ in the Outer Harbour (similar to Grahame, 1977) to a maximum value of $147.98\,mg\,m^{-3}$ during a bloom at station 14 (more than ten times greater than Grahame's highest values throughout the Harbour). Station 14 is situated in a sheltered area behind Gordon Cay, and receives large volumes of effluent from the Greenwich treatment plant, and hence high nutrient concentrations. Moreover, water is entrained in this semi-enclosed area by the prevailing southeast winds that affect the Harbour. The extremely high biomass observed there is in fact eight times greater than biomass values reported from eutrophic bays and harbours around the world (Beeton and Edmondson, 1972; Thompson and Ho, 1981; Alpine and Cloern, 1992) and five times greater than the most productive bay in the

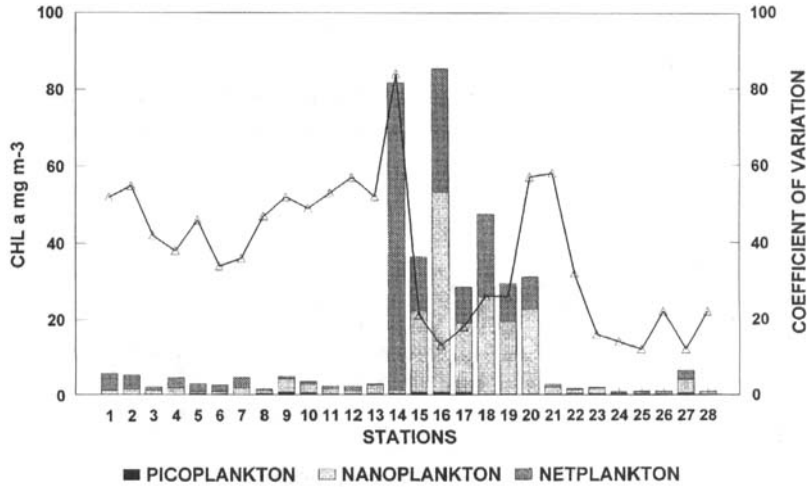

FIGURE 5 Mean size fractionated phytoplankton biomass and % coefficient of variation at stations sampled in Kingston Harbour.

Kingston/Hellshire region sampled immediately after flood rains (Webber *et al.*, 1992). The biomass during this bloom was also at least double the biomass recorded in Hunts Bay on the same day and represented a totally different phytoplankton community. This was evident from the different size fractions which dominated each area (net plankton at station 14, predominantly *Ceratium furca*, and nanoplankton at station 16 in Hunts Bay, *Trichodesmium thiebautii*). The presence of larger net plankton at station 14 is confirmation of high nutrient availability, while the high coefficient of variation in phytoplankton biomass indicates the irregularity of these high nutrient inputs. The dominance of intermediary size nanoplankton at station 16 with a mean biomass value comparable to station 14, but very low coefficient of variation, indicates nutrient additions of a lower magnitude but with greater regularity. The mean phytoplankton values for the sampling period (Fig. 5) which ranged between 1 and 82 $mg\,m^{-3}$ (up to five times greater than Grahame, 1977), and the high coefficient of variation, especially in the Inner Harbour, is indicative of episodic phytoplankton biomass due to pulses of high nutrient additions. These observations are widely accepted as characteristics of eutrophic waters (Moore and Sander, 1982; Alpine and Cloern, 1992; Webber *et al.*, 1992). These observations of proliferation under eutrophic conditions are confirmed by high phytoplankton abundance in Hunts Bay and at Gordon Cay of 29×10^8 cells l^{-1}.

Zooplankton abundances in this study ranged from 3,042 to 80,150 m^{-3} and were at maximum 4 times greater than the maximum reported by Grahame (1976) which ranged from 2,275 to 20,837, suggesting increased europhication and the accompanying increase in food and grazer population size. However, in some areas (*e.g.*, Hunts Bay) zooplankton abundances have decreased with increased eutrophication over the last 20 years indicating a severe reduction in the water quality whose effect supercedes the increase in food. The distribution of total zooplankton abundance (which was mirrored by biomass) showed a pattern of high numbers in the Inner and Outer Harbour zones, lower numbers in the Upper Basin and lowest in Hunts Bay; especially at stations 15, 16, 17 and 18 (Fig. 6). The zooplankton at these stations were probably deleteriously affected by lowered salinities, which is similar to findings by Webber *et al.* (1992) in response to severe flooding. Furthermore, these lowered zooplankton

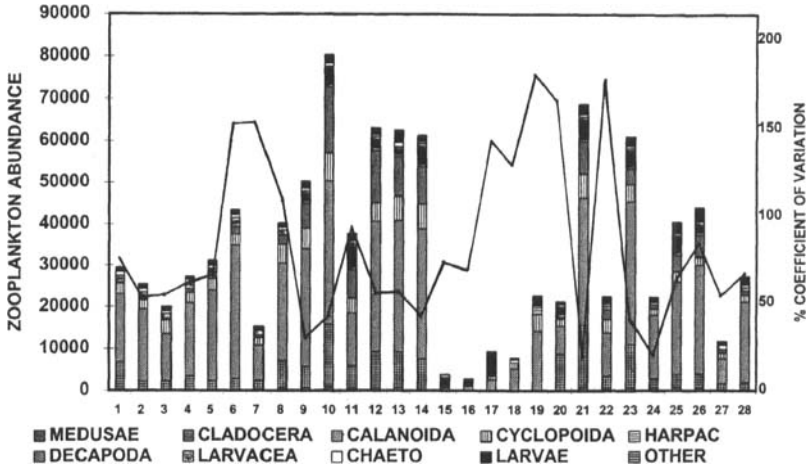

FIGURE 6 Mean zooplankton numbers per m^{-3} for dominant taxa and % coefficient of variation for total abundance at stations sampled in Kingston Harbour.

abundances could be due to the presence of toxic phytoplankton, *Alexandrium minutum*, *Scrippsiella* sp. and *Oxytoxum* sp., and high pesticide levels reported by Mansingh and Wilson (1995).

While showing significant spatial variation (ANOVA, $p < 0.0001$), the zooplankton abundance did not indicate a clear spatial pattern, with the exception of lowest numbers occurring in Hunts Bay (Fig. 5). This indicates an inverse relationship between phytoplankton and zooplankton densities which was previously suggested for this area by Moore and Sander (1982).

As expected the calanoid copepods were the dominant taxon (Clarke and Roff, 1990), but different species were responsible for this dominance in each zone of the Harbour. In the Upper Basin and, to a lesser extent, Inner Harbour, *Temora turbinata* dominated. Hunts Bay was dominated by *Acartia tonsa* and the Outer Harbour by *Paracalanus crassorostris* (Tab. I). The decapod, *Lucifer faxoni*, formerly reported as an indicator of Kingston Harbour waters, was only dominant in the Inner Harbour and to a lesser extent, the Outer Harbour. *Penilia avirostris* which was also previously reported as a "Harbour indicator" was only important at station 10 (Inner Harbour) and stations 21 and 23 (Outer Harbour). This reduced

TABLE I Numerically dominant members of the phytoplankton and zooplankton communities in the different zones of Kingston Harbour

Phytoplankton		*Zooplankton*	
Group 1 (Upper Basin and Inner Harbour)		Group 1 (Upper Basin)	
Ceratium furca	25%	*Temora turbinata*	26%
Ceratium fusus	14%	*Oikopleura sp.*	21%
Coscinodiscus wailesii	13%	*Penilia avirostris*	10%
Prorcentrum gracile	10%	*Corycaeus sp.*	9%
Trichodesmium erythreaum	9%	*Sagitta hispida*	6%
Nitzschia pungens	6%	*Acartia tonsa*	6%
Ceratium trichoceros	5%	*Oithona sp.*	5%
Rhizosolenia robusta	3%	Decapod larvae	4%
Group 2 (Gordon Cay)		Group 2 (Inner Harbour)	
Ceratium furca	47%	*Temora turbinata*	23%
Nitzschia pungens	13%	*Lucifer faxoni*	21%
Coscinodiscus wailesii	12%	*Oikopleura sp.*	19%
Pyrophacus horologium	6%	*Oithona sp.*	10%
Rhizosolenia robusta	3%	*Evadne tergestina*	8%
		Penilia avirostris	6%
Group 3 (Hunts Bay)		Group 3 (Hunts Bay)	
Trichodesmium thiebautii	41%	*Acartia tonsa*	40%
Gonyaulax turbynei	17%	*Obelia sp.*	31%
Alexandrium minutum	12%	Cirripede nauplius	11%
Nitzschia pungens	11%	Decapod larvae	5%
Ceratium furca	4%	*Oithona* sp.	3%
Group 4 (Outer Harbour)		Group 4 (Outer Harbour)	
Rhizosolenia robusta	20%	*Paracalanus crassorostris*	17%
Coscinodiscus wailesii	11%	*Oikopleura dioca*	17%
Navicula cancellata	9%	*Centropages furcatus*	15%
Biddulphia aurita	5%	*Lucifer faxoni*	11%
Chaetoceros didymus	4%	*Evadne tergestina*	11%
Nitzschia pungens	4%	*Oithona occulata*	7%
Ceratium trichoceros	5%	*Acartia lljeborgi*	5%
Ceratium furca	4%	Fish eggs/larvae	5%
		Decapod larvae	3%

number of "Harbour indicators" suggests significant changes in Harbour waters over the last 20 years.

Although biomass spatial distribution pattern mirrored that of the abundances, the values (range of 0.021 to 0.104 $g\,m^{-3}$) in present years are similar to those reported 20 years ago (range of 0.04 to 0.123 $g\,m^{-3}$), suggesting that the increased abundances are due to the presence of smaller taxonomic groups. This is expected as

eutrophication increases the community becomes dominated by small herbivorous zooplankton (Moore and Sander, 1982).

Phytoplankton and zooplankton species enumeration suggest that fewer species were found during the present study than found by Grahame in 1970–73. The reduction in species is typical of increasing eutrophication where the less hardy species die and the more tolerant proliferate. These conditions often lead to the development of phytoplankton blooms (see below). The mean number of species varied significantly (ANOVA, $p = 0.043$), indicated that the spatial variation in water quality with Hunts Bay having lowest number of species and the Outer Harbour, especially due to the phytoplankton, having the highest (Fig. 7). Inner Harbour and Upper Basin were indistinguishable with respect to number of species, suggesting the possible merging of these two zones (Figs. 7 and 8). The % CV accompanying both number of species plots indicate highest temporal variability in Hunts Bay, albeit for different reasons. In the case of the phytoplankton there was often an introduction of a fresh water community after significant rainfall, while for the zooplankton the variability was caused by the fluctuation of numerically insignificant members while the two dominant species (Tab. I) remained constant.

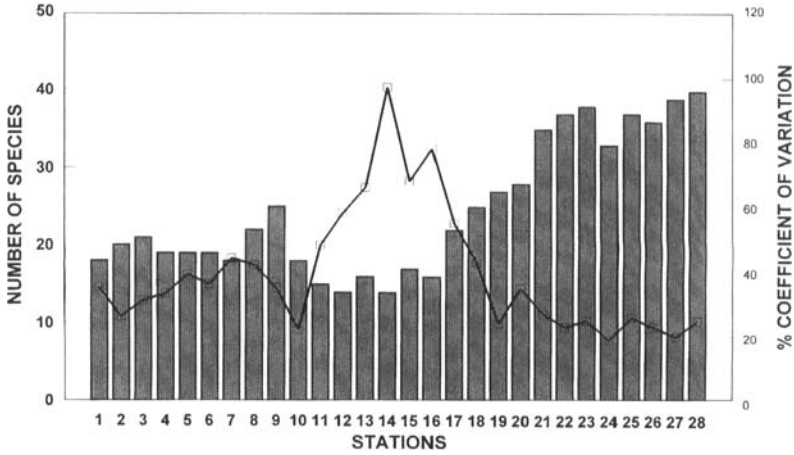

FIGURE 7 Mean number of phytoplankton species and % coefficient of variation at stations sampled in Kingston Harbour.

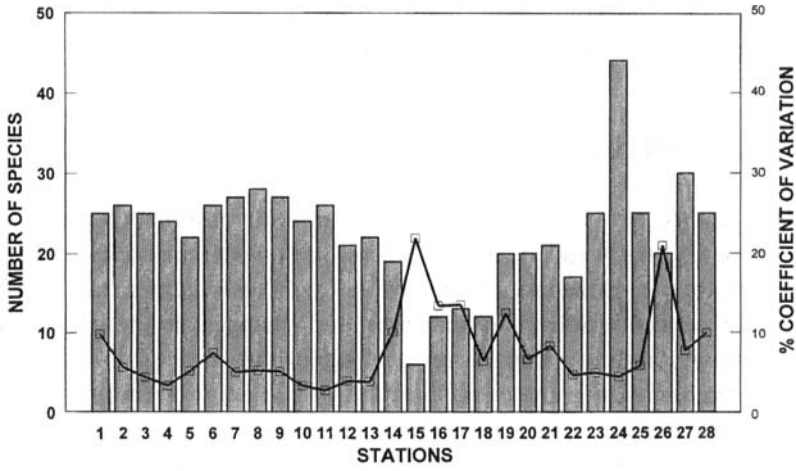

FIGURE 8 Mean number of zooplankton species and % coefficient of variation at stations sampled in Kingston Harbour.

Plankton blooms which are now a common feature in Kingston Harbour are characteristically dominated by one or two organisms which can make use of exceptional conditions to grow and reproduce rapidly (Paerl, 1988). Two organisms responsible for many previously reported blooms in Kingston Harbour, *Gonyaulax turbynei* and *Nitzchia pungens* (Grahame, 1977) have been shown to resist pesticide toxicity which often accompany land derived nutrient enrichment. Extensive but irregular and short lived blooms were recorded due to a proliferation of the organism, *Coscinodiscus* sp. (found frequently by Grahame, 1977 and during the present study). This "bloom and crash" phenomenon is an indication of eutrophication stress.

The phytoplankton and zooplankton species dominating the four main regions of Kingston Harbour support the redefining of Harbour zones based on water quality. On the basis of size fractionated phytoplankton biomass and species present at each station, the "Upper Basin" and "Inner Harbour" as described by Wade (1976) seem quite similar to each other, but generally worse than during the 1970s. The "Outer Harbour" as described by Wade, is in the least eutrophic condition, with the exception of station 26 which is situated at the mouth of Dawkins Pond. The similarity in species composition

of station 26 to Hunts Bay indicates that Dawkins Pond and Hunts Bay may still be connected subterraneously.

CONCLUSIONS

The results of this study indicate that with respect to physical parameters, the water quality of Kingston Harbour has not changed significantly over the last 20 years (1970s to 1990s) but increases in the nitrate concentrations and increases and changes in the plankton community indicate that there is a significant and in some cases alarming increase in the eutrophication of Kingston Harbour waters. This confirms that assessments dependent on physical parameters and nutrients as indicators of eutrophication are unreliable when not conducted in conjunction with studies of the biota.

The primary limitation of this study concerns the fact that the sampling was conducted irregularly over a 12 month period and thus the range of conditions possible over the annual cycle may not have been experienced. The gains, however, include the identification of the best combination of parameters for monitoring water quality of Kingston Harbour, these methods and indices providing a tool which can be used to assess and continually monitor the water quality in this and similar water bodies.

Acknowledgements

We wish to thank the staff of the Port Royal Marine Laboratory and the team of U.W.I. students (Miss E. Ranston, Miss R. Simmonds, Miss F. Dunbar and Mr. T. Clarke) who assisted in the collection of samples. Funding was provided by the departments of Botany, Zoology and the Centre for Marine Sciences, U.W.I.

References

Alpine, A. E. and Cloern, J. E. (1992) Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. *Limnology and Oceanography*, **37**, 946–955.

Beeton, A. M. and Edmondson, W. T. (1972) The eutrophication problem. *Journal of Fisheries Research Board of Canada*, **29**, 673–682.

Clarke, C. and Roff, J. C. (1990) Abundance and biomass of herbivorous zooplankton off Kingston, Jamaica, with estimates of their annual production. *Estuarine Coastal and Shelf Science*, **31**, 423–437.

Fichez, R., Jickells, T. D. and Edmunds, H. M. (1992) Algal blooms in high turbidity, a result of the conflicting consequences of turbulence on nutrient cycling in a shallow water estuary. *Estuarine, Coastal and Shelf Science*, **35**, 577–592.

Gallegos, C. L., Jordan, T. E. and Correll, D. L. (1992) Event-scale response of phytoplankton to watershed inputs in a sub-estuary: timing, magnitude and location of blooms. *Limnology and Oceanography*, **37**, 813–828.

Goodbody, I. M. (1970) The Biology of Kingston Harbour. *Information Bulletin of S.R.C. Ja.*, **1**, 10–34.

Grahame, J. (1976) Zooplankton of a tropical harbour: The numbers, composition, and response to physical factors of the zooplankton in Kingston Harbour, Jamaica. *Journal of Exploratory Marine Biology and Ecology*, **25**, 219–237.

Grahame, E. S. (1977) *The Ecology of Plankton in Kingston Harbour, Jamaica.* Scientific report of the S.R.C./U.W.I. Harbour Plankton Project, 1970–1973. Part 2: The Phytoplankton. Research report from the Zoology Dept. U.W.I. Kingston, Jamaica, (4), pp. 104.

Hecky, R. E. and Kilham, P. (1988) Nutrient limitation of phytoplankton in fresh water and marine environments: A review of recent evidence on the effects of enrichment. *Limnology and Oceanography*, **33**, 796–822.

Hopcroft, R. (1988) Size fractionated biomass and primary production of tropical neritic phytoplankton near Kingston, Jamaica. M.Sc. Thesis, University of Guelph, Canada, pp. 130.

Li, W. K. W. and Dickie, P. M. (1985) Growth of bacteria in sea water filtered through 0.2 μm nucleopore membranes: Implications for dilution experiments. *Marine Ecology Progress Series*, **26**, 245–252.

Lindo, M. K. (1991) The effect of Kingston Harbour outflow on the zooplankton populations of Hellshire, south-east coast Jamaica. *Estuarine Coastal and Shelf Science*, **32**, 597–608.

Lorenzen, C. J. and Jeffrey, S. W. (1978) Determination of chlorophyll in sea water. Report of intercalibration tests, sponsored by SCOR and carried out in Sept.–Oct. 1978. UNESCO Technical Papers in Marine Science, **35**, pp. 8.

Mansingh, A. and Wilson, A. (1995) Insecticide contamination of Jamaican environment. III. Baseline studies on the status of insecticide pollution of Kingston Harbour. *Marine Pollution Bulletin*, **30**, 649–645.

Miki, K. (1985) A mechanism of the establishment of phytoplankton community structure. Particular emphasis on the environmental variation of nutrients. *Japanese Journal of Limnology*, **46**, 63–64.

Moore, E. and Sander, F. (1982) Nutrient-phytoplankton-zooplankton relationships at a highly eutrophic tropical station. *Caribbean Journal of Science*, **18**, 95–102.

Paerl, H. W. (1988) Nuisance phytoplankton blooms in coastal, estuarine and inland waters. *Limnology and Oceanography*, **33**, 823–847.

Parsons, T. R., Maita, Y. and Lalli, C. M. (1984) *A Manual of Chemical and Biological Methods for Sea Water Analysis*, Pergamon Press Oxford, U.K., pp. 173.

Satsmadjis, J. (1985) Comparison of indicators of pollution in the Mediterranean. *Marine Pollution Bulletin*, **16**, 395–400.

Sidrak, G. H. (1993) Survey of total faecal coliform at selected sites in Kingston Harbour. In: Webber, D. (Ed.) *A Rapid Ecological Assessment of Kingston Harbour, Kingston Harbour Environmental Project Phase* 1 *Report.* SENTAR Consultants for National Water Commission of Jamaica, pp. 18–24.

Stedinger, K. A. (1979) Collection, enumeration and identification of free-living dinoflagellates. *Toxic Dinoflagellate Blooms.* Taylor/Selinger (Eds.) Elsevier North Holland, Inc., pp. 435–442.

Steven, D. M. (1965) Productivity of inshore waters off Jamaica, a comparative study at 4 stations. In: *Primary Productivity in the Tropical North Atlantic off Barbados and the Caribbean Sea off Jamaica*, Bermuda Biological station, Final Report submitted to Biology Branch, Office of Naval Research under contact. NONR 1135(05), pp. 64–87.

Steven, D. M. (1966) Characteristics of a red water bloom in Kingston Harbour, Jamaica, W. I. *Journal Marine Research*, **24**, 113–123.

Strickland, J. H. D. and Parsons, T. R. (1972) (2nd edn.) *A Practical Handbook for Sea water Analysis. Bulletin of the Fisheries Research Board Canada*, **167**, pp. 310.

Thompson, G. B. and Ho, J. (1981) Some effects of sewage discharge upon phytoplankton in Hong Kong. *Marine Pollution Bulletin*, **12**, 168–173.

Utermohl, H. (1958) Zur vervollkommung der qualitativen phytoplankton methodisk. *Mitteilungen Internationale Veroingung fur Theoretische und Sgeurandt Limnologie*, **9**, 1–38.

Wade, B. A. (1971) Marine pollution problems in Jamaica. *Marine Pollution Bulletin*, **2**, 1.

Wade, B. A. (1972) Benthic diversity in a tropical estuary. *The Geological Society of America Incorporated, Memoir*, **133**, 499–515.

Wade, B. A. (1976) The pollution ecology of Kingston Harbour Jamaica. 1. Scientific Report of the U.W.I./Kingston Harbour Research Project, pp. 142.

Webber, D. F., Webber, M. K. and Roff, J. C. (1992) Effects of flood waters on the planktonic community of the Hellshire coast, South-east Jamaica. *Biotropica*, **24**, 362–374.

Webber, D. F. and Roff, J. C. (1996) The influence of Kingston Harbour on the phytoplankton community of the nearshore Hellshire coast, south-east, Jamaica. *Bulletin of Marine Science*, **59**, 245–258.

Webber, M. K., Roff, J. C., Chisholm, L. A. and Clarke, C. (1996) Zooplankton distribution and community structure in an area of the South Coast Shelf of Jamaica. *Bulletin of Marine Science*, **59**, 259–270.

Wickstead, J. H. (1976) *Marine Zooplankton*, Edwards Arnold Ltd., London, pp. 59.

Youngbluth, M. J. (1976) Zooplankton populations in a polluted, tropical embayment. *Estuarine Coastal Marine Science*, **4**, 481–496.