Assessing the phytoplankton and water quality of Kingston Harbour and Hellshire coast, Jamaica, after the implementation of a waste water treatment facility

Helen A. Liu, Sheree A. Broomfield, Anya F. Duncan, Leon O. Grant, Patrice A. Francis, Dale F. Webber & Mona K. Webber

Centre for Marine Sciences, Department of Life Sciences, The University of the West Indies, Mona, Kingston 7, Jamaica W.I.; dale.webber@uwimona.edu.jm

Abstract: Deteriorating water quality of Kingston Harbour, due primarily to sewage discharge and its effect on nearby Hellshire Coast, has been an issue since the 1970s. The implementation of a new sewage treatment facility in 2007 to receive the harbour's waste at Soapberry was expected to make a positive difference. Physico-chemical and biological parameters were used to assess water quality to determine the effect of the facility. Eleven stations used in earlier studies (1990 to 1998) were re-sampled to represent Kingston, Hunts Bay and North East Hellshire coastline over a four week sampling regime between May and June 2011. While temperature, salinity, turbidity, dissolved oxygen and pH remained unchanged between the 1990's and 2011, BOD_5, faecal coliform and nitrate concentrations indicated that the water quality had improved minimally in Kinsgton and Hellshire, and deteriorated significantly in Hunts. Phytoplankton biomass decreased in Kingston (from 3.84 mg m^{-3} in 1998 to 2.81 mg m^{-3} in 2011) and increased significantly in Hunts (from 14.69 mg m^{-3} in 1998 to 24.17 mg m^{-3} in 2011). Biomass along Hellshire was similar (2.15 mg m^{-3} in 1998; 2.45 mg m^{-3} in 2011). In 1998 the nanoplankton biomass (2.7 to 20μm) dominated throughout the Harbour. In 2011 Hunts Bay was dominated by net-plankton (>20μm), indicative of eutrophic waters. Rev. Biol. Trop. 62 (Suppl. 3): 241-248. Epub 2014 September 01.

Key words: Soapberry, waste water, Kingston Harbour, Hunts Bay, Hellshire, eutrophication.

Kingston Harbour on the south east coast of the capital of Jamaica (17º58'N and 76º48'W), is a multipurpose resource with more than a half a million people and a variety of industries at its shores (Wade, 1972). These residencies and industries are the source of large volumes of waste introduced into the Harbour daily (Webber et al., 2003). Historically, the most significant point source contributors of organic pollution to the Harbour were the Greenwich and Western sewage treatment plants discharging 20mgd (Webber & Wilson-Kelly, 2003). Outflow from the eutrophic Kingston Harbour has been documented to flow southeasterly to impact the nearby recreational areas of Hellshire Coast (Webber, Webber & Roff, 1992; Webber & Roff, 1996). A new sewage treatment facility, Soapberry, was constructed and implemented in 2007 to accept and properly treat the waste from the city of Kingston. It is not however clear whether the implementation of the Soapberry system has significantly affected the water quality of Kingston Harbour and resulted in an improvement of water quality along the Hellshire Coast. A rapid ecological assessment was therefore conducted. It was designed to:

- Spatially assess and compare the existing water quality of Kingston Harbour, Hunts Bay and North East Hellshire Coastline (using physiochemical and biological indices).

- Determine if there was significant improvement or deterioration in water quality when compared to the earlier baseline studies (i.e. prior to the Soapberry waste treatment implementation).

MATERIALS AND METHODS

Sample programme: A total of four sampling sessions were conducted during the period of May 21st to June 19th, 2011, between the hours of 0700hours and 1200hours. Eleven stations (Fig. 1) were strategically selected along the North East Hellshire coastline (Stations 1-3), throughout Kingston Harbour (Stations 4–7) and in Hunts Bay (Stations 8–11), and based on previous studies by Webber and Roff (1996), Dunbar (1997), Ranston (1998) and Webber & Webber (1998). At each station physicochemical parameters were recorded using a Hydrolab Surveyor with a Datasonde 5 multi-parameter probe and whole water samples were collected at (i) the surface and (ii) 2m above the substrate (±0.10ºC temperature; ±0.2ppt Salinity; ±0.01mg l^{-1} LDO; ±1.0NTU Turbidity; and ±0.2units pH).

Whole water samples: Samples were collected from the surface (fresh water) layer as well as the underlying deeper (more saline layer) using a 6L Niskin bottle. At Hunts Bay, surface samples were collected (i) just below the surface of the water and (ii) deeper samples at 2m above the substrate using a horizontal position Niskin bottle (Ranston, 1998). An aliquot of each water sample was then transferred to 3L plastic bottles and kept in the dark until filtration was possible, generally within four hours of collection. The samples for Biochemical Oxygen Demand (BOD) analysis were collected in 300mL BOD bottles then stored on ice for three (3) hours, prior to analysis. A YSI Model 57 Oxygen meter (±0.1mg l^{-1} on 0-10 scale) was used to determine the initial dissolved oxygen of each sample. Samples were then incubated for five (5) days at 20ºC in total darkness with subsequent re-testing for dissolved oxygen (Eaton, Clesceri & Greenberg, 1995; Webber & Wilson-Kelly, 2003). The BOD_5 for each sample was derived using the formula: $BOD_5 = [(\text{Initial DO-Final DO}) \times (1\,000mL)]/300mL$).
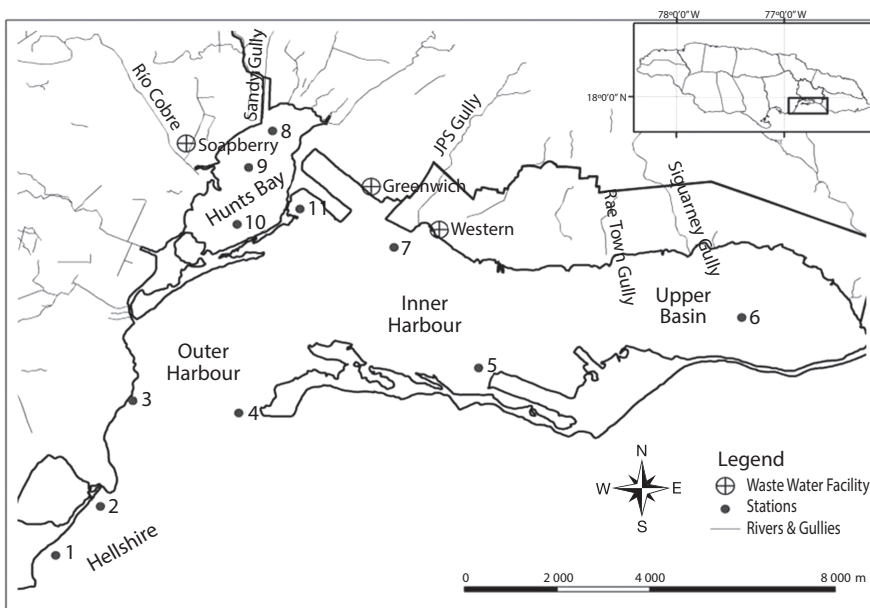

Fig. 1. Study area showing location of stations and waste water facility.

The 3L samples were filtered through a size fractioning tower with three filters of known pore sizes (Nitex screening: 20μm, Whatman glassfibre filters (GFD): 2.7μm and Whatman glassfibre filters (GFF): 0.7μm). Samples were gently homogenised prior to filtration. Two pseudo-replicates for each station at each depth were then poured through the fractionating tower. Size fractioning filtration was done within four hours of collection time (Parsons, Maita & Lalli, 1984). Each filter was rolled and then placed in labelled vials and stored in a freezer for later Chlorophyll α analysis. Chlorophyll α was extracted using 90% acetone (Parsons et al.,1984) under dark conditions for 24 hours in a refrigerator (Ranston, 1998). Each extracted sample was read on a Turner Flourometer TD-700. Values were recorded within 12 seconds of cuvettes being placed into the flourometer. Samples that contained high Chlorophyll that could not be read by the flourometer were diluted as outlined in Parsons et al. (1984). Chlorophyll α was calculated using the formula:

$$mg\ Chlorophyll\ \alpha\ m^{-3} = R\ x\ (v/V)\ x\ Dilution\ Factor$$

(Parsons et al., 1984)
Where: R = Flourometer reading; v = acetone extraction volume (mL); V = volume of seawater filtered (l)

Nutrient Analysis: Approximately 250mL of the filtrate from the size fractioning tower for each station was frozen for nutrient analysis. Nutrient samples were analysed on a Lachat QuickChem 8 000 Flow Injection Analyser ($\pm 0.001mg\ l^{-1}$), using sulfanilamide colour reagent, ammonium chloride buffer, and a cadmium reduction column. Samples were run with the cadmium column online for total nitrate+nitrite analysis, and offline for phosphate and nitrate analysis.

Bacteriological analysis: Coliform bacterial density was determined as Most Probable Number (MPN) counts using the multiple tubes fermentation technique. A series of dilutions of the samples were prepared; these dilutions

were 1.0mL, 0.1mL and 0.01mL. Five aliquots of each were inoculated into the growth medium and were incubated. A positive score was recorded whenever bubbles were formed as a result of fermentation. Lauryl Tryptose broth formed the presumptive phase and *Escherichia coli* broth medium with Durham inverted tube formed the confirmatory phase (Eaton et al., 1995).

RESULTS

The one month survey of the water quality of the Kingston Harbour provided important insight into the changes in that body of water. These changes were as a result of the introduction of a diverted sewage discharge over a short time period. The evidence of the spatial changes in key water quality parameters are divided here into physicochemical and biological indices.

Physiochemical indices: Temperature, salinity, dissolved oxygen; turbidity and pH were all within the expected ranges for coastal nearshore systems and demonstrated the spatial pattern consistent with the findings of Webber & Webber (1998). Lowest salinity and temperature accompanied by highest dissolved oxygen and pH were evident in Hunts Bay, while highest salinity and temperature and lowest pH were observed along the Hellshire Coast. There were also no significant differences in physicochemical indices in the 2011 study when compared to data collected in the surveys from the 1990's.

Nitrate-N concentrations were spatially variable with the expected increase from the previously classified mesotrophic Hellshire Coast, into the eutrophic Hunts Bay. The concentrations of nitrates were lowest along the Hellshire coast (0.63 to 0.78mg l^{-1} at stations 2 and 3), marginally higher in the Kingston Harbour (0.63 to 0.94mg l^{-1} at stations 6 and 7) and highest in Hunts Bay (1.45mg l^{-1} at station 9). While nitrate concentrations were much lower in 2011 than in the 1990's (Fig. 2) values in both studies were higher than the NEPA (2009)
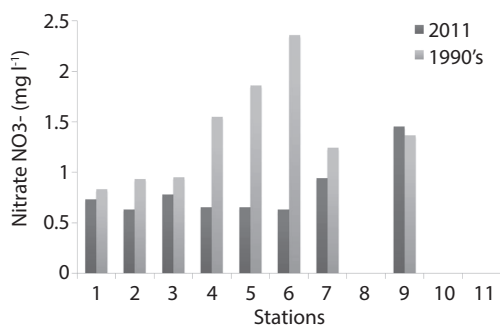
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Fig. 2. Graph comparing Nitrate NO_3 (mg l^{-1}) concentrations at stations in the 1990's and 2011 studies.

ambient marine water quality nitrate standard of 0.007-0.014 mg l^{-1}.

Biological indices: Mean phytoplankton biomass (as Chlorophyll α) in the 2011 study increased from the Hellshire Coast (1.8 to 2.19mg m^{-3} at Stations 2 and 3) into the Kingston Harbour (1.7 to 3.8mg m^{-3} at stations 6 and 7) and reached a maximum in Hunts Bay (12.6

to 33.1mg m^{-3} at stations 8–11). While this spatial pattern was similar to the 1998 studies, t-tests revealed significant difference (p= 0.02) between the two studies. The highest biomass in 1990's of 13.5 mg m^{-3} was observed in Hunts Bay with lowest values at Hellshire Bay 1.38mg m^{-3}. Phytoplankton biomass in the Kingston Harbour was however unchanged between 1990's and 1998. The single exception was at station 6 where biomass values decreased from 4.17 to 1.70 mg m^{-3} between 1998 and 2011. Both surface and deep water phytoplankton biomass in 2011 were greater than in the 1990's except at stations 9 and 11 (Hunts Bay) where sub-surface biomass in 1990's were greater than 2011 (Fig. 3a, b, c & d).

The nanoplankton biomass size fraction dominated surface waters at all stations in both the 2011 and 1990's studies, although the net plankton biomass size fraction accounted for a larger proportion of total phytoplankton biomass in the 2011 samples. This was especially so in Hunts Bay (stations 8-11) which clearly reflected that deep waters were
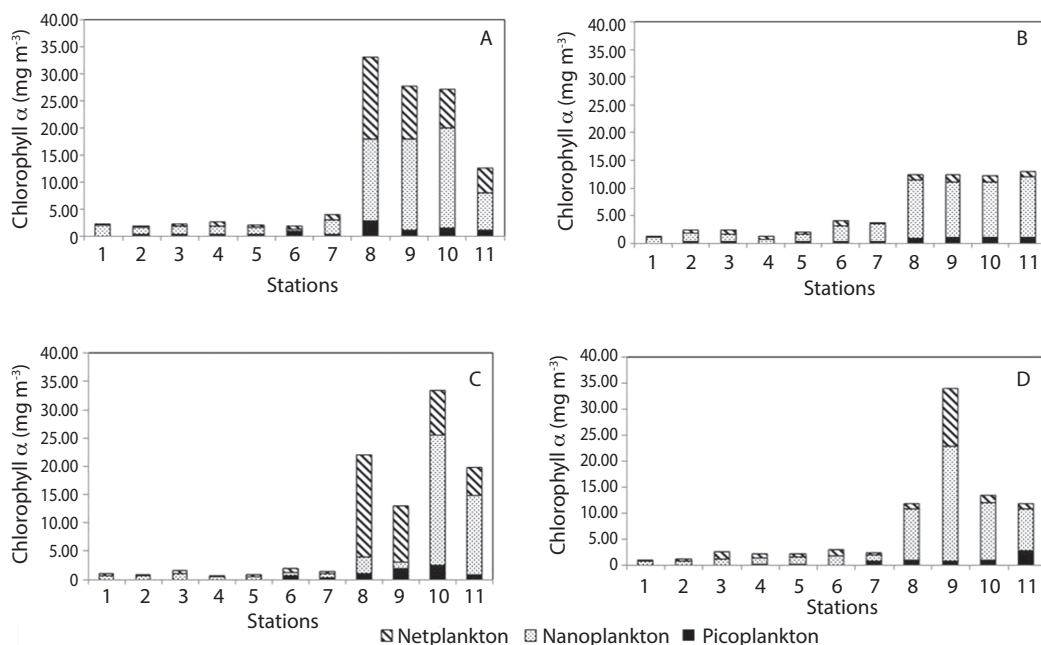

Fig. 3. Mean size fractionated biomass (mg m^{-3}) values at stations for 1990's and 2011 studies. 2011 surface, B) 1990's surface, C) 2011 deep, D) 1990's deep.

dominated by the net plankton biomass size fraction (Fig. 3c & 3d).

Faecal coliform counts increased from station 1 along Hellshire coast to station 9 in Hunts Bay (Fig. 4). Coliform concentration ranged from <20 to 1 200MPN/100mL with highest concentration at station 9, while the lowest concentrations were found at stations 1 to 3 (Hellshire Coast). Apart from station 9 in Hunts Bay all other values were below the World Health Organization (WHO) 1988 standard of 1 000MPN/100 mL (Owili, 2003) but higher than the National Environment and Planning Agency [NEPA], 2009) standard of <2-13MPN/100mL for ambient marine waters. Faecal coliform counts along the North East Hellshire coast and in the Kingston Harbour were generally lower in the 2011 (20 to 300MPN/100 mL) than the 1990's (>500MPN/100 mL) while counts in Hunts Bay were higher in 2011 (>2 400MPN/100 mL) than in the 1990's (1 200MPN/100 mL).

The BOD_5 values recorded in both studies ranged from 1 to 52mg l^{-1}. The lowest BOD_5 value was recorded along the Hellshire Coast at station 3 (2.8mg l^{-1}) in 2011 and station 1 (1mg l^{-1}) in 1990's. While samples from the Kingston Harbour were observed to have much reduced BOD_5 in 2011(4.6 to 4.9mg l^{-1}) over the 1998 data (10-35mg l^{-1}), water samples from Hunts Bay were observed to consistently have the highest BOD_5 in both studies 50 to 52mg l^{-1} (Fig. 5).

DISCUSSION

Physico-chemical parameters and the phytoplankton community were used to assess the current water quality in The Kingston Harbour, Hunts Bay and the North East Hellshire Coastline. The objectives of the study were to spatially compare the existing water quality of and to determine if there was significant change in water quality when compared to the earlier baseline studies (i.e. before the Soapberry Treatment Facility implementation).

A specified concentration of nutrients in an environment has the ability to serve as
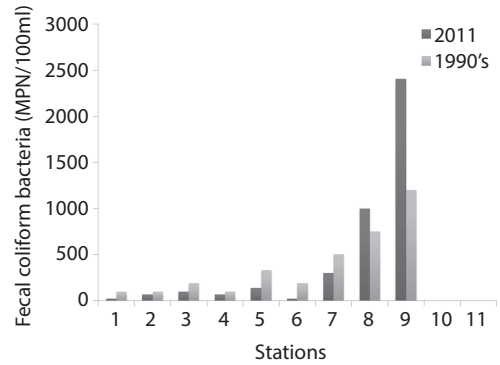

Fig. 4. Mean Faecal coliform concentrations at the stations in 1990's and 2011 studies.
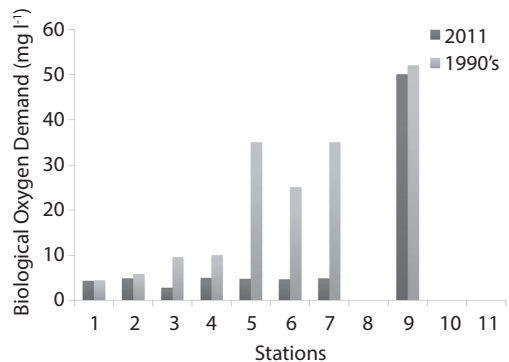

Fig 5. Mean Biological Oxygen Demand (B.O.D) concentrations at stations in 1990's and 2011 studies.

an indicator of pollution to that environment (James & Adejare, 2010). Nitrate concentrations at all sample stations were several times greater than the upper limit established by NEPA. This is due to the nutrient rich waters which enter the Harbour from sewage treatment as well as river and storm water inflow (Webber & Wilson-Kelly, 2003) as well as the nitrate recycling that is thought to take place from the benthos. Though greater than the NEPA standard, according to Seroka (2004) and James & Adejare (2010), nitrate values less than 5mg l^{-1} can still be indicative of unpolluted waters. Therefore Kingston Harbour nitrate values are not a good index of water quality. However, lower nitrate values in the Kingston Harbour and Hellshire coast suggest a reduction in

nutrient input or uptake by the biota resulting in improved water quality.

Using the Faecal coliform bacteria counts as the index, Hunts Bay, the Kingston Harbour and the Northern Hellshire Coast are all still heavily polluted based on NEPA standards for coastal waters. By WHO standards, the sample area is moderately polluted with Hunts Bay continuing to be extreme. However at the same time, Kingston Harbour and the Hellshire Coast coliform counts have reduced from the initial 1990's values indicating some improvement. These data imply that improperly treated sewage is still entering the Harbour area and that its waters are not safe for human contact with human skin. Based on the relative locations of the previous point sources (now diverted to the Soapberry Treatment Facility) and the discharge from that facility into Hunts Bay, it appears that the improvement in water quality in Kingston Harbour and Hellshire Coast and reduction in Hunts Bay are associated with the Soapberry Treatment Facility implementation.

Biochemical Oxygen Demand values obtained for each station surpassed the range ($1.16mg$ l^{-1}) set out by NEPA for ambient marine water. This suggests a general poor water quality throughout the area. Although all values were in excess of the national threshold (i.e. NEPA), the spatial differences observed were not unexpected. That is, with Hunts Bay having the highest BOD_5 and thus the poorest water quality and the Harbour and Hellshire Coast both having similar but lower BOD_5 values (2.8 to $4.8mg$ l^{-1}). This was also expected since Hunts Bay is almost totally enclosed and receives inflows from (i) Sandy Gully which is the largest storm water drainage gully in the City of Kingston, (ii) the Rio Cobre which drains extensive farming areas of Jamaica as well as (iii) the newly commissioned Soapberry Treatment Facility. The significantly lower BOD_5 values observed in 2011 compared with the 1990's values indicate that despite the improvement in water quality in the Harbour and along Hellshire Coast since the 1990's, the levels are still elevated indicating the presence of organic and inorganic pollution, especially in Hunts Bay.

Nutrients, water clarity, biochemical oxygen demand, chemical contaminants and bacteria are the indices frequently employed in determining water quality. Although the planktonic community is tedious to analyse, it is perhaps the most reliable tool in the assessment of water quality and possible changes due to eutrophication (Webber & Webber, 1998). This can be due to nutrients being taken up rapidly by the phytoplankton (Satsmadjis, 1985), short generation times, motile existence and reaction with pollutants such as oils and toxins (Webber & Webber, 1998).

Total phytoplankton biomass values as Chlorophyll $α$, were generally higher for all stations located in Hunts Bay than for those recorded in Kingston Harbour and Hellshire. This pattern is similar to that observed in the extensive studies of the 1990's (Ranston, 1998). However, while the pattern remains the same, the doubling of phytoplankton biomass values observed in Hunts Bay indicates a significant increase in nutrient, or introduction of biomass. Thompson & Ho (1981) examined the effects of sewage discharge on phytoplankton population in Hong Kong. Their results showed estuarine waters influenced by riverine discharge had Chlorophyll $α$ values between 2 and $6mg$ m^{-3} while values ranged between 12 and $20mg$ m^{-3} in waters that were influenced by untreated sewage effluent. Hunts Bay values are extremely elevated ($33.1mg$ m^{-3}) compared with Thompson & Ho (1981) values. This suggests that Hunts Bay is even more eutrophic than in the 1990's when average values were approximately $13.5mg$ m^{-3}. The pattern was repeated for subsurface total biomass with Hunts Bay demonstrating reduced water quality. However Kingston Harbour and Hellshire Coast had lower total biomass values indicating improved water quality.

Simmonds (1997) and Ranston (1998) found that the waters throughout Kingston Harbour and Hunts Bay were dominated by the nanoplankton Chlorophyll a size fraction which accounted for more than 50% of the

standing crop. Ranston and Webber (2003) determined that there was a sporadic enrichment of relatively higher concentrations of nutrients, which could occasionally support greater proportions of net plankton biomass throughout Hunts Bay. The 2011 dominance of the net plankton size fraction biomass in both the surface and the deep values in Hunts Bay suggest that nutrient inputs increased significantly since the 1990's and resulted in the proliferation of larger size fraction. In 1998, Ranston suggested that while Hunts Bay nutrient values were high for both surface and deep waters, low variability among values suggested that there are consistently high nutrient inputs but not high enough to support large proportions of net plankton. Smaller cells can grow faster at lower nutrient concentrations, whereas larger cells require higher concentrations to achieve equivalent growth rates (Hopcroft & Roff, 1990). The dominance of net plankton, which are better able to absorb nutrients when present in large quantities, is an indication of nutrient enriched waters in Hunts Bay (Webber & Webber, 1998). Nanoplankton have greater surface to area volume and can absorb nutrients more efficiently at lower concentrations than net plankton (Ranston, 1998). Picoplankton are indicators of oligotrophic waters as their small size allows them to absorb nutrients when nutrient levels are low (Ranston et al., 2003).

Another possible explanation for the size class shift in the phytoplankton is the possible release of larger species or chains of phytoplankton cells from the Soapberry Treatment Facility, especially since the species used in the pond treatments are large and chain forming (e.g. *Scenedesmus* sp. and *Spirulina* sp.). Such species would both increase the biomass and change the size fraction dominance. However, Polat and Aka (2007) stated that the physical and chemical properties of a given environment are very important in controlling phytoplankton size distribution and further state that both the large and small size fractions can contribute similarly to the overall total phytoplankton biomass. Hunts Bay may be a one of those areas

with special chemical and physical properties (Ranston & Webber, 2003).

The comparison between this study and the one conducted by Webber and Webber (1998) provides evidence that the water quality in the Kingston Harbour has indeed improved over the 15 year period due to the 73% reduction seen in nitrates, 82% reduction in Biochemical Oxygen Demand and 50% reduction in phytoplankton biomass (all of which were significant). However despite these general reductions, areas of the Harbour are still very polluted with Hunts Bay having reduced water quality since the 1998 study. This is evident by the higher nitrates (increased by 6%) and Biochemical Oxygen Demand concentrations (increased by 4%) than previously observed in 1998. Moreover, Chlorophyll α values at stations in Hunts Bay were increased by almost 90% over previously recorded 1998 values. There was also a shift in phytoplankton size class domination towards a more eutrophic profile in Hunts Bay. Therefore, after the implementation of a new waste water treatment facility for the city of Kingston, the water quality of the Kingston Harbour and the northern Hellshire Coast has improved, while important parameters indicate a deterioration of water quality in Hunts Bay.

ACKNOWLEDGMENTS

RESUMEN

Evaluación de la calidad de las aguas de la Bahía de Kingston y la costa Hellshire, Jamaica, después de la implementación de una planta de tratamiento de aguas residuales. El deterioro de la calidad del agua del puerto de Kingston es debido principalmente a la descarga de aguas residuales y su efecto en los alrededores de la Costa de Hellshire, esto ha sido un problema desde la década de 1970. La implementación de una nueva planta de tratamiento de aguas residuales en 2007 para recibir residuos

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del Puerto de Kingston en Soapberry se esperaba hiciera una diferencia positiva. Parámetros físico-químicos y biológicos fueron utilizados para evaluar la calidad del agua y determinar el efecto de la planta de tratamiento. Once estaciones que fueron utilizadas en estudios anteriores (1990-1998) se muestrearon nuevamente para representar el puerto de Kingston, Bahía Hunts y la costa North East Hellshire sobre un régimen de muestreo de cuatro semanas entre mayo y junio de 2011. Mientras la temperatura, salinidad, turbidez, oxígeno disuelto y pH se mantuvieron sin cambios entre los años noventa y 2011, BOD_5, coliformes fecales y concentraciones de nitratos indicaron que había mejorado la calidad del agua del puerto y la costa mínimamente mientras que la calidad del agua en la bahía Hunts se había deteriorado significativamente. La biomasa del fitoplancton disminuyó en el puerto de Kingston (de 3.84mg m^{-3} en 1998 a 2.81mg m^{-3} en el 2011), y aumentó significativamente en bahía Hunts (de 14.69mg m^{-3} en 1998 a 24.17mg m^{-3} en el 2011). La biomasa en la costa permaneció similar (de 2.15mg m^{-3} en 1998 a 2.45mg m^{-3} en 2011). En 1998 la biomasa de nanoplancton (2.7 a 20μm) dominó a lo largo del puerto. En el 2011 la bahía Hunts era dominada por neto-plancton (>20μm), indicativo de aguas eutróficas.

Palabras clave: Soapberry, aguas residuales, Puerto de Kingston, eutrofización, Bahía Hunts, Hellshire

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