Rapid reassessment of the eutrophication status of Kingston Harbour, Jamaica using the zooplankton community

Patrice A. Francis, Stacy A. Maxam & Mona K. Webber*

Department of Life Sciences, The University of the West Indies (UWI), Mona, Kingston 7, Jamaica; patrice.francis06@uwimona.edu.jm, stacymax1@hotmail.com, mona.webber@uwimona.edu.jm

* Correspondance

Received 01-IX-2013 Corrected 31-III-2014 Accepted 01-IV-2014

Abstract: Previous extensive studies of zooplankton distribution in the eutrophic Kingston Harbour established that it was being continuously contaminated. We assessed the community in 2011, 17 years after a previous study and five years after the introduction of a tertiary waste water system. Sampling was conducted for four weeks at eight stations identical to those sampled in a previous study. We used horizontal surface tows with a 200µm net. A total of 73 zooplankton taxa were identified and copepods dominated with 20 species. Mean total abundances were high, ranging from a minimum of 2 383 animals m^{-3} in the southern region of Hunts Bay to 194 166 animals m^{-3}at the Inner Harbour. Five zooplankton taxa (*Acartia tonsa, Paracalanus spp., Temora turbinata, Penilia avirostris* and *Lucifer faxoni*) that were previously identified as indicators, were again important in the Harbour. The overall zooplankton abundances were similar and in some cases higher than the previous study. There was no significant improvement in the water quality since the introduction of the treatment system at Soapberry. This may be a result of unknown nutrient inputs or of nutrient remaining in the sediments. Rev. Biol. Trop. 62 (Suppl. 3): 231-239. Epub 2014 September 01.

Key words: Kingston Harbour, zooplankton, rapid assessment, waste-water, eutrophic.

Previous extensive studies of zooplankton distribution in the eutrophic Kingston Harbour established that the harbor was being continuously contaminated (Grahame, 1974; Dunbar, 1997). Based on the different zooplankton communities, the harbor was zoned with the Upper Basin and Hunts Bay being the most eutrophic, the Inner Harbour, showing less contamination and the Outer Harbour least eutrophic (Dunbar, 1997; Dunbar & Webber, 2003). Dunbar recommended on-going monitoring of Kingston Harbour water quality using the zooplankton indices: total abundances, total number of species and the number of the "indicator" species especially at stations representing the previously defined zones. Since these recommendations, one key change has occurred through the implementation of centralized tertiary sewage treatment system for the city of Kingston; located at Soapberry in St. Catherine. The aim was to "significantly reduce pollution in Kingston Harbour and thus redress the existing environmental concerns" (Urban Development Corporation, 2006). The construction of a cross-island highway system- "Highway 2000" which involved extensive mangrove removal as well as reclamation and dredging of parts of Hunts Bay to expand the container shipment terminal by the Port Authority of Jamaica are the other two major changes which have occurred since the previous extensive study in the 1990's.

Approximately 17 years have passed since the 1990's study and with the changes as described above; a rapid assessment was needed to determine whether Kingston Harbour water quality had begun to improve and required a new baseline. It was hypothesized that areas closest to the Soapberry outfall (Hunts Bay) as well as areas closest to the previous sewage plants (Inner Harbour) would first experience change in eutrophication status and thus in the zooplankton community.

The objectives of the study were therefore to determine zooplankton abundance and species composition in representative areas of Kingston Harbour and to compare these to abundance and species found 17 years ago at the same stations.

MATERIALS AND METHODS

Station selection: Eight stations were selected throughout the Kingston Harbour between 17°57' 14.0" N and 76° 48'13.33"W. The stations were identical (Fig. 1, Table 1) to those sampled by Dunbar (1997) and Ranston (1998) and represented each of the zones identified by Dunbar & Webber (2003). Sampling was conducted for four weeks between May 21, 2011 and June 9, 2011.

Zooplankton collections: *Outer, Upper and Inner Harbour*- Zooplankton collections were made with a SCOR, WP2 pattern 20µm plankton net with a hoop diameter of 0.5m (United Nations Educational, Scientific and Cultural Organization [UNESCO], 1968). Horizontal surface tows were conducted in a circular path at approximately 1knot ($0.5ms^{-1}$). Each tow lasted for two minutes with the net kept just below the surface of the water. Flow meter readings were taken before and after each tow using a calibrated (one revolution= 0.048m) General Oceanics flow meter which hung in the mouth of the net. This replicated the sampling method employed by the previous baseline study (Dunbar & Webber, 2003).

Hunts Bay-Replicate zooplankton samples were collected at each station using a 100µm mesh aperture net with a 12.5cm hoop diameter. Replicate oblique or vertical hauls were done at each station through the water column. The net with attached weight and rope (marked at 1m intervals) was hand-thrown as far as possible from the boat. It was allowed to sink far

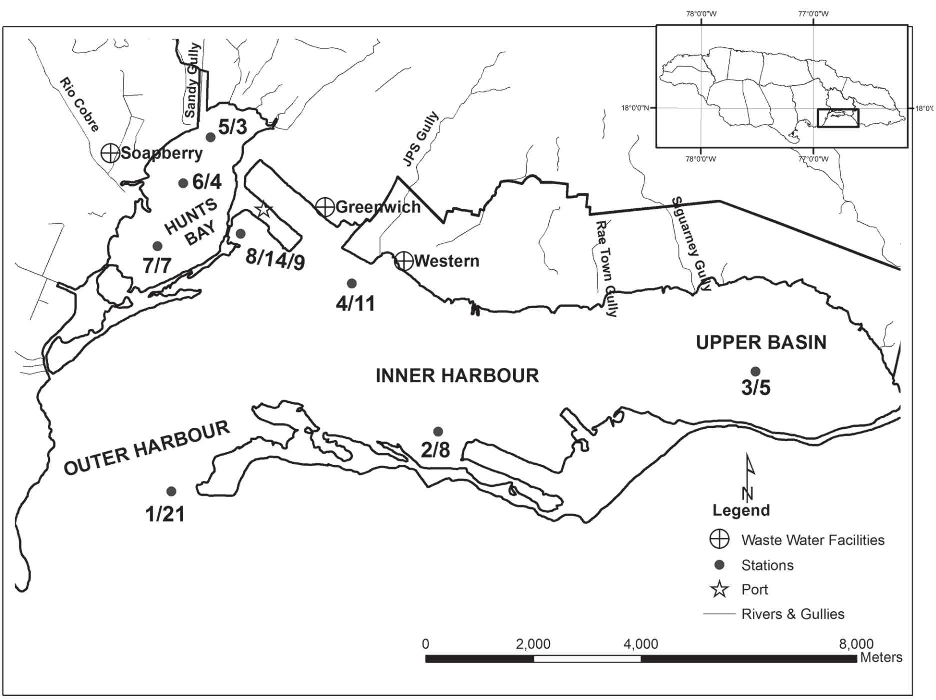


Fig. 1. Study area showing the location of sampling stations.

TABLE 1
Location of stations sampled in present and past studies (Fig. 1)

Kingston Harbour Representative Zone	Current Study	Dunbar 1997	Ranston 1998	GPS coordinates
Outer Harbour-Harbour Shoal Beacon (HSB)	Station 1	Station 21		N 17°56'101" • W76°50'927"
Inner Harbour Port Royal Mangrove (IHM)	Station 2	Station 8		N17°56'657" • W76°48'639"
Upper Basin (UB)	Station 3	Station 5		N 17°57'337" • W 76°45'638"
Inner Harbour Shipping Channel (SC)	Station 4	Station 11		N17°58'129" • W76°49'218"
North Bay (NB)	Station 5		Station 3	N17°59'279" • W76°50'464"
Middle Bay (MB)	Station 6		Station 4	N17°58'471" • W76°50'499"
South Bay (SB)	Station 7		Station 7	N17°58'332" • W76°51'920"
Hunts Bay Bridge (HBB)	Station 8	Station 14	Station 9	N17°58'597" • W76°50'418"

enough below the surface then an oblique/vertical haul was done at a steady pace at approximately $2ms^{-1}$ at the total distance hauled with this net was at least 8m. With this deployment the net sampled both the upper fresh water and lower more saline layers of the water column without disturbing the soft sediment at the bottom of the bay. This replicated the sampling method employed during the previous sampling of Hunts Bay by Ranston (1998).

Samples at each station were immediately fixed in the field using 10ml of full strength formalin (37% formaldehyde) and later preserved in 10% formalin. The volume of sea water filtered was calculated using the formula $\pi r^2 h$, where 'r' is the radius of the hoop of the plankton net and 'h' is distance towed; determined by the number of revolutions of the calibrated flow meter. The filtering efficiency (FE) of each net was applied to the volume calculations based on FE values generated from studies done by Dunbar (1997).

Identification and counting of the zooplankton were conducted on preserved subsamples obtained using the beaker split method (Van Guelphen, Markle, & Duggan, 1982; Webber, Roff, Chisholm, & Clarke, 1996; Dunbar, 1997). Each sub-sample was transferred to a Bogorov tray and counted using a Wild M5/M7 Binocular Microscope. The taxonomic guides employed to identify the animals included: Davis (1955), Gonzales and Bowman (1965), Wickstead (1965), Owre and Foyo (1967), Newell and Newell (1977), Ramirez and Zamponi (1981), Michel (1984), Campos–Hernández and Suárez-Morales (1994), Todd, Laverack and Boxshall (1996) and Webber (2004). The numbers of each species were converted to numbers per m^3 using the formula and the relevant dilution factors. All samples were pseudo-replicated.

Physico-chemical data were collected at each station on each sampling occasion using a Hydrolab® Surveyor DS5. These included depth (±0.08m); Temperature (±0.15°C); Salinity (±0.1ppt); pH (±0.2 units); dissolved oxygen ($\pm 0.2mgl^{-1}$).

Statistical analysis: Two tailed t-tests were applied to normally distributed physiochemical and biological data to determine if there were significant differences between the present and previous studies.

RESULTS

Variation in physico-chemical parameters: Temperature, Salinity and Dissolved Oxygen were the primary physico-chemical parameters which varied significantly across the Harbour. The variations in temperature were minimal with values ranging from 28°C at Outer Harbour to 31ºC at Hunts Bay. The greatest temperature was recorded at the Hunts Bay stations 5 to 7. Temperatures recorded in 2011were not significantly different from those recorded in 1994.

In both studies, Hunts Bay stations 5 to 8 had the lowest salinity values (Fig. 2B), while

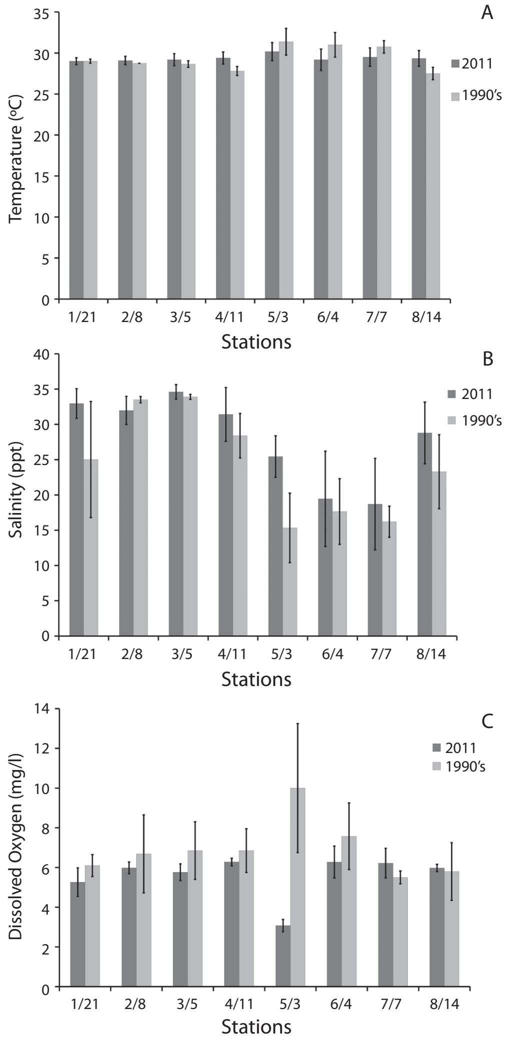


Fig. 2. Mean (±1SE) physicochemical parameters sampled in the 1990's and 2011 studies. (A) Temperature, (B) Salinity and (C) Dissolved Oxygen. Vertical bar denotes standard errors.

Outer Harbour, Inner Harbour and Upper Basin stations (1 to 4) had greatest salinity values. Low salinity is indicative of fresh water inputs from the Rio Cobre, Duhaney River and Sandy Gully. The salinity values in 2011 were shown to be significantly higher than those of the previous study.

Higher Dissolved Oxygen (D.O.) readings were recorded in the 1994 study at all except stations 7 and 8 (Hunts Bay) where the 2011 study had slightly higher dissolved oxygen readings. The lowest DO reading for 2011 was recorded at station 5/3 in Hunts Bay. This is the opposite to the findings of the previous study where that station recorded the highest DO value. The two t-test revealed no significant difference in dissolved oxygen between the studies.

Variation in zooplankton parameters: A total of 73 zooplankton taxa were identified from the eight stations sampled during the present study which is the same amount (73 species) found in the 1994 study of the harbor. Again the copepods were the most dominant group, however only 20 species were recorded, 18 species less than previously (Dunbar, 1997; Dunbar & Webber, 2003). In the present study, eight copepod species were from the order Calanoida, one more than Cyclopoida (seven species) while the Harpacticioda had five species. The second most dominant group after copepods was the group comprised of larvae with 19 species. The average number of species varied significantly (p=0.01, Table 2) between the two studies (Fig. 3). Station 1/21 had the highest average number of species 28 and 35 for the 2011 and 1994 studies respectively. The lowest number of species were found at the Hunts Bay stations with station 6 having the lowest (7 species) for the 2011 study and station 3 (10 species) for the 1994 study.

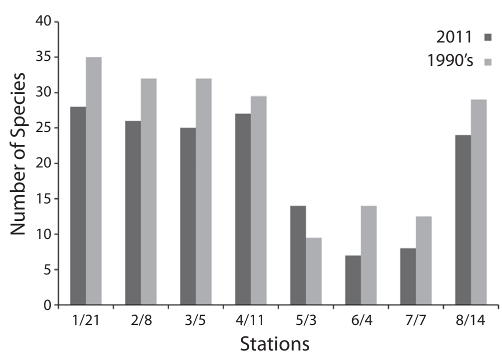


Fig. 3. Number of zooplankton species recorded for the 1990's and 2011 studies.

TABLE 2
Results of the tailed test on physicochemical and biological parameters

Variable	Deg. of Freedom	T-value	P-value
Temperature	7	0.007	0.50
Salinity	7	2.757	**0.01****
Dissolved Oxygen	7	1.577	0.08
No. of species	7	3.134	**0.01****
Total Zooplankton	7	2.252	**0.03***
Acartia sp.	7	1.573	0.08
Penilia avirostris	7	2.649	**0.02***
Temora turbinate	7	0.057	**0.04***
Lucifer faxoni	7	1.000	0.17
Paracalanus spp.	7	1.841	**0.05***

**significance.

Mean zooplankton abundances ranged from 2383 animals m^{-3} at Station 7 Hunts Bay- South to 194 166 animals m^{-3} at station 4 in the Inner Harbour near the Shipping Channel (SC) for the 2011 study (Fig. 4). In 1994, a minimum value of 381 animals m^{-3} were found at station 4 (middle of Hunts Bay) and maximum of 81 742 at station 8 (near the Port Royal Mangroves). The two-tailed test revealed significantly higher abundances for the 2011 study over the 1994 study (p=0.03), with higher abundances at the Inner Harbour stations (2 and 4) and lower abundances at the Hunts Bay stations (5 to 7). During the present study five indicator species were identified, *Acartia spp.*, *Paracalanus spp.*, *Penilia avirostris, Temora turbinata* and *Lucifer faxoni*. These species had a similar distribution to the mean total zooplankton numbers, with maximum numbers at the airport-mangrove station and minimum numbers at the Hunts Bay stations (Fig. 5). *T. turbinata* was the only species with maximum numbers at the shipping channel station. The 1994 study had *T. turbinata, Paracalanus spp*. and *P. avirostris* showing dominance at the airport-mangrove station while *Acartia spp.* and *Lucifer faxoni* were dominant at the shipping channel station. *T.* turbinata*, Paracalanus spp*. and *P. avirostris* were found to be significantly different between the two studies with *T. turbinata* and *Paracalanus* spp. having higher abundances during 2011 and *P. avirostris* being more abundant in 1994.

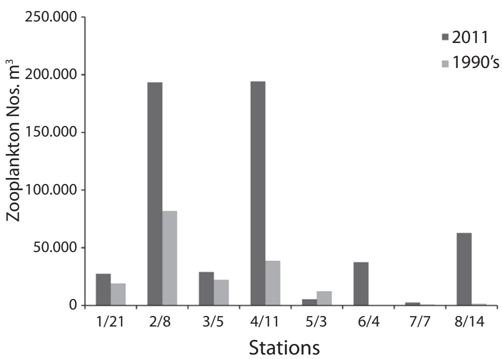
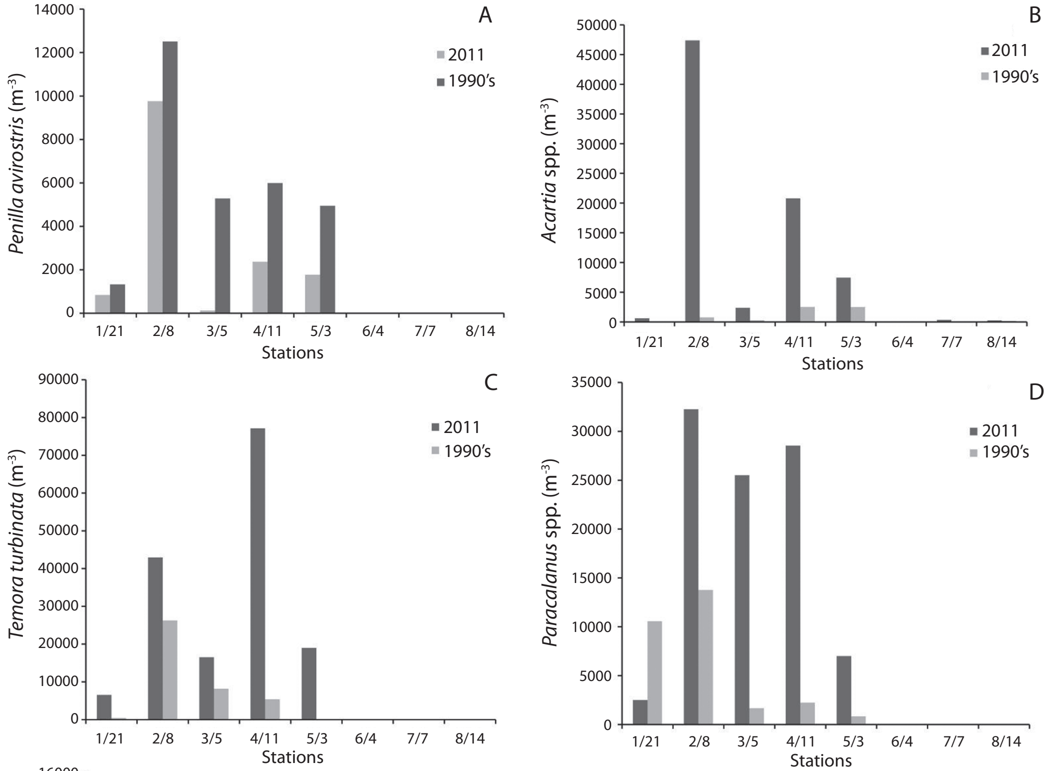


Fig. 4. Mean total number of zooplankton numbers found in the 1990's and 2011 study for at the same stations and for the same months.

DISCUSSION

Although the results showed significant difference in the abundance between the two studies, there was no difference in relative eutrophication levels between zones, based on the zooplankton. Hunts Bay remained the most eutrophic area and the Outer Harbour, the least eutrophic. Although zooplankton abundances at the pairs of Hunts Bay stations were higher in the present study than in previous study in 1994, the abundances were low in comparison to the other areas of the Harbour. Webber and



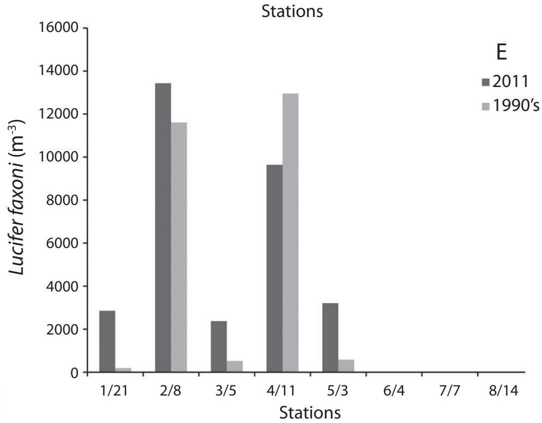


Fig. 5. Mean total numbers of indicator species. (A) *Penilia avirostris*, (B) *Acartia spp*., (C) *Paracalanus spp*., (D) *Temora turbinata* and (E) *Lucifer faxoni.*

Wilson-Kelly (2003) suggested that the very poor water quality of Hunts Bay can cause a decline in the zooplankton abundances and species richness. They further concluded that high nutrient and fresh water inputs and proliferation of algal blooms were the main reasons for the decline in the water quality of the Hunts Bay area. Duncan (2011) reported Biological Oxygen Demand (BOD) and nutrient (NO_3+NO_2) values greater than the National Ambient Water Quality Standard for marine waters due to the release of treated sewage from the Soapberry wastewater treatment ponds, which were established, on the fringes of Hunts Bay. This explains the continued low species number at the Hunts Bay stations in comparison to the other stations.

This and other studies (Webber et al. 1996; Dunbar & Webber, 2003) have shown Outer Harbour to be the least eutrophic due to its influence by mesotrophic waters and the introduction of species from the shelf area. The diversity (number of species) found in the Outer Harbour in this present study, though higher than the other sections of the harbor, was lower than that obtained by Dunbar (1997). This was accompanied by increased zooplankton abundances, which are indices of increased eutrophication (McArthur, 1955; Clutter, 1972).

In the 1974 study of the Harbour, Grahame found the plankton community of the Upper basin to be the "most diverse and biologically accommodating, offering the largest number of niches available to the zooplankton in the Harbour". It was therefore expected that the zooplankton community observed in this area would be different from the other areas of the Harbour. The mean abundance for the Upper Basin was higher than what was observed by Dunbar (1997), but lower than adjacent areas of the harbor during the present study. High numbers were also reported by Grahame (1974) in the Upper Basin. This suggests relative stability in the water quality within the Upper Basin, which could be explained by a lack of any major inputs to that area. The upper basin has no major rivers or gullies but is influenced by a series of small gullies (22), which, as shown by Webber and Wilson-Kelly (2003), are only of significance during periods of heavy rainfall.

Like the previous studies (Grahame, 1974; Dunbar, 1997), the Inner Harbour had the greatest zooplankton abundances. High zooplankton abundances were recorded at the airport-mangrove station (2) and the shipping channel station (4). The greatest abundance was recorded at station 4, which is probably due to the proximity to direct sewage inputs caused by the dysfunctional Greenwich sewage treatment plant outflow (Francis, 2011). In a contemporaneous study of the harbor by Duncan (2011), high nutrient levels at this station were reported suggesting that sewage is still flowing through the Greenwich treatment plant, instead of going to Soapberry. An alternative explanation is that the sediments in that area are a continuous source of eutrophication due to several years of continued large scale inputs. This sediment-source will continue to supply nutrients to the water column for several years after the inputs have stopped (Clau, 2004).

The maximum abundance (193 287 animals m^{-3}) found at station 2 (Airport runway/mangroves) is similar to the maximum of 194 248 animals/m^3 reported by Dunbar (1997) for the 1994 study. These values were significantly higher than the mean number recorded by Grahame (1976) of 25 248 animals m^{-3}. The mangrove area is said to be "one of the most productive areas in the Harbour" (Dunbar, 1997). The high abundance of this station could therefore be attributed to the station's proximity to the mangroves.

Conditions within the harbour have not changed significantly since the last baseline conducted 17 years ago by Dunbar (1997) and the implementation of the Soapberry treatment facility five years ago. The most eutrophic area remains within the Hunts Bay as indicated by minimal species diversity and zooplankton abundances. The abundance and diversity within the Upper Basin were lower than the Inner Harbour, suggesting deterioration of the water quality in the Upper Basin. However, overall the Upper Basin area was relatively unchanged. The Outer harbour, while remaining the least eutrophic area of the Kingston Harbour, had higher abundances than in previous studies.

It therefore can be concluded that while changes (slight improvements) have taken place in areas like Hunts Bay, where the new Soapberry sewage treatment system outfall is located; there was no significant improvement in the water quality in the Kingston Harbour since the last baseline study or the introduction of the tertiary sewage treatment system at Soapberry. There either continues to be unregulated nutrient inputs into the harbour or the nutrient loading of the sediments over the last 25-30 years makes them a continued source of nutrients to the water column.

ACKNOWLEDGMENTS

We thank our research partners Sheree Broomfield, Anya Duncan, Helen Liu, Leon Grant and the staff of the Port Royal Marine Laboratory, University of the West Indies (UWI) for their assistance with fieldwork collection. Department of Life Sciences, UWI provided funding for this research.

RESUMEN

Reevaluación rápida del estado de eutrofización del puerto de Kingston, Jamaica utilizando la comunidad de zooplancton. Extensos estudios previos de la distribución de zooplancton en el Puerto de Kingston estableció que ha sido contaminado continuamente. Evaluamos la comunidad en el 2011, 17 años después de un estudio previo y cuatro años después de la introducción de un sistema de lagunas de aguas residuales terciarias. Utilizamos arrastres superficiales horizontalescon una red de 200 µm. Se identificó un total de 73 taxones de zooplancton y copépodos de los cuales los predominaron 20 especies. La media de las abundancias totales fueron altas y los valores oscilaron entre un mínimo de 2 383 animales m^{-3} en la zona sur de Bahía Hunts a 194 166 animales m^{-3} en lo interior del puerto. Cinco taxones de zooplancton (*Acartia tonsa, Paracalanus spp., T. turbinata, Penilia avirostris* y *Lucifer faxoni*) identificados previamente como indicadores, fueron importantes de nuevo en la Bahía. La abundancia total de zooplancton fue similar y en algunos casos superior a la del estudio anterior. No hubo mejoría significativa en la calidad del agua desde la introducción del sistema de tratamiento terciario en Soapberry. Esto puede ser resultado de la entrada continua de nutrientes desconocidos y no regulados en los sedimentos.

Palabras clave: Puerto Kingston, zooplancton, evaluación rápida, aguas residuales , eutrófico.

REFERENCES

Campos-Hernández, A., & Suárez- Morales, E. (1994). *Copépodos pelágicos del Golfo de México y Mar Caribe: Biología y sistemática* (Vol. 1). CIQRO.

Clau, K. W. (2004). A three-dimensional eutrophication modeling in Tolo Harbour. *Applied Mathematical Modelling, 28*(9), 849-861.

Clutter, R. I. (1972). *Subtle effects of pollution on inshore tropical plankton.* Marine Pollution Sea Life. FAO report.

Davis, C. (1955). *The Marine and Freshwater Plankton.* Michigan: Michigan State University Press.

Dunbar, F. N. (1997). *Zooplankton abundance and community structure in Kingston Harbour, a polluted tropical embayment.* Unpublished Masters Dissertation. The University of the West Indies, Mona Campus, Jamaica.

Dunbar, F. N., & Webber, M. K. (2003). Zooplankton distribution in the eutrophic Kingston Harbour, Jamaica. *Bulletin of Marine Science, 73*(2), 343-359.

Duncan, A. F. (2011). *An assessment of the water quality in the Kingston Harbour, Jamaica.* Unpublished Masters Dissertation. The University of the West Indies, Mona Campus, Jamaica.

Francis, P. A. (2011). *A resurvey of the zooplankton associated with key sections of the Kingston Harbour, Jamaica.* Unpublished Masters Dissertation. The University of the West Indies, Mona Campus, Jamaica.

Grahame, J. (1974). *The ecology of the plankton in Kingston Harbour, Jamaica Part 1.* The zooplankton. Research report from the Zoology Department, U.W.I. No. 4.

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

Gonzales, J. G., & Bowman, T. E. (1965). Planktonic copepods from Bahia Fosforescente, Puerto Rico and adjacent waters. *Proceedings of the U.S. National Museum Smithsonian Institution, 3513*(117), 241-304.

McArthur, R.1955. Fluctuations of animal populations, and a measure of community stability. *Ecology, 36*, 533-536.

Michel, H. B. (1984). Chaetognaths of the Caribbean sea and adjacent areas. *NOAA Technical Report. National Marine Fisheries service, 15*, 25.

Newell, G. E., & Newell, R. C. (1977). *Marine Plankton, a practical guide.* London: Hutchinson.

Owre, H. B., & Foyo, M. (1967). *Copepods of the Florida Current.* Miami: Institute of Marine Sciences, University of Miami.

Ramirez, F. C., & Zamponi, M. O. (1981). *Hydromedusae.* Atlas del zooplancton del Atlántico sudoccidental y metodos de trabajo con zooplankton marino. Retrieved from http://afrilib.odinafrica.org/handle/0/16209

Ranston, E. R. (1998). *The phytoplankton community and water quality of a highly eutrophic estuarine bay, Hunts Bay, Kingston Harbour, Jamaica.* M.Phil. Thesis, The University of the West Indies, Mona, Jamaica. 242p.

Todd, C. D., Laverack, M. S., & Boxshall, G.A. (1996). *Coastal marine zooplankton: A practical manual for students.* Cambridge: Cambridge University Press.

United Nations Educational, Scientific and Cultural Organization. (1968). *Zooplankton sampling; Monographs on oceanic methodology*. Paris: UNESCO.

Urban Development Corporation. 2006. *Annual report Financial year 2005-2006*. Retrieved from http://www.udcja.com/Annual%20Report/UDC%20ANNUAL%20REPORT%202005-06%20.pdf.

Van Guelphen, L., Markle, D. F., & Duggan, D. J. (1982). An evaluation of the accuracy, precision and speed of several zooplankton subsampling techniques. *Journal du Conseil. Conseil Permanent International pour l'Exploration de la Mer, 40*, 226-236.

Webber, D. F., & Wilson- Kelly, P. (2003). Characterization of the sources of organic pollution to Kingston Harbour. *Bulletin of Marine Science, 73*, 257-271.

Webber, M. K., Roff, J. C., Chisholm, L. A., & Clarke, C. (1996). Zooplankton distribution and community structure in an area of the south coast shelf of Jamaica. *Bulletin of Marine Science, 59*(2), 259-270

Webber, M. K. (2004). *An identification guide to the zooplankton found in the Kingston Harbour and the Port Royal mangroves*. Jamaica: Department of Life Sciences Research Report #5.

Wickstead, J. H. (1965). *An introduction to the study of tropical plankton.* California: Hutchinson Tropical Monographs.