

Deepening, Lengthening and Widening of Berth 203 to 205, Pier 2, Container Terminal, Port of Durban -

Central Sandbank Mitigation Plan

Authority Reference No: 14/12/16/3/3/2/275

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Amendments Page

Date:	Nature of Amendment	Amendment Number:
September 2015	Client Review Based on 12 Months Monitoring	01
March 2017	Client Review Based on 24 Months Monitoring	02
April 2017	Client Comments on Draft Report	03
May 2017	Client Comment on Final Report	04
August 2017	EMC Comments on Final Report	05
October 2017	Client Comment on Final Report	06

Executive Summary

Transnet National Port Authority (TNPA) plans to deepen, lengthen and widen Berth 203 to 205, Pier 2, Container Terminal in the Port of Durban. The project is also known as the Berths 203 to 205 Expansion Project, Pier 2, Container Terminal in the Port of Durban. The existing Blockwork Quay wall structure along Pier 2 Berth 203 to 205 was designed in the 1970s to support dockside cranes with the lifting capacity of 4 tonnes. The quay walls are presently operating beyond their original design limitations. Recent studies have concluded that the existing quay walls do not meet the minimum Eurocode 7 Safety Standards and that there is a risk of potential quay wall failure (PRDW, 2011)

The upgrade would include the following activities:

1. The westward lengthening of Berth 205 by 170m, the eastward lengthening of Berth 203 by 100m and the seaward widening of Berths 203 to 205 by 50m;
2. The deepening of the berth channel, approach channel, and vessel turning basin from the current -12.7m CDP to -16.5m CDP;
3. The construction of caissons, storage of sheet piles or precasting of elements of the Deck on Pile at Bayhead Lot 10;
4. The offshore disposal of dredge material and the offshore sand winning for infill material;
5. The installation of new Ship to Shore cranes and associated infrastructure; and
6. The extension of the Central Sandbanks within the Port using dredge material.

Nemai Consulting was appointed by Transnet National Port Authority to undertake the necessary Environmental Authorisation Process for the Proposed Berth 203 to 205 Expansion Project. The Department of Environmental Affairs granted a positive Environmental Authorisation (EA) for the development in January 2015. Condition 27 of the EA stated that baseline monitoring must be undertaken over a period of 24 months to establish thresholds of acceptable change. In addition, the EA contained a number of specific conditions including the need for the Environmental Management Programme (EMPr) to contain a monitoring programme during the extension of the Central Sandbanks.

The EA was challenged by 3 Appellants for various reasons, including the sustainable extension of the Central Sandbank. The EA was upheld however Condition 4.2.4 of the Appeal Decision stated that the outcome of the baseline monitoring must inform a Central Sandbank Mitigation Plan (CSMP).

The Environmental Management Programme was developed as a suite of 2 specific EMPrs namely, (1) a generic Environmental Management Programme and (2) a specific Central

Sandbank Mitigation Plan which addresses the monitoring requirements for the extension of the Central Sandbank.

While the EA and the Appeals Decision only made reference to baseline monitoring around the Central Sandbank, Transnet undertook a holistic approach and extended the monitoring programme to include all Sandbanks in the Port.

While the information below, is an overview of the findings of the baseline monitoring in the entire Port over 24 months, the proposed acceptable thresholds to be used during the construction of the extension of the Central Sandbank are specific to the Central Sandbank.

Water Quality

Aspects of water quality (temperature, salinity, dissolved oxygen, pH, turbidity and TSS) were measured in an attempt to establish a baseline water condition for the Port. Water quality measurements were taken every 3 months at 20 stations distributed in the navigation channels surrounding the main intertidal and shallow subtidal sandbank areas. Data obtained was analysed by deriving appropriate summary statistics according to season and location and graphically represented to show any spatial and temporal trends. Environmental Quality Targets (EQT's) specific to the Port were derived using protocols included in the UNEP-GEF West Indian Ocean Project (2009).

There was no indication of anthropogenic influences on the ambient temperature data collected in the Port. Overall, water temperature varied little between stations. Slightly warmer temperatures were recorded in the upper as opposed to the lower regions of the Port. There was also a progressive decrease in water temperature with increasing depth across all stations. Lowest average temperature occurred in winter and the highest in the summer. Summer surface water temperatures were expectedly higher than in other seasons, resulting in more pronounced decreases in temperature through the water column. EQTs for temperature were established for each water quality station based on the 20th percentile and 80th percentile of the baseline data collected.

There were no indications of hypersaline conditions or that the Port is salinity stratified. All stations represented estuarine or marine conditions with salinities ranging between 22-35 PSU. The greatest fluctuations in salinity occurred in the upper regions of the Port, at sites located closest to the uMbilo, uMhlatuzana and aManzimnyama river inlets. The seasonal fluctuations in salinity were greatest in summer and spring and likely associated with elevated rainfall and increased freshwater inflow during these periods. Using the baseline data collected, EQTs for salinity were established for each station based on the 20th percentile and 80th percentile values.

Variation in dissolved oxygen levels through the water column recorded at stations located in the upper reaches of the Port indicated marked changes in oxygen levels with depth (decreasing with increasing depth). Oxygen levels in the lower regions and closer to the Port entrance remained relatively uniform with depth. In terms of seasonal variations, dissolved oxygen concentrations were greatest in summer across all stations, and varied between

surface and bottom waters. EQT values were determined by calculating the 20th percentile of the baseline variability of dissolved oxygen measured at each station in the Port.

Turbidity varied little between stations with mean turbidity values ranging between 1-7 NTU and only showing slight increases with increasing depth. The largest variations in turbidity through the water column occurred in summer and spring across all sites. This is associated with increased rainfall over these periods and the subsequent greater input of suspended particulate matter from the river and storm water inlets. EQT values were established based on the 80th percentile of the natural variability of turbidity measured at each site over the two-year period.

Total Suspended Solid (TSS) concentrations were slightly higher in the upper regions of the Port but varied little in the middle and lower reaches. Overall, TSS concentrations were high and may be associated with dredging activity and/or vessel movements, which unavoidably coincided with sampling events. TSS concentrations varied little between seasons. Slightly higher concentrations were recorded during spring and summer, particularly in the upper regions of the Port and are likely associated with increased freshwater inflow at this time. TSS guideline values were calculated corresponding with the 80th percentile of the baseline data.

Overall, pH levels varied little throughout the Port, ranging from 7.8-8.6. Recorded pH values in summer showed the greatest variation when compared to the other seasons. The fluctuations observed during spring and summer is again likely associated with rainfall events and elevated freshwater inflow at this time. Guidelines values for pH were determined by calculating the 20th percentile and 80th percentile of the baseline variability range.

The limited spatial variation between stations observed in this study reflects the marine dominance and general uniformity in physico-chemical conditions. Impaired water quality recorded in surface waters of the upper regions are almost certainly associated with the limited water exchange, freshwater inflow from storm water inlets and riverine water introduced via the aManzimnyama and uMhlatuzana/uMbilo canals.

During the construction phase of the project, water quality measurements must be taken at 20 stations distributed in the navigation channels surrounding the main intertidal and shallow subtidal sand bank areas in the Port. Water quality profiles must be measured at each station once every three months (each quarter - autumn, winter, spring, summer) during the construction of the Sandbank Extension and must include an assessment of the salinity, temperature, dissolved oxygen and turbidity parameters. Once the construction of the Sandbank Extension is completed, the same variables must be measured at each station, once every six months until the end of construction of the Berth 203 to 205 Expansion Project. Continuous monitoring should be undertaken of turbidity and dissolved oxygen levels at five monitoring stations (3 impact and 2 control stations) during dredging operations and sandbank construction. Data from such monitoring must be available in real time to the person coordinating dredging activities.

The TSS threshold has been developed for the dredging Works at the Port to ensure that the environmental impact of dredging is limited. The TSS threshold limit is set as the greater of the 80th percentile of the baseline monitoring data, which corresponds to a TSS of 43 mg/l or

10% greater than the natural background Port turbidity. For the purposes of this project, the natural background Port turbidity is deemed to be the greater of the real-time readings at control stations WQ2 and WQ7. If the TSS approaches the threshold limit set above at any of the surveillance monitoring stations namely, WQ3, WQ4 or WQ5, mitigation measures are to be put in place to prevent any further increase in suspended solid concentration such as reduce rate of dredging, relocate dredger, etc. If the mean turbidity level, that is the average of measured values in any one-and-a-half-hour period, exceeds the threshold, dredging is to be suspended until measured levels drop below the threshold.

Threshold levels to be adopted for dissolved oxygen during the construction phase are as follows:

- The 20th percentile of the baseline monitoring data (Appendix 1), which for stations WQ3, WQ4 and WQ5 corresponds to a level of 5.33 mg/l.
- Ten percent (10%) lower than natural background dissolved oxygen levels. For the purposes of this project, the natural background oxygen level is deemed to be the lower of the real-time readings at control stations WQ2 and WQ7.

Temperature, salinity and pH in the water column are not expected to be affected by project related activities. It is essential, however, that these parameters be monitored during the construction and post-construction periods as they will provide an indication of the occurrence of any external (i.e. non-project related) natural or anthropogenic perturbations in the Port.

Biomonitoring

Samples of the bivalve *Perna perna* (brown mussel) were collected from 36 channel marker buoys lying adjacent to the sandbanks in the Port. Samples collected were placed in sampling jars on ice immediately after collection and were submitted to a SANAS accredited analytical laboratory for determination of trace metal (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg) content. Trace metal levels in mussels, collected from the Port, were compared with the maximum legal limits prescribed for each contaminant in shellfish for human consumption in South Africa, as stipulated by the Regulation R.500 (2004) published under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972). Where guidelines have not been specified in national legislation, those adopted by other countries were used.

Findings indicate that mussels in the Port have accumulated high concentrations of arsenic (As), cadmium (Cd), lead (Pb), zinc (Zn) and mercury (Hg). High levels of lead contamination were recorded throughout the Port. There was indication that mussels in the upper regions were more contaminated than elsewhere in the Port.

During the construction of the Sandbank Extension, samples of the bivalve *Perna perna* must be collected from 16 channel marker buoys lying adjacent to the sandbanks once every three months (each quarter - autumn, winter, spring, summer). Thereafter, the samples must be collected once every six months throughout the remainder of the Berth 203 to 205 Expansion

construction phase. The samples must be analysed at a SANAS accredited laboratory for trace metal (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg) content.

Threshold (warning) levels to be adopted for levels of trace metals in mussel samples from the impact monitoring stations during the construction phase corresponding to the 90th percentile of baseline levels (as measured during the baseline monitoring programme) and 20% above background levels (as measured at control stations) have been recommended.

Sediments

The analysis of sediments in the Port provides a better understanding of the spatial extent and significance of metal contamination compared to water sample analysis. Sediment samples were collected each quarter (autumn, winter, spring, summer) for two years from 104 stations (53 intertidal and 51 subtidal) distributed on the top and sides of the various sandbanks in the Port. The extent of metal contamination in sediments in the Port was more pronounced in the upper reaches, with the poorest sediment quality in the Bayhead Canal, Congella Basin and the Yacht Basin. The same features that make the upper reaches of the Port susceptible to poor water quality apply to sediment.

During the construction of the Sandbank Extension, sediment samples must be collected every three months' (each quarter - autumn, winter, spring, summer) from 21 intertidal-impact monitoring stations, 10 intertidal control stations, 18 subtidal impact-monitoring stations, and 7 subtidal control stations. Thereafter, samples must be taken from a further 20 intertidal impact-monitoring stations on and immediately adjacent to the newly created sandbank during the remainder of the Berth 203 to 205 Expansion construction phase.

The samples must be analysed at a SANAS accredited laboratory for grain size distribution, organic and trace metal (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg) content.

Threshold (warning) levels to be adopted for grain size (% sand and % mud) and Total Organic Content (%TOC) for sediment samples collected from the newly established sandbank areas corresponding to the 10th and 90th percentiles of the baseline monitoring data and 20% above or below background levels as measured at the control stations are recommended. If levels exceed these limits, negative impacts on biota such as invertebrates, fish and birds in the Port can be expected, and additional mitigation may be indicated.

Benthic Microalgae (Microphytobenthos)

Benthic microalgae samples were collected from the same stations as for sediment quality monitoring. Samples were collected by slowly inserting a glass vial of known diameter (20 mm), either directly into the sand bank sediment (in the case of the intertidal samples) or into the top layer of sediment collected by the grab sampler (in the case of the subtidal samples). Samples were then placed on ice in a dark container and submitted to an analytical laboratory for analysis of Chlorophyll-a concentration. Analysis of the intertidal sediments indicated peaks in chlorophyll concentration at the mangrove sites, Centre Bank and the Northern Banks. Subtidal chlorophyll concentrations were on the whole considerably lower than those

in intertidal sediments. Highest chlorophyll concentrations were recorded in the subtidal sediments at Little Lagoon and at the Mangrove site. Microphytobenthos biomass recorded in autumn and winter was considerably lower in both intertidal and subtidal sediments than those in spring and summer, indicating seasonal variation in benthic microalgae biomass.

During the construction of the Sandbank Extension, samples for assessment of benthic microalgae biomass must be collected, from the same sampling stations as for the sediment monitoring activities, once every three months (each quarter - autumn, winter, spring, summer). Thereafter, the samples must be collected once every six months throughout the remainder of the Berth 203 to 205 Expansion construction phase.

The biomass of the microalgae in the samples must be estimated as total chlorophyll (Chla) according to the methods of Whitney & Darley (1983), Dandonneau & Neveux (2002) and Seuront & Leterme (2006).

Threshold (warning) levels to be adopted for benthic microalgae indicated that biomass at the intertidal and subtidal impact monitoring stations should not drop below 80% or rise above 120% of the median baseline monitoring level or of corresponding values measured at the control stations. Monitoring stations on the newly constructed sandbank area are required to comply with the same criteria as the impact monitoring stations and must remain within the guideline levels for at least two years for recovery to be considered complete. If levels exceed these limits, recovery of other biota in the affected areas may be delayed and additional mitigation may be required.

Benthic Macrofauna

Soft-bottom benthic macrofauna (animals living in the sediment that are larger than 0.5 mm) are frequently used as a measure to detect changes in the health of the marine environment resulting from anthropogenic impacts. This is largely because these species are short lived and, as a consequence, their community composition responds rapidly to environmental changes.

Benthic macrofauna samples were collected from the same stations as the sediment and benthic microalgae monitoring. Intertidal samples were collected at spring low tide by inserting a large (18 cm) diameter corer into the sediment, plugging the open end, extracting the core and transferring the contents to a 0.5 mm mesh bag. Three cores were taken and pooled at each sampling station. The mesh bag was agitated until all the fine sediment has been removed and the remaining contents placed in a sample jar and adding 5% formalin. Subtidal samples are collected using a Van Veen grab deployed from a small inflatable boat. Two grabs were taken and pooled at each subtidal sampling station. Macrofauna from the samples were extracted from the residual sediment in the lab, identified to species level, counted and weighed (wet weight).

Considerable spatial variability in macrofaunal community structure in the Port was evident. Macrofaunal communities of the Mangroves and Centre Bank differed significantly from the other sandbank habitats. Differences observed in community structure are likely associated with the differences in sediment grain size characteristics and quality. The fine, organic-rich

nature of the Mangrove sediments contrasted with the coarser and better aerated sediments at Centre Bank mostly likely accounted for the differences in community structure of the macrofauna communities in the different areas. Univariate analysis indicated significant differences between macrofaunal abundance, biomass and number of species for both the intertidal and subtidal habitats. Further, multivariate analyses comparisons between sandbank habitats indicated significant dissimilarities when comparing Centre Bank and the Mangroves to other sandbank habitats in the Port. SIMPER analysis identified indicator and discriminatory species in the intertidal and subtidal communities of the significantly different sand bank habitats. Temporal comparisons indicated higher mean intertidal abundance in autumn and lower in spring, while subtidal abundance was highest in the summer and lowest in winter. Univariate analysis of spatial patterns indicated overall significant seasonal differences in abundance, biomass and number of species for the intertidal and subtidal habitats.

Description of intertidal and subtidal macrofaunal communities presented in this study provide a benchmark against impacts from the proposed development and the rate at which the newly created sand bank habitats are colonised in future can be evaluated. The newly created sandbank will be considered “functionally equivalent” to the habitat lost when species number, abundance and/or biomass of the communities is 80% similar to that of the existing Central Sandbank, and remains at that level for a period of at least three to five years.

During the construction of the Sandbank Extension, benthic macrofauna samples must be collected, from the same 25 sampling stations as for sediment and benthic microalgae monitoring activities, once every three months (each quarter - autumn, winter, spring, summer). Thereafter, the samples must be collected once every six months throughout the remainder of the Berth 203 to 205 Expansion construction phase.

The macrofauna extracted from the residual sediment in the intertidal and subtidal samples must be identified to species level, counted and weighed (wet weight).

Threshold (warning) levels to be adopted for benthic invertebrate fauna at the impact monitoring stations during the construction phase require that abundance, biomass and species richness do not drop below 80% or rise above 120% of median baseline monitoring levels or of corresponding values measured at the control sites. Monitoring stations on the newly constructed sandbank area are required to comply with the same criteria as the impact monitoring stations and must remain within the guideline levels for at least two years for recovery to be considered complete. If levels exceed these limits, recovery of invertebrate populations may be delayed and negative impacts on other biota such fish and birds can be expected. Additional mitigation may be indicated if this is the case.

Fish

The nearshore fish community in the Port was sampled quarterly using a beach seine net (30 m length, 2 m depth and 12 mm stretch mesh) at 24 sites over the period of two years. A total of 1 424 869 fish representing 62 species were captured in the 192 hauls made. Overall, the catch was dominated by glassies *Ambassis dussumieri* that contributed 96% numerically and

58% by weight to the total catch. Other very abundant species in samples were pony *Leiognathus equulus*, thorny anchovy *Stolephorus holodon*, and groovy mullet *Liza dumerilii*. Several important angling or food fish species contributed significantly to the total mass of fish sampled, these included spotted grunter *Pomadasys commersonnii*, needlescaled queenfish, freshwater mullet *Myxus capensis*, pickhandle barracuda *Sphyraena jello* and bartailed flathead *Platycephalus indicus*. Estuarine resident and estuarine dependent species dominated catches throughout the estuary, making up 99% of the catch numerically in all areas except Island View where they contributed 90%. Excluding *Ambassis dussumieri*, the remainder of the catch in the upper reaches of the estuary (Mangroves and Little Lagoon), was still dominated by estuary resident and estuary dependent species, (~97%), whilst 75-91% of the catches in the Centre Sandbank and Island View area, and approximately 60% of the catch in the Northern Bank area, were estuarine species.

Overall fish abundance, biomass and species richness were highest in the upper parts of the estuary (Little Lagoon and Mangroves areas) and the Northern Bank where several canals discharge freshwater, and lowest at marine dominated sites around Centre Bank and at Island View. These differences were not consistent through all seasons but tended to be more pronounced during the autumn and winter surveys than during the spring and summer surveys. There were statistically significant differences in species richness, and biomass between a priori defined areas within the Port, but not between seasons, whilst significant differences between both seasons and sandbanks (and an interaction effect) were detected for fish abundance.

Multivariate analyses take account of the individual species in the samples as well as their relative abundance, revealed some structure between priori defined areas that corresponded to a marine-estuarine gradient. An ANOSIM test showed the fish community sampled at the Centre Bank to be significantly different to that sampled in the Little Lagoon and the Mangrove areas. The principal species contributing to these dissimilarities were lower abundances of estuarine dependent and resident species such as *Ambassis dussumieri*, *Leiognathus equulus*, *Thryssa vitirostris*, *Rhabdosargus sarba*, *Myxus capensis*, *Acanthopagrus berda* and *Pomadasys commersonnii* at the Centre Bank sites compared to the Little Lagoon and Mangrove sites.

The new sandbank as an extension of the existing Central Sandbank is expected to create additional intertidal and shallow subtidal habitat that could potentially benefit estuarine dependent fish in the Port. As these habitats function as feeding and nursery areas, these are likely to be of significant value for fish communities in the Port. The utilisation of the sandbank extension, however, will depend on the successful establishment of benthic infaunal assemblages that resemble those at the other sandbank sites. Full recovery of the fish fauna will thus only take place once a benthic invertebrate community has become fully established.

During the construction of the Sandbank Extension, fish present at 9 impact monitoring stations and 5 control stations sites along the margins of the Central Sandbank must be sampled quarterly during the year (autumn, winter, spring, summer). Thereafter, samples must be taken once every six months for the remainder of the construction phase of the Berth 203 to 205 Expansion Project.

The fish collected at each sample point must be identified, enumerated, weighed and measured, and if possible, returned to the sea alive.

Threshold (warning) levels adopted for fish at the impact monitoring stations require that abundance, biomass and species richness not drop below 80% of median baseline monitoring levels or of corresponding values at control stations. If levels exceed these limits, recovery of fish populations may be delayed and negative impacts on other biota such as birds can be expected. Additional mitigation may be indicated if this is the case.

Birds

A total of 16 789 birds representing 71 species were recorded in monthly counts between October 2014 and September 2016. The relative contribution of six different taxonomic groups to the bird numbers in the Port vary substantially between summer (September-April) and winter (May-August). This is mainly due to the arrival of large numbers of migratory waders in September and their departure by the end of April. Accordingly, median bird abundance was significantly higher in summer. Spatial variability in avian community structure in the Port was clearly evident. Compared to the Northern Bank, which has intertidal sand flats with similar grain size, the Centre Bank and Little Lagoon habitat had similar abundance but significantly higher species richness and diversity. This was likely due to the occurrence of resident and migratory waders other than Common greenshank and Blacksmith lapwing. These were unique to the Centre Bank and Little Lagoon habitat and included Common whimbrel, Curlew sandpiper, Grey plover and Common ringed plover. The Centre Bank and Little Lagoon, due to its isolated position, clearly represent the most important intertidal sand flat habitat for waders in the Port.

The Open Water habitat had low bird abundance and ranked third in terms of species richness. Compared to the other habitats however, Open Water had the highest bird diversity, which was surprising due to the high level of disturbance caused by shipping, maintenance and construction activities in the Port. In contrast to the Centre Bank and Little Lagoon, the Open Water habitat did not have a unique set of species. Egyptian geese and White-breasted cormorants were the most abundant species in this area. White-breasted cormorant and kelp gull are thought to rely on Open Water habitat as a feeding ground.

The Central Sandbank is a crucial avian habitat in the Port, which supports high bird abundances and a unique set of species. Estuarine-dependent species such as migratory waders rely on the Central Sandbank habitat for feeding and roosting and any disturbance has a very high probability of significantly impacting on community structure. This study also demonstrated that the Northern Bank is not an equitable intertidal sandbank habitat when compared to the Centre Bank. Mitigation measures as proposed in the avian specialist study undertaken as part of the EIA for the redevelopment of Berth 203-205 must be followed to ensure that the impact on wader species in the Port is minimised to prevent further local extinction of sensitive bird species.

Bird counts on the Central Sandbank must be taken once per month at spring-low tide for the duration of the Berth 203 to 205 Expansion construction phase. The number of birds of each

species must be recorded within a series of counting sections. Counts must be conducted at low tide in the morning within a six-hour period.

Threshold (warning) levels to be adopted for birds at the impact monitoring stations require that monthly counts of numbers of water birds and water bird species on Centre Bank and Little Lagoon do not drop below 80% of median baseline monitoring levels for the avifauna assemblage as a whole and for key groups (Waterfowl; Cormorants, darters, pelicans; Wading birds; Birds of prey; Waders; Gulls; Terns). If levels exceed these limits, recovery of bird populations may be delayed and additional mitigation may be indicated.

Conclusion

In spite of the transformation in the Bay, the Port of Durban is still considered to be an estuary with high national conservation importance (Turpie & Clark, 2007). It is ranked as the 10th most important estuary in South Africa (Turpie & Clark, 2007). The extension of the Central Sandbank will assist in securing the benefits provided by this system in terms of ecosystem goods and services. Hence, it is imperative that the construction phase of the extension of the Central Sandbank is closely monitored against the thresholds identified in the Central Sandbank Mitigation Plan.

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List of Abbreviations

CDP	Chart Datum Point
CSD	Cutter Suction Dredger
CSIR	Council for Scientific and Industrial Research
CSMP	Central Sandbank Mitigation Plan
CTD	Conductivity-Temperature-Depth
DEA	Department of Environmental Affairs
EA	Environmental Authorisation
EIA	Environmental Impact Assessment
EMPr	Environmental Management Programme
EQT	Environmental Quality Target
KZN	KwaZulu- Natal Province
NEMA	National Environmental Management Act (No. 107 of 1998)
NOAA	National Oceanic and Atmospheric Administration
REI	River - Estuary Interface
TEU	Twenty-Foot Equivalent Unit
TOC	Total Organic Carbon
TNPA	Transnet National Port Authority
TSHD	Trailing Suction Hopper Dredger
TSS	Total Suspended Solids
NTU	Nephelometric Units
WIO	West Indian Ocean

Glossary

Anthropogenic	Environmental pollution originating from human activity
Benthic	Pertaining to the environment inhabited by organisms living on or in the ocean bottom
Biodiversity	The variability among living organisms from all terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems
Bioequivalent	A term which implies that key community descriptors (such as mean density of a particular organism) of a community assemblage at one site falls within a predefined percentage of that at another site for a defined time interval (i.e. that the communities are biologically equivalent - contain a similar or the same set of species in the same or similar numbers). See also functionally equivalent below.
Biota	All the plant and animal life of a particular region
Bivalves	An aquatic mollusc which has a compressed body enclosed within a hinged shell, such as oysters and mussels
CTD	An instrument that is lowered into the water to record profiles for conductivity, temperature and depth
Community Structure	Taxonomic and quantitative attributes of a community of plants and animals inhabiting a particular habitat, including species richness and relative abundance structurally and functionally
Fauna	General term for all of the animals found in a particular location
Flora	General term for all of the plant life found in a particular location
Filter-Feeders	Animals that feed by straining suspended matter and food particles from water
Functional Group	A collection of organisms of specific morphological, physiological, and/or behavioural properties
Functionally equivalent	A term used to describe communities from the same or different areas that comprise of species with the same or similar life history characteristics, morphology and behaviour even though the actual species present may be different.
Intertidal	The shore area between the high- and the low-tide levels
Invertebrate	Animals that do not have a backbone. Invertebrates either have an exoskeleton (e.g. crabs) or no skeleton at all (e.g. worms)
Lower Region	Section of estuary closest to the sea
Macrofauna	Animals larger than 0.5 mm
Piscivore	A carnivorous animal which eats primarily fish
Replicate	Taking more than one sample or performing more than one analysis
Sessile	Anchored in one place

**Thermal
Stratification**

Temperature layers within a body of water caused by separation of water with different densities

Upper Region

Section of estuary closest to the head/river inflow

1 INTRODUCTION

1.1 Background to the Deepening, Lengthening and Widening of Berth 203 to 205, Pier 2, Container Terminal, Port of Durban

Transnet National Port Authority (TNPA) plans to deepen, lengthen and widen Berth 203 to 205, Pier 2, Container Terminal in the Port of Durban. The project is also known as the Berths 203 to 205 Expansion Project, Pier 2, Container Terminal in the Port of Durban. The existing Blockwork Quay wall structure along Pier 2 Berth 203 to 205 was designed in the 1970s to support dockside cranes with the lifting capacity of 4 tonnes. The quay walls are presently operating beyond their original design limitations. Recent studies have concluded that the existing quay walls do not meet the minimum Eurocode 7 Safety Standards and that there is a risk of potential quay wall failure (PRDW, 2011)

Vessel sizes have also increased since the original terminal was constructed and Berth 203 to 205 cannot therefore safely accommodate fully laden new generation container vessels due to insufficient water depth at these berths. At present these vessels enter and exit the Port partially laden and during the high tide window. This creates an unsafe operating condition and the risk exists that vessels could run aground. TNPA has proposed the deepening, lengthening and widening of Berth 203 to 205 in order to improve the safety of the berths as well as to improve the efficiency of the Port. The Port handled the greatest number of containers between 2003 and 2009 of all South African Ports (SAPO, 2010). Container size is often described as twenty-foot equivalent unit (TEU) and between 2003 and 2011; there has been a 7.2% increase in the number of containers landed in the Port (Urban-Econ, 2012). This trend of increased containers has continued into 2012 which suggests that container traffic will continue to increase.

The proposed upgrade would include the following activities:

1. The westward lengthening of Berth 205 by 170m, the eastward lengthening of Berth 203 by 100m and the seaward widening of Berths 203 to 205 by 50m;
2. The deepening of the berth channel, approach channel, and vessel turning basin from the current -12.7m CDP to -16.5m CDP;
3. The construction of caissons, storage of sheet piles or precasting of elements of the Deck on Pile at Bayhead Lot 10;
4. The offshore disposal of dredge material and the offshore sand winning for infill material;
5. The installation of new Ship to Shore cranes and associated infrastructure; and
6. The extension of the central sandbanks within the Port using dredge material.

Nemai Consulting was appointed by TNPA to undertake the necessary Environmental Authorisation Process for the Proposed Berth 203 to 205, Expansion Project. The proposed development triggered activities listed in Government Notices No. R. 544, R. 545 and R. 546.

Hence, a full Scoping and Environmental Impact Assessment (EIA) study as per the August 2010 EIA Regulations promulgated in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998) was undertaken.

The Department of Environmental Affairs granted a positive Environmental Authorisation (EA) for the development in January 2015. Condition 27 of the EA stated that baseline monitoring must be undertaken over a period of 24 months to establish thresholds of acceptable change. In addition, the EA contained a number of specific conditions including the need for the Environmental Management Programme (EMPr) to contain a monitoring programme for the extension of the Central Sandbank.

The EA was challenged by 3 Appellants for various reasons, including the sustainable extension of the Central Sandbank. The EA was upheld however Condition 4.2.4 of the Appeal Decision stated that the outcome of the baseline monitoring must inform a Central Sandbank Mitigation Plan (CSMP).

The Environmental Management Programme was developed as a suite of 2 specific EMPrs namely, (1) a generic Environmental Management Programme and (2) a specific Central Sandbank Mitigation Plan which addresses the monitoring requirements for the extension of the Central Sandbank.

1.2 Purpose and Use of the CSMP

The aim of the CSMP is to satisfy Condition 27 of the EA and Condition 4.2.4 of the Appeal Decision. Hence, the CSMP provides thresholds for acceptable change to ensure the successful ecological functioning of the extension of the Central Sandbank in relation of the existing sandbank. The Independent Environmental Control Officer and/or a competent Marine Ecologist appointed by the Environmental Control Officer will monitor environmental compliance during the construction phase of the project.

As with all natural environments, the Port of Durban is subject to a range of natural (e.g. floods, storms) and anthropogenic perturbations (e.g. oil spills) that occur over different spatial and temporal scales. It is critically important that impacts associated with the Berths 203 to 205 Expansion Project which fall within the scope of anthropogenic perturbations, can unequivocally be separated from other non-project related perturbations.

For this reason, the CSMP recommends a suite of monitoring stations comprising of both “impact” and “control” monitoring stations. The “impact” stations are located in close proximity to Berth 203 to 205 which is within the anticipated range of impacts from the proposed development. The “control” stations are located a good distance away from the construction site, sufficiently far away that the likelihood of them being affected by the development is negligible, while at the same time being sufficiently similar to be reflective of conditions within the anticipated zone of impact. The “control” stations will assist in distinguishing between perturbations that are linked to the Berths 203 to 205 Expansion (e.g. elevated turbidity levels resulting from dredging operations) from other non-project related anthropogenic and natural perturbations (e.g. elevated turbidity resulting from a large rainfall event). It can be assumed that any changes that occur across both the control and impact stations are likely unrelated to the project activities, a fact that will need to be confirmed based on observations of other

unrelated variables such as rainfall, runoff, wave height, oil spill etc., while perturbations that are recorded at the impact monitoring stations only, and cannot be linked unequivocally linked to some external event, are likely to be linked to project related activities, and will need to be mitigated.

For the reasons outlined above, it is important to note that the CSMP cannot be translated into a checklist for environmental compliance as one would do with the EMP. Hence, benchmark thresholds for compliance monitoring during the construction phase included in the CSMP, are mostly comprised of two components:

- (a) A maximum deviation from what is considered “normal” baseline levels as measured during the baseline monitoring programme (usually expressed as a percentile value, e.g. 20th or 80th percentile); and
- (b) A maximum deviation from background levels as measured at designated control stations during the construction and post-construction period (usually expressed as a percentage, e.g. 10%).

In the event of a non-compliance, the Environmental Control Officer, with support from the Marine Ecologist, would recommend appropriate mitigation measures to Transnet.

1.3 Overview of the Extension of the Central Sandbank

The following information provided by the Engineers, ZAA, details the method for the Sandbank Extension. Figure 1.1 below shows the Sandbank extension area.

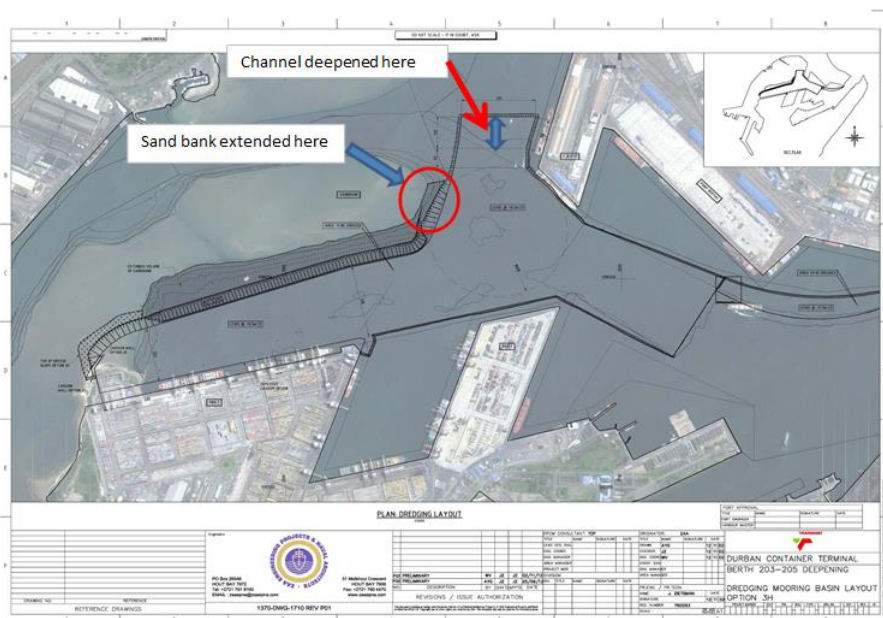


Figure 1.1: Sandbank Extension area

The estimated quantity of sand to be dredged and placed is approximately 1,000,000 m³. Based on a single 2,700 m³ TSD and with a bulking factor of 1.12 a nett deposition of about 1,800 m³ could be expected per dredged load. This requires some 550 loads at a cycle time

of some 6 hours. Thus, the maximum sand deposition rate will be of the order of 5,400 m³ / day which would take at least 6 months of uninterrupted work. It should be noted that the actual equipment available to and selected by the contractor may change these rates and durations significantly.

The major part of this work will be carried out during Phase 1 of the work, during which the basin and turning circle will be dredged to its new depth and the slope protection installed. Phase 1 also includes the construction of the new Berth 205 and the deepened basin and turning circle must be available for the larger ships that will use Berth 205 after it is commissioned. Extension of the sandbanks will progressively follow the dredging work.

The following procedure provides a simplified, high-level overview of the Contractor's process of reclamation and extension of the Central Sandbank.

- Set up a survey programme, determining setting out points of the area to be filled. This must be compared with previous surveys and the baseline agreed;
- Conduct a video survey of the existing slopes for record purposes;
- Set up pollution control measures;
- Mobilise and commission suitable dredging equipment, marine operating staff, diving crews and support boats.;
- Dredge suitable material from within the Port;
- Provide samples for confirmation of suitability of material;
- Place sandbags along the line of the new toe of the extended sandbank to form a low retaining structure. Bio-degradable sandbags would be preferred;
- Pump the reclaim material behind the sandbag retaining structure in a sequence so that the area is filled evenly and rises in layers from below. This procedure will reduce entrainment of sand in the water column and thus reduce turbidity;
- Monitor turbidity in the water column and adjust deposition rates as needed;
- Fill to the pre-determined level, with periodic dives providing video records of the new profile; and
- Conduct interim and acceptance surveys for confirmation of final levels achieved and for measurement of quantities.

The following specific measures must be adopted to reduce pollution and turbidity to the absolute minimum.

- Grading of the sand selected for reclaim and sandbank extension shall match that of the existing sandbank as closely as possible. The material shall be free of clay, organic matter or other detritus.
- Pumping shall be controllable in rate so that it can be slowed if turbidity levels rise. It is expected that pumping can be maximised over both high and low tide periods, but

may have to be reduced as tidal flows in both directions increase. In particular turbidity during tidal flows away from the sandbank and towards the new basin must be strictly controlled to prevent sand flowing back into the newly dredged areas.

- Floating containment curtains extending well into the water will be required to restrict movement of the more turbid water until it has settled.

1.4 Overview of Existing Central Sandbank

During the EIA, a number of Ecological Specialist Studies were undertaken including an Estuarine Impact Assessment (Anchor Environmental, 2013), Avifauna Impact Assessment (Anchor Environmental, 2013) and Potential Long Term Impacts to Sandbank Habitat, Water and Sediment Quality Study (CSIR, 2013).

Habitats available to estuarine flora and fauna include intertidal areas, benthic substratum and the overlying water column that are each utilised by a range of organisms. The most important of these include microalgae, phytoplankton, invertebrates, zooplankton, fish and birds. The intertidal sand bank habitats in the Port have been identified as extremely important to its ecological functioning (CSIR, 2008; CSIR, 2011). They have significant ecological importance as they contribute to the various ecosystem goods and services provided by the Port. Sand banks in the Port become exposed at low tide and play an important role in the recycling of terrestrial and marine derived nutrients and organic matter. The sandbank habitats are important from a conservation perspective as they harbour a diverse invertebrate fauna and are important feeding areas for fish and birds and thus help maintain biodiversity in the Port (Allan et al. 2005). The sandbank habitat has accordingly been identified for conservation by the Bay of Natal Estuary Management Plan (MER/ERM, 2012).

Only a small proportion of shallow and moderately shallow, subtidal areas of Durban Bay remain, as most of it has been dredged to 12.8 m below sea-level (CSIR, 2011). The shallow subtidal areas are the rarest habitats in the Durban Bay (CSIR) and have great ecological importance for both invertebrate and fish communities by providing nursery and feeding areas. They are also important for many indigenous and migratory birds.

A number of studies have been completed in recent years focusing on the estuarine biota of the Port (see for example Allan et al. 1999; Pillay, 2003; Blackler et al. 2004; Forbes & Demetriades, 2006; Angel & Clark, 2008; CSIR, 2008; CSIR, 2011; MER/ERM, 2012). Key sand bank habitats in the Port include the Central Sandbank also known as the Centre Bank, Little Lagoon, Northern Banks and the Mangrove area.



Figure 1.2: Location of intertidal sand bank habitats in the Port (Google Earth 2015)

The Central Sandbank is the largest intertidal and subtidal sand flat in the Port. It has an intertidal area of approximately 83 hectares and a steep subtidal section that forms the slopes of the sand flat, which falls away quickly to the Port operational depth (CSIR, 2011). Overall, the sand bank habitats are rich in invertebrate fauna including many species of polychaetes, amphipods, tanaeids, isopods, mysids, brachyurans and echinoderms. Densities of organisms range between 500 and 2 000 ind./m², although densities of greater than 10 000 indiv./m² have been recorded at some areas during certain times of the year (Forbes & Demetriades, 2003). The sand bank habitats in the Port also support high densities of sand prawn *Callichirus kraussi* (CSIR, 2008). These crustaceans play a crucial role as bioturbators by increasing the sediment-water interface, thereby facilitating particle exchange between the sediment and water column. They are also a very important food source for many fish, particularly the recreationally targeted spotted grunter *Pomadasys commersonnii*. Sand Banks in the Port also provide favourable conditions for growth of benthic microalgae or diatoms (MER/ERM, 2012). Benthic microalgae support a suite of microorganisms that in turn, support many species of macrofauna and juvenile's fishes in the Port (MER/ERM, 2012).

1.5 Baseline Monitoring

While the EA and the Appeals Decision only made reference to baseline monitoring around the Central Sandbank, Transnet undertook a holistic approach and extended the monitoring programme to include all Sandbanks in the Port. Baseline monitoring data from all Sandbanks within the Port over 24 months.

Baseline monitoring was necessary to establish monitoring thresholds to confirm the following:

- Defined maximum/minimum water quality thresholds are not exceeded during the construction phase as a result of project related activities; and
- The biotic community composition on the existing sandbank and to allow comparisons after the Sandbank Extension which show whether the extension has been successful.

During the 24 months monitoring period, quarterly sampling was undertaken for the water and sediment quality, benthic microalgae, macrofauna and fish surveys, while monthly sampling was undertaken for the bird surveys. Dates of the quarterly surveys were selected to correspond with the middle of each season and were centered on one of the Spring tide episodes in each period. Surveys were undertaken in the following months:

- November 2014 (Spring);
- January 2015 (Summer);
- May 2015 (Autumn);
- July 2015 (Winter);
- November 2015 (Spring);
- January 2016 (Summer);
- May 2016 (Autumn); and
- July 2016 (Winter).

Bird counts were undertaken every month between October 2014 and September 2016 with the exception of December 2014.

The baseline monitoring survey assessment focussed on the following components:

- Physico-chemical (habitat) variables:
 - Total Suspended Solids (TSS);
 - Salinity;
 - Temperature;
 - Dissolved Oxygen;
 - Sediment Grain Size Distribution;
 - Organic Carbon Content; and
 - Trace metal content in sediment (Cd, Hg, As, Cr, Cu, Pb, Ni, Zn).
- Faunal and floral assemblages:
 - Benthic microalgae (microphytobenthos);
 - Benthic macrofauna;
 - Ichthyofauna; and
 - Avifauna.

This report is an assessment of environmental baseline conditions of the Central Sandbank habitat in the Port to inform the CSMP. The information aims to serve as a benchmark against which (1) the impacts of any disturbance associated with the proposed development can be assessed and (2) as an end-reference point at which the new extension of the Central Sandbank can be considered equivalent to the habitat lost as a result of the development.

This baseline study addresses all major fauna and flora groups that could potentially be affected by the developments and their drivers.

The Sections to follow provide an in depth understanding of the baseline monitoring protocol used over the 24 months of monitoring and an analysis of the monitoring data. Based on the baseline monitoring data, the team has developed benchmark thresholds for compliance monitoring during the construction phase of the project.

2 WATER QUALITY DATA

2.1 Introduction

Estuaries are extremely productive ecosystems due to the combination of high nutrient river water with a shallow, sheltered habitat. Estuaries are also valued for their importance as nurseries for juvenile marine fish and invertebrates, which recruit to these protected and nutrient rich areas during their developmental stages (Beck et al. 2001). Despite their massive importance, estuary habitats in South Africa (and indeed the world over) have been extensively impacted by poor catchment management upstream including erosion, pollution and water abstraction. This, along with harbour development, in the case of the Bay of Natal, has resulted in the water quality in the Bay becoming severely degraded, leading to concern for the biota within the systems. Over the years there have been numerous reports of fish kills in response to pollution events in the Port. Development of the harbour has resulted in poor circulation and limited water exchange in the upper regions. This has resulted in the retention of pollutants introduced via the uMhlatuzana and aManzimnyama canals. The accumulation of the pollutant in stagnant regions impacts negatively on water quality, leading to negative ecological consequences. Monitoring of water quality is important for the identification of pollution events and the types of hazardous contaminants being introduced into the system. For example, the introduction of organic wastes can lead to deoxygenation, eutrophication and/or the formation of algal blooms which can have adverse impacts on biodiversity.

Formulating a baseline on the water quality in the Port involves the analysing and quantifying of the relevant physical-chemical parameters (salinity, temperature, dissolved oxygen, pH and turbidity). The information obtained will be used to monitor changes to the water quality during the construction and operational phases of the Berth 203-205 development project. Reference conditions identified from the baseline study will be used to formulate guidelines to aid in maintaining a standard on water quality that is deemed to be within the natural range for the Port ecosystem. This will furthermore aid in identifying impacts associated with the construction and operational phases and developing appropriate mitigation measures to address them.

2.2 Sampling Methodology

Water quality measurements were taken at 20 stations distributed in the navigation channels surrounding the main intertidal and shallow subtidal sandbank areas in the Port using a conductivity-temperature-depth meter, see Figure 2.1. This includes the Centre Sandbank, Little Lagoon, Wilsons Wharf, Victoria Embankment and the Island View Basins. Water quality profiles (salinity, temperature, dissolved oxygen, pH and turbidity) were measured at each station at spring high, spring low, neap high and neap low tide during each quarterly survey (autumn, winter, spring, summer). The instrument was held at the surface for approximately one minute to flush the sensors and was then lowered and retrieved at approximately 1 m.s⁻¹. The SBE 19plus CTD samples data at 4 Hz, i.e. 1 sample every 0.25 seconds. After each

survey, data were downloaded and processed according to the manufactures' recommendations.



Figure 2.1: Locations of the 20 water quality monitoring stations in the Port.

Concentrations of suspended solids in surface water were determined by measuring the mass retained on a filter per volume of water, presented as mg.l-1. One litre of water was collected at each water quality station on each survey; vacuum filtered through a pre-dried and pre-weighed 47 mm diameter glass microfiber filter (0.7 µm pore-size). The filters were dried at 105°C for two hours and reweighed. TSS concentrations were calculated by the difference in the weight of the filters before and after filtration.

Water quality data from each monitoring station were analysed by deriving appropriate summary statistics over each tidal phase in each season and graphically represented to show the physico-chemical variability in the Port. Where applicable, results were compared to the South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment, DWAF 1995, Table 2.1). However, owing to the fact that the Port is actually an estuary, the guidelines are not necessarily the most appropriate. Therefore, protocols included in the UNEP-GEF West Indian Ocean Project (2009) along with data collected during the baseline survey were used to derive Environmental Quality Targets (EQT's) specific to the Port (see Table 2.2). When there was considerable physico-chemical variability between surface and bottom water conditions, individual guideline values were calculated for each. Refer to Annexure 1 for all Water Quality Monitoring Data.

Table 2.1: South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment - DWAF 1995).

Parameter	Guideline values
Temperature	Maximum acceptable variation in ambient temperature is $\pm 1^{\circ}\text{C}$
Salinity	33-36 PSU
Dissolved oxygen	Should not be $< 5 \text{ mg.l}^{-1}$ 99% of the time and $< 6 \text{ mg.l}^{-1}$ 95% of the time
Turbidity	Should not reduce the depth of the euphotic zone by more than 10% of background levels measured at a comparable control site.
Total suspended solids	Should not be increased by more than 10% of the ambient concentration
pH	7.3 - 8.6

Table 2.2: Recommended Environmental Quality Targets (EQTs) for physico-chemical variables in coastal waters in the West Indian Ocean (WIO) region as adopted from ANZECC (2000). (WIO Lab, UNEP-GEF, CSIR. 2009)

Parameter	Recommended Environmental Quality Targets
Temperature	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value should be determined as the range defined by the 20 th percentile and 80 th percentile of the seasonal distribution for the reference system. Test data: Median concentration for the period
Salinity	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value should be determined as the 20 th percentile or 80 th percentile of the reference system(s) distribution, depending upon whether low salinity or high salinity effects are being considered. Test data: Median concentration for the period
pH	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value range should be determined as the range defined by the 20 th percentile and 80 th percentile of the seasonal distribution for the reference system. pH changes of more than 0.5 pH units from the seasonal maximum or minimum defined by the reference systems should be fully investigated. Test data: Median concentration for the period
Turbidity	Where an appropriate reference system(s) is available and there are sufficient data for the reference system, the guideline values should be determined as the 80 th percentile of the reference system(s) distribution. Additionally, the natural euphotic depth (Zeu) should not be permitted to change by more than 10%. Test data: Median concentration for period
Suspended solids	
Dissolved oxygen	Where an appropriate reference system(s) is available, and there are sufficient data for the reference system, the guideline value should be determined as the 20 th percentile of the reference system(s) distribution. Where possible, the guideline value should be obtained during low flow and high temperature periods when DO concentrations are likely to be at their lowest. Test data: Median DO concentration for the period, calculated by using the lowest diurnal DO concentrations

2.3 Temperature

2.3.1 Overview

Water temperature is closely associated with many of the chemical and biological processes occurring in estuaries. Dissolved oxygen concentration and saturation levels in the water column are parameters that are directly influenced by temperature. As water temperature increases, the solubility of oxygen decreases, therefore cold water holds more dissolved oxygen than warm water. Temperature also influences a wide range of biological processes such as plant photosynthesis, reproductive cycles, migrations, metabolic rates of fauna and their susceptibility to parasites and disease. Water temperature in estuaries varies in relation to water depth, season, anthropogenic influences, atmospheric conditions and tidal exchange. Thermal stratification, layering of water bodies of different temperatures as a result of differing densities of cold and warmer water, is a characteristic of many estuarine systems. If persistent, thermal stratification can have negative impacts on benthic habitats through the formation of hypoxic or anoxic conditions in bottom waters. These conditions develop as the oxygen demand in the bottom water exceeds the rate at which it is replenished due to a lack of mixing.

2.3.2 Results and Analysis of Data

Depth profile data for temperature (median, 20th and 80th percentiles) at each water quality monitoring stations over the entire survey period are shown in Figure 2.2, while the seasonal water temperature depth profiles are presented in the Annexure 1.

Overall, water temperature did not differ greatly between water quality stations. Slightly warmer water temperatures were recorded at the shallower stations located in the upper regions of the Port, with the highest surface (27°C) and bottom (24°C) water temperature recorded at Station WQ1. There was a progressive decrease in median water temperature with increasing depth across all stations, however, the change in temperature through the water column was minimal (approximately 1°C) indicating that the water column is almost always well mixed. Median annual surface temperatures across all stations ranged between 22-23°C, while bottom water temperatures approximated 21°C.

Summer surface water temperatures were expectedly higher than in other seasons resulting in more pronounced decreases in temperature with depth. The greatest change in temperature with depth was recorded in summer at station WQ1, where temperatures dropped from 28-24°C between the surface and the bottom. Water temperatures recorded in spring were less varied with median surface and bottom temperature ranging from 22-23°C. In winter and autumn, water temperatures remained relatively uniform with depth approximating 23°C and 21°C, respectively.

There was little difference in the natural range of temperature between stations and seasons. Recorded temperatures ranged between 19-28°C for surface waters and 18-24°C for bottom waters. Marginally higher temperatures were recorded in the shallower stations located in the upper regions and in the warmer summer season. However, there was no indication of any strong seasonal or event-scale effects on the natural variability of temperature in the Port.

Furthermore, there was no indication of anthropogenic influences nor was there any indication of persistent thermal stratification in the water column at any station.

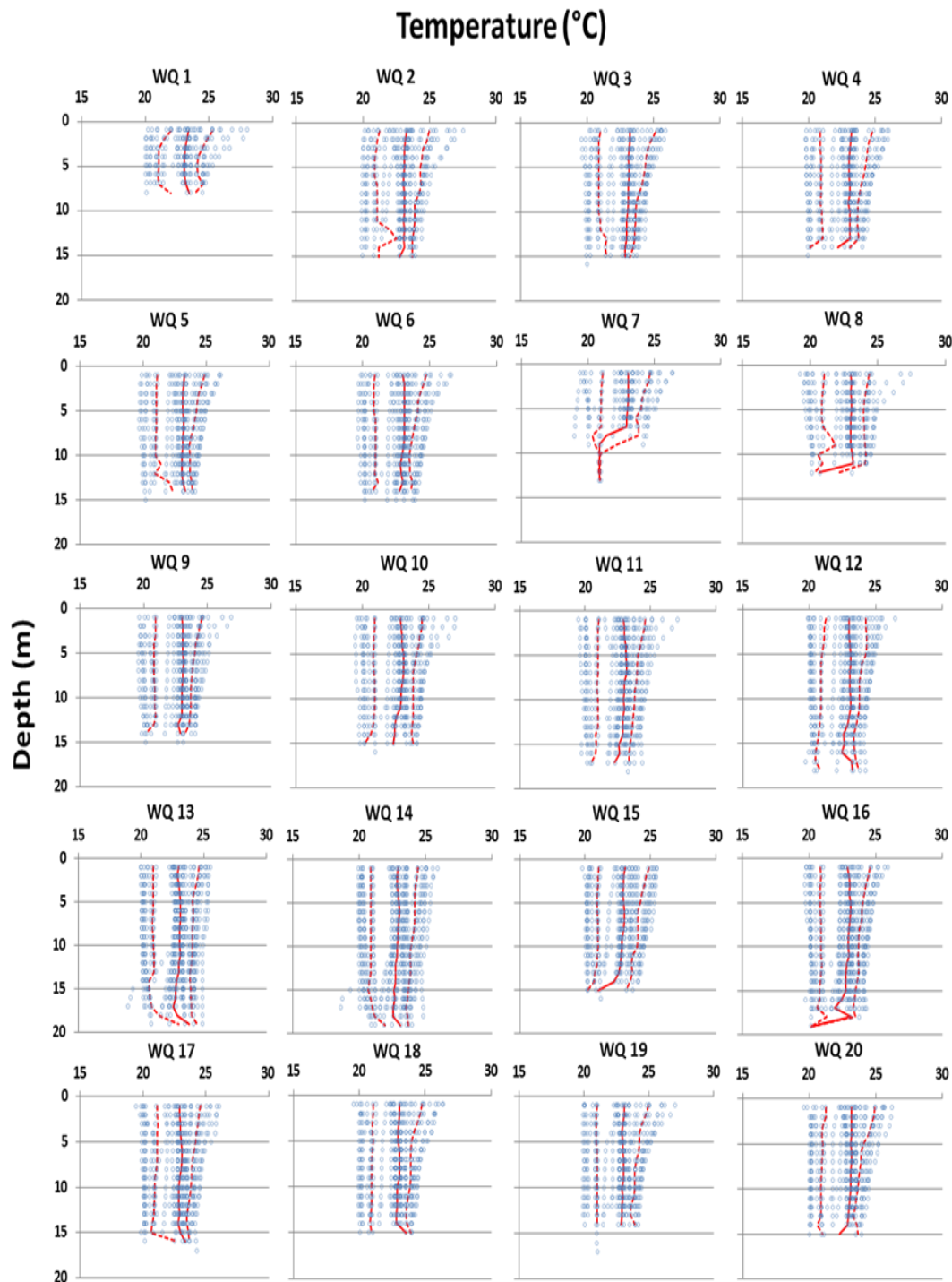


Figure 2.2: Profile data for temperature at the 20 water quality monitoring over each tidal phase in each season. The solid red line indicates the mean and the dotted lines the 20th and 80th percentile values.

2.4 Salinity

2.4.1 Overview

Salinity is a measure of the amount of dissolved salts in water. In the marine environment, salinity averages around 35 PSU, whereas, in an estuarine environment salinity levels are generally much more variable. Gradients in salinity can have a direct influence on the type and distribution of plants and animals in an estuary as many marine and freshwater species are adapted to tolerate only a narrow salinity range. The input of freshwater from river inflow or anthropogenic discharge via storm water canals result in fluctuating gradients in salinity. Salinity levels also fluctuate seasonally. During the rainy season, greater volumes of freshwater enter estuaries thereby lowering salinity levels. In contrast, a dry season would result in far less freshwater input and therefore possibly less variation in salinity levels. As with temperature, salinity stratification of the water column is a characteristic of estuarine systems. If mixing in the water column is limited, salinity stratification over long periods risks the development of hypoxic or anoxic conditions in benthic habitats.

2.4.2 Results and Analysis of Data

Median salinity depth profiles for each sampling station with 20th and 80th percentile limits are presented in Figure 2.3, while the seasonal salinity depth profiles are presented in Annexure 1.

All water quality stations approximated estuarine or marine conditions with median salinities values ranging between 32 and 35 PSU. The greatest fluctuations in salinity occurred in the upper regions of the Port (WQ1-6), with the lowest salinity recorded in the upper 2 m of the water column. Water quality sites located closest to the uMbilu, uMhlatuzana and aManzimnyama river inlets had the lowest recorded mean salinity values in the upper surface layers reflecting the influences of freshwater inflow. Variations in salinity at stations located in the lower regions of the Port were much lower than in the upper reaches. There was no indication of persistent salinity stratification anywhere in the Port.

The greatest fluctuation in salinity with increasing depth occurred in summer and is likely associated with increased seasonal rainfall. There was less variability over the other seasons, however, stations located in the vicinity of the Yacht Basin (WQ6 -WQ10), fluctuated during spring and is likely associated with concurrent rainfall and storm water runoff. Median salinity values in the lower regions of the Port remained relatively constant approximating 35 PSU.

Overall, the Port is clearly as an estuarine embayment, dominated by marine influences with limited freshwater inflow from rivers. However, variability in salinity was recorded between stations and seasons in the upper surface layers.

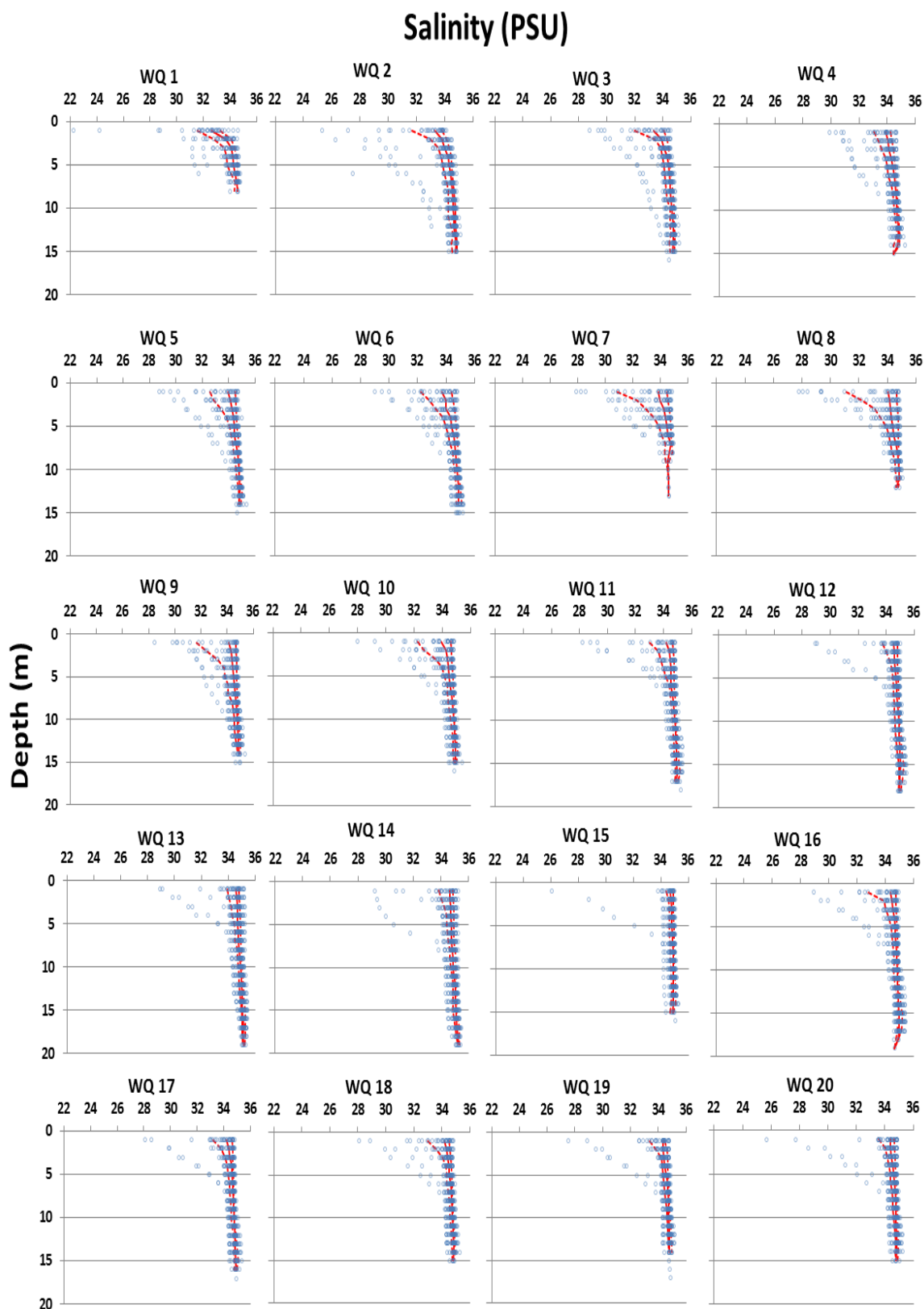


Figure 2.3: Profile data for salinity at the 20 water quality monitoring stations over each tidal phase in each season. The solid red line indicates the mean and the dotted lines the 20th and 80th percentile values.

2.5 Dissolved oxygen

2.5.1 Overview

Dissolved oxygen concentration refers to the amount of oxygen present in water and is vital for the survival of most forms of aquatic life. Dissolved oxygen plays an important role in the various chemical and biological processes occurring in estuaries. In estuaries, dissolved oxygen levels are influenced by season, temperature, salinity and plant photosynthetic activity. Sufficient levels of dissolved oxygen are crucial for the survival of estuarine fauna and thus have an important influence on their distribution and abundance. The monitoring of dissolved oxygen in estuarine environments is important as it is good indicator of estuary health. Concentrations in estuaries typically range between 6-8 mg.l⁻¹. When dissolved oxygen concentrations fall between 2-5 mg.l⁻¹, and persist over a period over time, fauna become stressed. If concentrations decrease to levels below 2 mg.l⁻¹ conditions are considered hypoxic (oxygen deficient) and can have deleterious consequences on estuary fauna. Concentrations below 0.5 mg.l⁻¹ are considered anoxic and can result in the death of organisms which require oxygen for survival. If dissolved oxygen concentrations reach levels that are insufficient to support aerobic respiration, decomposition of organic matter by anaerobic bacteria begins. Anaerobic decomposition involves the breakdown of organic matter by microbial activity in the absence of oxygen. This anaerobic process produces noxious by-products such as hydrogen sulphide (H₂S). The toxicity of some metal contaminants such as copper, lead and zinc, can increase with a decrease in dissolved oxygen concentrations.

2.5.2 Results and Analysis of Data

Annual dissolved oxygen depth profiles with median, 20th and 80th percentile limits are presented in Figure 2.4, while depth profiles for each season are presented in the Annexure 1.

In the upper regions of the Port dissolved oxygen concentrations fluctuated considerably with increasing depth. The greatest variation in dissolved oxygen occurred at Station WQ1, with concentrations ranging from 1.6-8.5 mg/l-1. Overall, trends in the upper regions indicated deeper water having lower dissolved oxygen concentrations. These trends observed reflect the influence of freshwater input and the limited water movement in the upper regions of the Port. The median variation in dissolved oxygen concentrations through the water column recorded at stations located in the lower regions and closer to the entrance of the Port did not fluctuate as considerably, approximating 6 mg/l-1 throughout the water column.

The greatest variations in dissolved oxygen concentrations occurred during summer across all stations. Median dissolved oxygen concentration varied considerably between surface and bottom water in the upper regions, ranging from 3-5 mg/l-1. In spring, dissolved oxygen concentrations did not fluctuate as greatly as in summer, but showed similar trends between stations and with increasing depth. There was little variation in dissolved oxygen concentrations through the water column in the winter and autumn surveys. Median winter concentrations (5.4 mg/l-1) were slightly higher than in autumn (4.9 mg/l-1), however, concentration stayed relatively uniform at most stations with increasing depth. Seasonal

variation between stations WQ 11-15 were minimal and likely associated with their close proximity to the Port entrance.

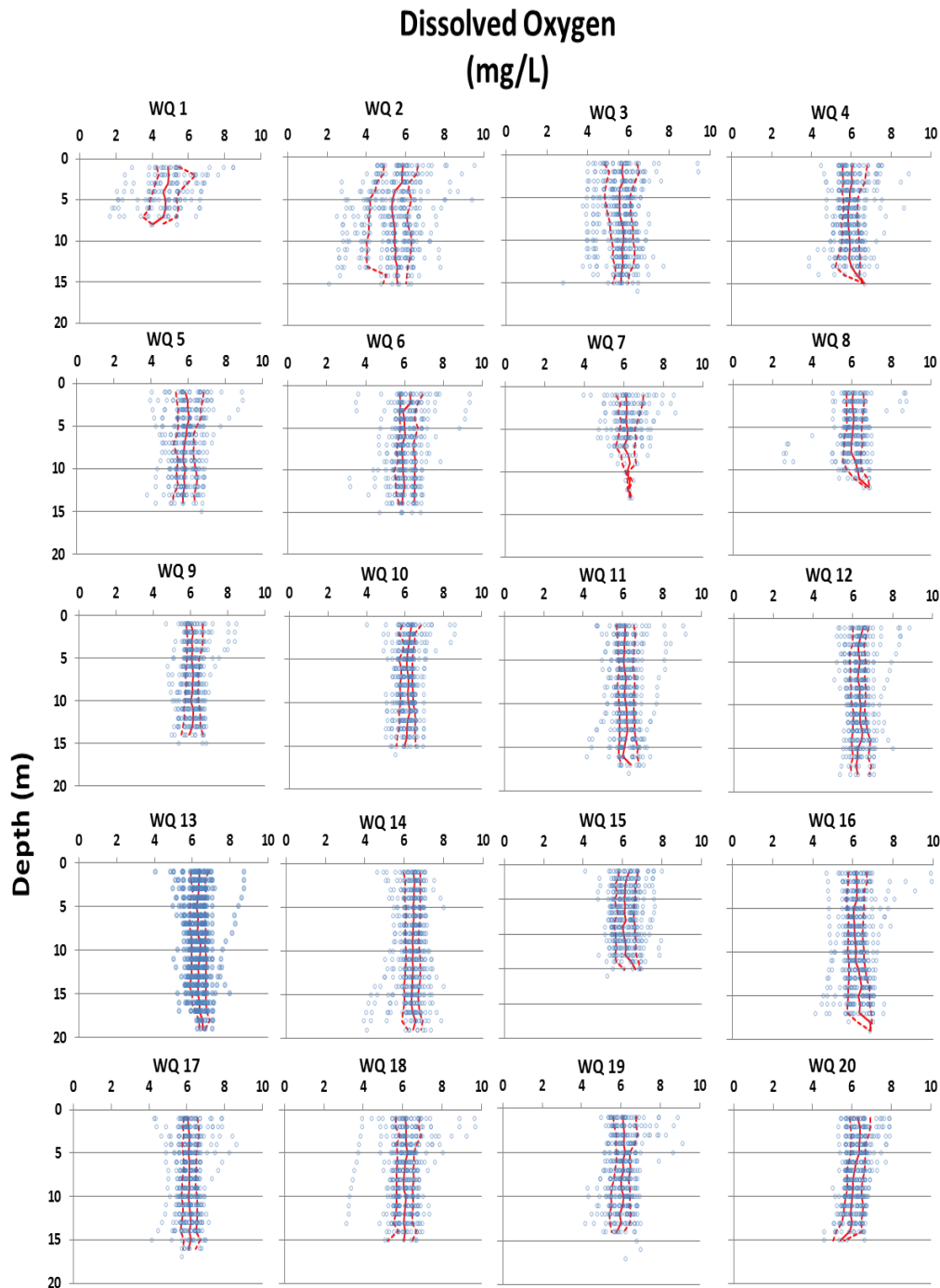


Figure 2.4: Profile data for dissolved oxygen concentrations at the 20 water quality monitoring stations over each tidal phase in each season. The solid red line indicates the mean and the dotted lines the 20th and 80th percentile values.

2.6 Turbidity and Total Suspended Solids

2.6.1 Overview

Turbidity and total suspended solids are both important measures of water quality and there is usually a strong relationship between these two parameters. Turbidity is measure of light conditions in the water column, it is the transparency of the water in relation to the amount of light scattered by particulates and dissolved substances. TSS, however, is the measure of the mass of the suspended solids in the water column per unit volume of water. This includes both inorganic and organic particulate matter, such as fine sediment, algae and plankton. Turbidity is recorded in Nephelometric Units (NTU), whereas, TSS is a measured in milligrams of solids per litre of water. Monitoring turbidity and TSS concentrations in aquatic environments is important as changes in turbidity and TSS can have detrimental ecological effects. High concentration of particulates in the water column can affect light penetration and productivity. Reduced light penetration due to high turbidity can limits plant photosynthesis reducing food availability and oxygen production. High TSS can clog fish gills and alter benthic community composition by impeding feeding efficiency by filter feeders. High turbidity and TSS can also influence predator-prey interactions by reducing visibility. Indirectly, suspended solids can promote stratification by heat retention by particulate matter in the surface layers. This sequentially reduces mixing of the water column and limits the downward flux of oxygen and replenishment of nutrients in the surface layers.

2.6.2 Results and Analysis of Data

2.6.2.1 Turbidity

As turbidity is an approximation of TSS the correlation between the two parameters was investigated for linearity (Figure 2.5). The relationship between these two variables in the Port is reasonable ($r^2 = 0.4$) and can be used to derive an estimate for suspended solid concentrations in the water column from measurements of turbidity. Turbidity values of the annual median with 20th and 80th percentile limits are presented in Figure 2.6, while depth profiles for each season are presented in Annexure 1.

Overall, turbidity did not vary markedly between stations with annual median turbidity values ranging between 1-7 NTU throughout the water column. Larger variations were recorded at stations located in the upper regions and are again likely associated with the inflow of turbid freshwater from the river inlets. The largest variations in turbidity through the water column occurred in summer and spring across all sites. This is likely associated with increased rainfall over these periods and the subsequent greater input of suspended particulate matter from river and storm water drain inlets. Turbidity during winter and autumn did not vary as much, remaining relatively uniform with increasing depth at most stations.

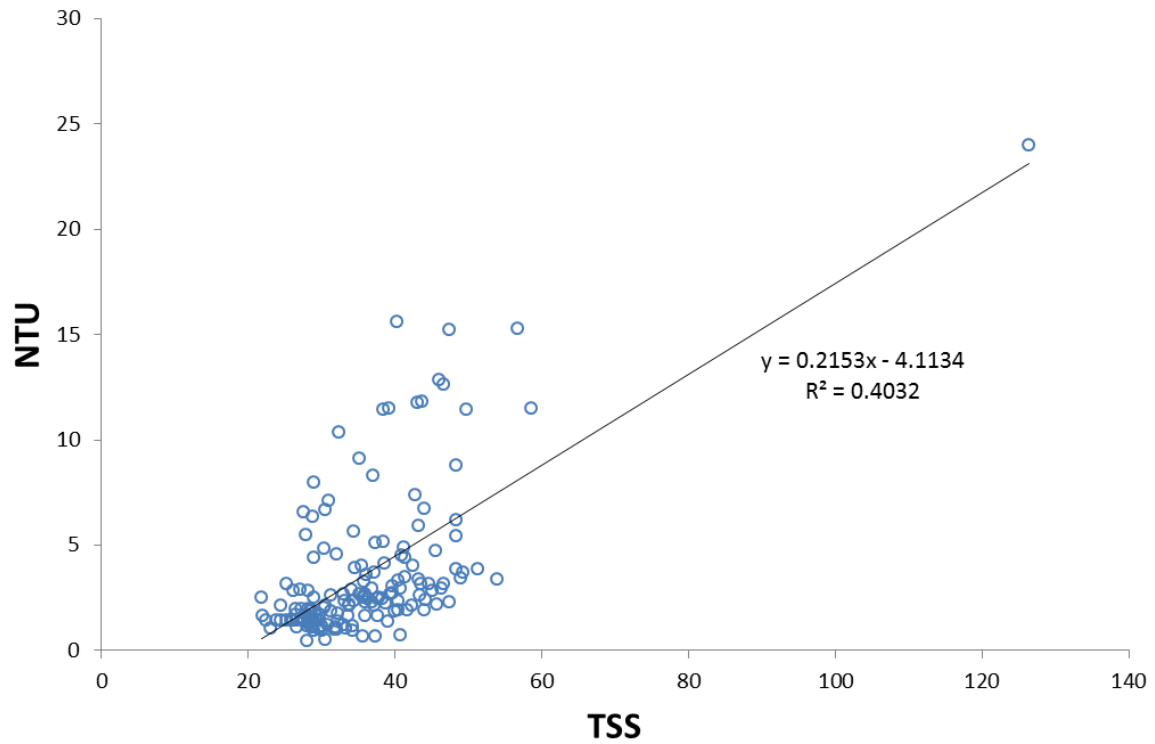


Figure 2.5: Relationship between turbidity and TSS concentrations recorded in the Port

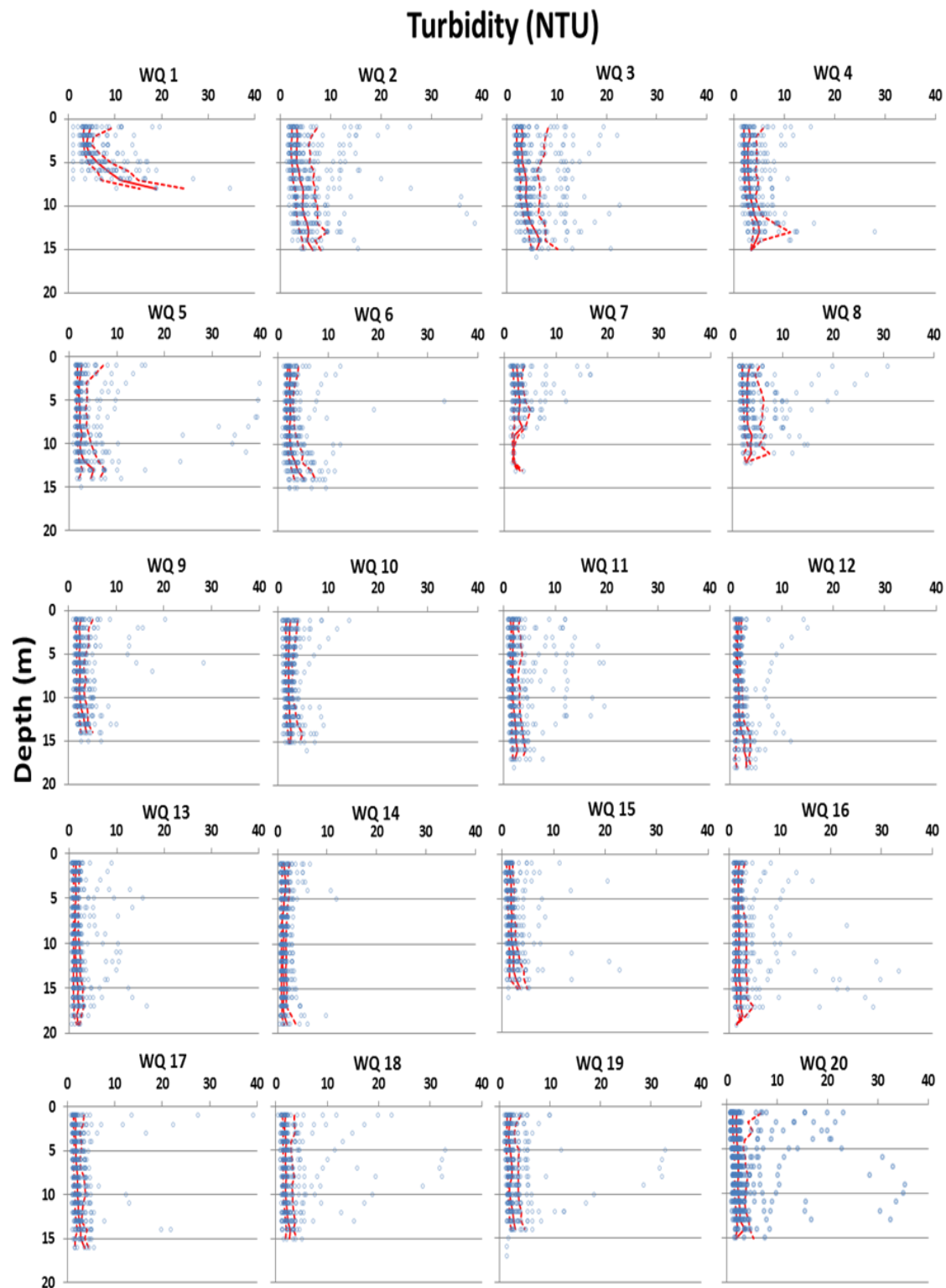


Figure 2.6: Profile data for turbidity at the 20 water quality monitoring stations over each tidal phase in each season. The solid red line indicates the mean and the dotted lines the 20th and 80th percentile values

2.6.2.2 Total suspended solids

Mean TSS concentrations in surface waters from the Port for each season are presented in Figure 2.7. Concentrations were slightly higher in the upper regions of the Port than the middle and lower reaches. Overall, TSS concentrations were high and are likely linked to the ongoing maintenance dredging, ship movements and rainfall events which unavoidably coincided with some of the sampling events. The slightly higher TSS concentrations in the upper regions of the Port are likely due to the input of suspended solids from the uMbilu, uMhlatuzana and aManzimnyama river inlets.

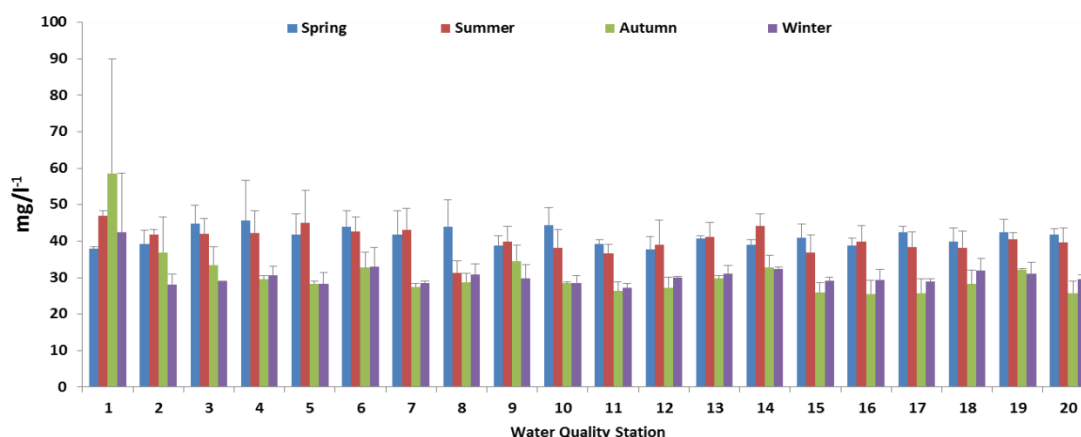


Figure 2.7: Mean total suspended solids concentrations in water samples collected from selected sites in the Port for each season.

Table 2.3: The 80%ile values for TSS (mg/L) from each of the water quality monitoring stations.

Station	80%ile		Station	80%ile	
	summer/spring	winter/autumn		summer/spring	winter/autumn
WQ1	46.66	71.16	WQ11	39.72	28.58
WQ2	43.08	37.18	WQ12	43.00	30.22
WQ3	47.7	32.76	WQ13	42.88	31.65
WQ4	51.76	31.54	WQ14	43.44	34.24
WQ5	50.04	29.95	WQ15	42.86	29.23
WQ6	47.34	37.52	WQ16	42.22	30.4
WQ7	48.58	28.7	WQ17	43.1	29.72
WQ8	42.6	32.23	WQ18	43.1	33.28
WQ9	42.44	35.68	WQ19	43.78	33.12
WQ10	45.64	29.51	WQ20	43.48	29.69

TSS concentrations did vary between seasons. Higher concentrations were recorded during spring and summer, particularly in the upper regions of the Port. This is again likely associated with increased rainfall over these periods and the subsequent greater input of suspended solids from the river and storm water drain inlets. Concentrations were expectedly lower in winter when freshwater inflow is more limited.

2.7 pH

2.7.1 Overview

pH is recorded on a scale of 0 to 14 and is a measure of the alkalinity or acidity of a solution. In estuaries, it is an important measure as slight changes in pH can significantly alter the chemistry of the water and influence biological and chemical reactions. Changes in pH can also influence the solubility of some metals, such as copper and iron, and the toxicity of many compounds such as NH_3 . The preferred range of pH values for estuarine fauna is between 6.5-8.6. Most fauna are unable to survive pH levels lower than 5 or greater than 9. When pH values in estuarine environments fall either below 5 or rise above 10, this is often an indication of the introduction of industrial or agricultural pollutant to the system.

2.7.2 Results and Analysis of Data

pH profiles, the annual median with 20th and 80th percentile limits are presented in Figure 2.8, while data for each season are presented in Annexure 1.

Overall, water pH levels were fairly consistent throughout Port, ranging between 7.9-8.4 and a median approximating 8.1 pH throughout the water column. There were, however, slight differences between stations in the upper regions. Station WQ 1 had the greatest variation in pH with increasing depth, ranging from 7.9-8.7 pH and is likely associated with the input of freshwater from rivers and storm water drains.

Median pH values recorded in summer showed the greatest variation when compared to the other seasons. Slight variations were also recorded in the surface water at various stations during spring. The fluctuations observed during spring and summer is again likely associated with the higher rainfall over these periods. In autumn and winter, pH values stayed relatively stable at 8.1 and did not vary greatly with depth.

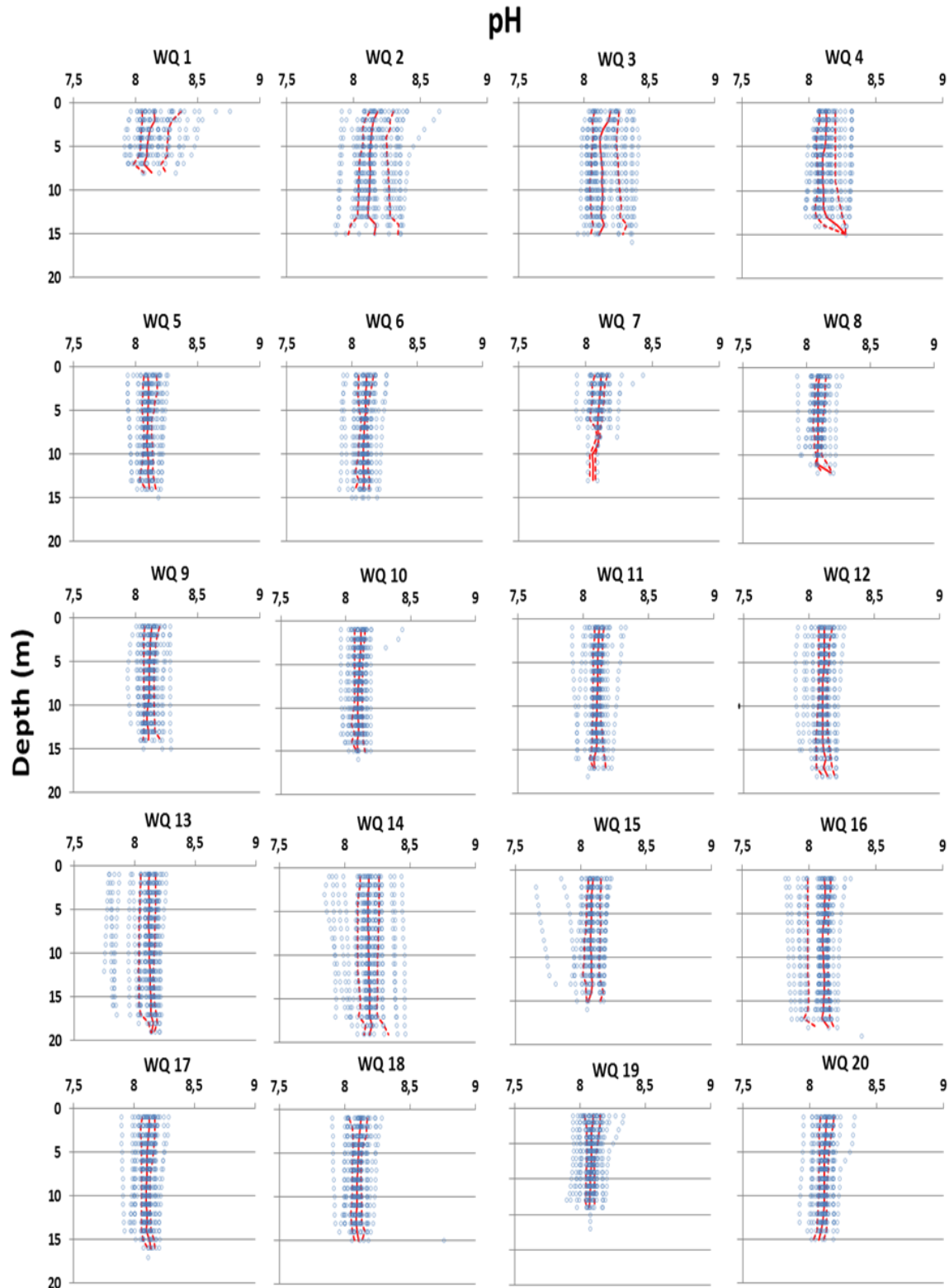


Figure 2.8: Profile data for pH at the 20 water quality monitoring stations over each tidal phase in each season. The solid red line indicates the mean and the dotted lines the 20th and 80th percentile values

2.8 Comparison with Data from Previous Studies

Previous studies investigating water quality in the Port have revealed similar trends in the spatial and temporal variations in physico-chemical conditions as for this study (Pillay, 2004; Pillay & Newman 2007; CSIR, 2008; Demetriades & Forbes, 2008; Deyzel et al. 2009; Newman et al. 2012, Newman et al. 2014, 2015 & 2016). Water temperature in the Port has been found to vary little on a seasonal basis, with summer temperatures (~26°C) being marginally higher than in winter (~20°C). Temperatures in the upper reaches of the Port also differ little from those in the middle and lower reaches. Salinities within the Port have changed over the past decades due to its developments and have become progressively more uniform (Hay, 1993). As recorded in this baseline study, salinity near the entrance of the Port have been documented to vary little on a seasonal basis (remaining around 34 PSU throughout the year) but can drop to low levels (20 PSU) at the head (upper reaches of the Port) from time to time. Turbidity is generally low in the lower and middle reaches of the Port for most of the year (<7 NTU) but is somewhat higher in the upper reaches (often exceeding 10 NTU). Levels of dissolved oxygen in the Port are variable, but tend to be higher in the lower and middle reaches (average 6 mg.l-1) than in the upper reaches (average 5 mg.l-1). Levels of dissolved oxygen in the bottom water in the upper regions do drop to very low levels (<2 mg.l-1) from time to time (Demetriades & Forbes, 2008). Water quality in the upper reaches of the Port is in fact considered to be severely impaired relative to those lower down (Pillay & Newman, 2007; Newman et al. 2008; Demetriades & Forbes, 2008; Deyzel et al. 2009; Newman et al. 2012; Newman et al. 2014), and is believed to be linked to the introduction of pollutants from the numerous storm water inlets including the uMhlatuzana/uMbilu and aManzimnyama river canals, and extended residence time of water in the Port. Although the exact sources of contaminants entering the Port was not explicitly addressed in this study, the spatial patterns corresponded with areas where the sources of contaminants entering the Port have been identified in previous studies (CSIR, 2008; Deyzel et al. 2009; Newman et al. 2014).

Findings of the most recent water quality assessments by the CSIR (2013-2015) as part of their long-term ecological monitoring program in the Port corresponded with many of the spatial and temporal trends in water quality found in this baseline survey. The CSIR's findings indicated that water quality in the upper reaches of the Port, such as the Silt Canal and Yacht Basin, were far more impaired than the lower regions. Concerning levels of dissolved oxygen, pH and turbidity were similarly found in the same areas when formulating the physico-chemical baseline for the Port. While the ranges of the physico-chemical parameters recorded in this baseline survey concur with those of the CSIR studies, their studies only present data from single sampling event in the summer and winter of each year. This baseline survey has attempted to measure the extent of natural variability of the various physico-chemical parameters in the Port through intensive sampling across spring/neap tidal ranges for each of the four seasons over a two-year period, thus allowing for the formulation of a much more detailed baseline.

2.9 Conclusion – Water Quality

Development of Port infrastructure and other infrastructure surrounding the Port has all but eliminated much of the original physico-chemical gradients that would have provided for a rich diversity of habitats and flora and fauna in Durban Bay. The limited spatial variation between stations observed in this study reflects the marine dominance and general uniformity in physico-chemical conditions in the Port. The gradients which were observed were restricted to upper regions near the Silt Canal and at times the Yacht Basin. Gradients in several parameters observed in surface waters of the upper regions are almost certainly associated with the limited water exchange, freshwater inflow from storm water inlets and riverine water introduced via the aManzimnyama and uMhlatuzana/uMbilo canals. Seasonal variation was indicated by more pronounced gradients in physico-chemical parameters in the upper regions during the wet seasons when riverine inflow is greatest.

3 BIOMONITORING USING MUSSELS (*PERNA PERNA*)

3.1 Introduction

There is an increasing global trend emerging in countries like Canada, Australia, New Zealand and South Africa to monitor the long-term effects of pollution by assessing impacts on specific marine species or species assemblages. Mussels and oysters (i.e. filter feeding organisms) are considered to be good indicator species for the purpose of monitoring water quality as they tend to accumulate trace metals, hydrocarbons and pesticides in their flesh. This provides a time integrated indication of pollutant levels that may not be detectable between pollution events, or may occur at chronic low levels that are difficult to measure in the water column itself. Mussels are sessile organisms (anchored in one place for their entire life) and will be affected by both short-term and long-term trends in water quality. Monitoring the contaminant levels in mussels can therefore provide a robust indication of poor water quality and changes in bioavailable contaminant levels in the water column over time.

Trace/heavy metals are persistent pollutants of aquatic ecosystems. However, they are all naturally occurring elements, some of which (e.g. copper & zinc) are required by organisms in considerable quantities (Phillips, 1980). Aquatic organisms accumulate essential trace metals that occur naturally in water as a result of, for example, geological weathering. All of these metals, however, have the potential to be toxic to living organisms at elevated concentrations (Rainbow, 1995). Human activities greatly increase the rates of mobilisation of trace metals from the earth's crusts and this can lead to increases in their bioavailability in coastal waters via natural runoff and pipeline discharges (Phillips, 1995). Dissolved metal concentrations in water are typically low (presenting analytical problems), have high temporal and spatial variability (e.g. with tides, rainfall events etc.) and most importantly reflect the total metal concentration rather than the portion that is available for uptake by aquatic organisms (Rainbow, 1995). Measuring metal concentrations in sediments resolves some of the analytical and temporal variability problems as metals accumulate in sediments over time and typically occur at higher concentrations than dissolved levels, but this still does not reflect their bioavailability. Measuring metal concentrations in the tissues of aquatic organisms appears to be the most suitable method for assessing ecotoxicity as the metals are frequently accumulated to high (easily measurable) concentrations and reflect a time-integrated measure of bioavailable metal levels (Rainbow, 1995).

Filter feeding organisms such as, mussels have been successfully used as bio-indicator organisms in environmental monitoring programs throughout the world (Kljaković-Gašpić et al. 2010). Mussels are abundant, have a wide spatial distribution, are sessile, are able to tolerate changes in salinity, are resistant to stress, and have the ability to accumulate a wide range of contaminants (Phillips & Rainbow, 1993; Desideri et al. 2009; Kljaković-Gašpić et al. 2010).

Elevated levels of cadmium reduce the ability of bivalves to efficiently filter water and extract nutrients, thereby impeding successful metabolism of food. Cadmium can also lead to injury of the gills of bivalves further reducing the effectiveness of nutrient extraction. Similarly,

elevated levels of lead result in damage to mussel gills, increased growth deficiencies and possibly mortality. Elevated levels of zinc are known to suppress growth of bivalves at levels between 470 to 860 mg/l and can result in mortality of the mussels (DWAf, 1995). Elevated levels of many trace metals in seafood can also pose a serious human health risk.

3.2 Sampling Methodology

Samples of the bivalve *Perna perna* (brown mussel) were collected from 36 channel marker buoys lying adjacent to the sandbanks each quarter (autumn, winter, spring and summer) (Figure 3.1). Some of the targeted channel markers located in the upper region of the Port contained no mussels (Sites 24 & 25), and it is likely that the water in this area is too fresh and/or too turbid for mussels to colonise. All samples that were successfully collected were placed in sampling jars on ice immediately after collection and were submitted to a SANAS accredited analytical laboratory for determination of trace metal (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg) content.



Figure 3.1: Location of biomonitoring sites in the Port. Bivalves (brown mussels *Perna perna*) were collected from channel marker buoys at these sites and analysed for trace metal content.

Trace metal levels in mussels collected from the Port were compared with the maximum legal limits prescribed for each contaminant in shellfish for human consumption in South Africa, as stipulated by the Regulation R.500 (2004) published under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972, Table 3.1). Where guidelines have not been specified in national legislation, those adopted by other countries have been used.

Table 3.1: Regulations relating to maximum levels for metals in molluscs in different countries

Country	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Cd (ppm)	Hg (ppm)
South Africa ¹		0.5		3.0	3.0	0.5
Canada ²	70.0	2.5	150.0	1.0	2.0	
Australia & NZ ³		2.0			2.0	0.5
European Union ⁴		1.5			1.0	0.5
Japan ⁵		10.0			2.0	0.2
Switzerland ²		1.0			0.6	0.5
Russia ⁶		10.0			2.0	
South Korea ²		0.3				
USA ^{7,8}		1.7			4.0	
China ⁹					2.0	
Brazil ¹⁰						0.5
Israel ¹⁰						1.0

1. Regulation R.500 (2004) published under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972)
2. Fish Products Standard Method Manual, Fisheries & Oceans, Canada (1995)
3. Food Standard Australia and New Zealand (website)
4. Commission Regulation (EC) No. 221/2002
5. Specifications and Standards for Foods. Food Additives, etc. Under the Food Sanitation Law JETRO (Dec 1999)
6. Food Journal of Thailand. National Food Institute (2002)
7. FDA Guidance Documents
8. Compliance Policy Guide 540.600
9. Food and Agricultural Import Regulations and Standards.
10. Fish Products Inspection Manual, Fisheries and Oceans, Canada, Chapter 10, Amend. No. 5 BR-1, 1995.

3.3 Results and Analysis of Data

Mean trace metal concentrations for copper, lead, zinc, arsenic, cadmium and mercury recorded in *Perna perna* from the Port over the two years of monitoring are presented in Table 3.2. Values which exceeded guideline limits are indicated in red. Findings indicate that in certain areas of the Port, mussels have accumulated high concentrations of cadmium, lead, zinc and mercury. Data showed that concentrations of lead in mussels in the Port were consistently above the regulatory limit for foodstuffs (0.5 ppm), with values averaging over 3.0 ppm in most cases (Table 3.1 and Table 3.2). Zinc concentrations in mussel tissue collected at station DHBN 12, situated along the northern side of the Central Sandbank, frequently exceeded the 150 ppm regulatory limit listed by the Canadian Authorities. Mercury concentrations have largely been within the regulatory limit of less than 0.5 ppm, apart from stations located either side of the Central Sandbank. High concentrations were recorded at DHMB 3 and 4 on the western side on the Central Sandbank (0.8 and 1.5 ppm respectively), station DHBM 7 (0.7 ppm) at the end of the Central Sandbank and stations DHMB 11 (1.2 ppm), 13 (0.5 ppm), 14 (1.0 ppm), 31 (0.7 ppm) and 36 (0.6 ppm) located in the channel between the Northern Bank and The Central Sandbank. Concentrations of cadmium were found to exceed the regulatory limit of 3 ppm only at stations located in the Island View basin. Copper concentrations did not exceed regulatory limits at any stations in the Port.



Figure 3.2: Biomonitoring of *Perna perna* – Port channel marker buoy (left), *Perna perna* collected from channel marker buoy (middle), Starboard channel marker buoy (right).

Table 3.2: Mean trace metal concentrations in brown mussels *Perna perna* collected during quarterly sampling over two years from 36 channel marker buoys lying adjacent to the sandbanks in the Port of Durban. Red text indicates levels in excess of regulatory or guideline limits.

	As (ppm)		Cd (ppm)		Cu (ppm)		Pb (ppm)		Zn (ppm)		Hg (ppm)	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
DHBM1	2.2	1.2	0.8	0.8	26.8	12.8	6.4	2.6	36.9	175.9	0.2	0.2
DHBM2	2.7	1.9	0.7	0.8	30.7	14.1	5.7	5.2	88.9	189.4	0.1	0.1
DHBM3	2.5	1.4	0.9	0.9	21.3	7.0	5.1	3.0	43.0	148.0	0.8	0.4
DHBM4	2.4	1.7	2.0	2.0	31.6	17.7	5.6	3.9	57.6	161.8	1.5	0.9
DHBM5	2.0	1.4	1.4	1.4	23.3	26.7	5.7	5.8	128.3	202.1	0.1	0.1
DHBM6	2.4	1.7	0.7	0.9	13.6	5.1	4.8	2.5	34.5	126.1	0.1	0.0
DHBM7	1.6	1.2	0.6	0.6	16.9	8.4	7.1	6.6	62.4	161.1	0.7	0.7
DHBM8	1.7	1.4	0.6	0.5	18.1	9.5	8.2	9.5	90.5	174.9	0.1	0.1
DHBM9	2.5	1.8	0.7	0.8	15.4	12.3	5.7	6.4	90.0	165.5	0.1	0.1
DHBM10	1.8	1.7	0.6	0.5	18.8	13.3	7.0	6.1	101.9	196.8	0.3	0.2
DHBM11	2.5	1.8	0.5	0.4	18.2	5.5	5.4	2.0	39.8	143.7	1.2	0.6
DHBM12	2.2	1.6	1.2	1.9	30.2	46.2	4.1	1.9	186.9	213.6	0.1	0.2
DHBM13	2.0	1.1	0.5	0.5	11.7	4.7	5.1	2.7	31.4	128.7	0.5	0.3
DHBM14	2.0	1.8	0.4	0.3	16.6	7.6	4.8	3.4	64.4	191.4	1.0	0.5
DHBM15	1.8	1.3	0.4	0.5	12.6	1.8	4.0	2.9	19.1	130.9	0.1	0.0
DHBM16	1.7	1.4	0.6	0.4	14.8	3.6	6.3	5.3	61.7	161.4	0.1	0.1
DHBM17	1.5	1.2	0.3	0.3	12.9	4.5	4.7	3.0	53.0	154.4	0.1	0.0
DHBM18	1.3	0.8	0.6	0.6	12.1	6.9	5.3	4.8	51.8	144.2	0.1	0.1
DHBM19	1.3	0.8	0.6	0.6	18.8	16.8	5.7	6.9	80.2	158.1	0.1	0.1
DHBM20	2.4	1.3	0.8	0.6	22.0	17.8	7.4	6.6	26.5	157.4	0.1	0.0
DHBM21	1.6	0.9	0.7	0.7	12.1	7.2	5.1	3.7	60.0	145.9	0.0	0.0
DHBM22	1.1	1.5	0.8	1.3	18.4	8.3	5.1	2.7	40.3	166.7	0.1	0.0
DHBM23	2.1	1.8	0.7	1.3	13.8	6.0	5.1	3.1	59.4	152.8	0.0	0.0
DHBM24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DHBM25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DHBM26	2.1	1.8	6.3	7.3	18.0	6.0	5.3	3.6	53.5	148.2	0.1	0.1
DHBM27	1.9	1.1	5.5	7.8	15.9	8.4	3.8	3.6	33.0	131.4	0.0	0.1
DHBM28	2.0	1.1	5.2	7.7	17.8	9.4	4.1	1.9	38.6	135.4	0.0	0.0
DHBM29	2.4	1.0	0.4	0.3	13.9	5.6	5.0	2.3	18.1	126.7	0.2	0.1
DHBM30	2.2	1.3	0.8	0.8	15.6	6.2	13.1	9.6	52.7	165.2	0.2	0.2
DHBM31	1.8	1.6	0.4	0.5	9.8	4.5	3.4	2.8	29.6	138.0	0.7	0.4
DHBM32	0.9	0.6	0.8	0.4	11.9	6.8	6.9	6.5	90.4	128.4	0.1	0.0
DHBM33	1.6	1.2	0.5	0.3	12.4	6.9	4.9	3.8	82.4	179.4	0.4	0.2

	As (ppm)		Cd (ppm)		Cu (ppm)		Pb (ppm)		Zn (ppm)		Hg (ppm)	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
DHBM34	2.2	1.3	1.2	1.0	16.1	8.1	9.0	11.3	102.9	216.7	0.2	0.2
DHBM35	2.3	1.1	1.1	0.6	18.6	1.6	11.4	11.8	101.2	178.6	0.4	0.4
DHBM36	2.0	1.4	0.4	0.2	10.3	6.0	8.3	6.1	19.8	158.9	0.6	0.4

3.4 Comparison with Data from Previous Studies

Historic studies on trace metals in mussel collected from the Port have produced some rather contradictory data. Deyzel et al. (2009) reported that mussels in the Port had some of the lowest metal concentrations compared to other ports in South Africa and that concentrations of lead had notably decreased in 2009 when compared to 2008. Newman et al. (2012 & 2014), however, reported that trace metals concentrations were found to be amongst the highest recorded from any South African Port, indicating possible increased trace metal pollution in the Port. Their study found evidence for accumulative trace metal contamination in mussels in the Port with high concentrations of lead, zinc and mercury all being recorded in mussel tissue (Table 3.3). They also highlighted the fact that mussels located in the upper regions of the Port had overall higher concentrations of trace metals than those in the lower regions. The contrasting results between Deyzel et al. (2009) and Newman et al. (2012; 2014 & 2016) may have been affected by seasonal or inter-annual differences in rainfall for each study. Higher rainfall and increased storm water runoff is expected to result in increases in the metal load entering the Port and consequently higher concentrations in mussel tissue. This emphasises the need for continued regular biomonitoring of mussels in the Port to help determine baseline contamination levels and identify pollutions events.

Table 3.3: Range of trace metal concentrations measured in Brown mussels (*Perna Perna*) from recent ecological monitoring for the Port by the CSIR (CSIR, Newman et al. 2012, 2014 & 2016).

Survey period	As (ppm)	Cd (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppm)
2011-2012	0.70-1.50	0.03-0.04	3.90-6.10	0.72-0.90	14.00-31.00	0.01-0.03
2013-2014	1.00-1.90	0.10-0.15	2.00-9.70	0.40-1.80	25.00-55.00	0.01-0.04
2015-2016	8.00-11.50	1.00-14.50	12.00-75.00	3.10-7.10	150.00-250.00	0.08-0.80

3.5 **Conclusion – Biomonitoring Using Mussels**

Biomonitoring of mussels is an important tool for the assessment of pollution levels and indicates when action is required to limit heavy metal contamination in the Port. Evidence suggests that trace metal contaminants are present in the water column in the Port. No apparent spatial trends were evident in lead contamination in the Port, as high values were recorded at all sites, but peaks in cadmium, mercury and zinc were evident at various sites. The likely sources of these pollutants are from ship repair and maintenance activities, sewage and industrial effluent entering the Port via the rivers and storm water drains. In agreement with the CSIR's recent findings there were indications that mussels in the upper regions were more contaminated than elsewhere in the Port despite overall concentrations being below regulatory limits. The upper regions are in close proximity to river and storm water inflow points and the ship repair facilities from which pollutants and contaminants are known to be introduced into the Port.

It would be difficult to establish guideline values for metal concentrations in mussels for the construction and operational phases of planned development, as accumulation of metals by mussels is influenced by various factors such as, mussel size, age, and the physico-chemical conditions of their environment (salinity, pH etc.). Furthermore, comparing tissue concentrations between mussels collected at different stations is problematic due to the differences in their physico-chemical characteristics of the water column. The data presented in this study does, however, offer a baseline of metal concentrations in mussels from the various regions in the Port. The results of this study together with findings from the annual CSIR monitoring program offer a comparative baseline that will aid in identifying any increases in the bioavailability of metals that may result from the development. Continued monitoring of trace metals concentrations in *Perna perna* during the construction and operational phases is advised.

4 SEDIMENT DATA

4.1 Introduction

4.1.1 Grain Size Composition

Estuarine sediments are derived from fluvial, aeolian, biological and marine processes. Sediments interact with the hydrodynamic and geomorphological characteristics of the estuary creating distinct differences in the size composition and distribution of sediments. The heterogeneous distribution of sedimentary characteristics has both ecological and physico-chemical implications in estuarine systems. Fine sediments tend to accumulate in regions where there is minimal hydrodynamic disturbance. Conversely, coarse sediments typically accumulate in high energy regions where current, tidal and wave disturbances are prevalent. Understanding the sedimentary characteristics provides valuable insight into the diversity and distribution patterns of benthic macrofaunal communities. Benthic macrofauna respond to differences in sediment properties either as larvae or adults and are thus strongly associated with the sedimentary composition of their habitat (Gray, 1974; Etter & Grassle, 1992; Bergen et al. 2001; Ellingsen, 2002; Thrush et al. 2003; Anderson, 2008).

Understanding grain size characteristics also provides valuable insight when interpreting trends in contaminant concentrations. Contaminants, such as metals and organic toxic pollutants, are strongly associated with fine sediment particles (mud or cohesive sediments). This is due to the fact that fine grained particles have a relatively larger surface area for the adsorption and binding of pollutants and organic material. Higher proportions of mud, relative to sand or gravel, can thus lead to high organic loading and elevated trace metal levels (assuming that these pollutants continue to be introduced to the system). Furthermore, disturbance to the sediment (e.g. dredging) can lead to re-suspension of the mud component from underlying sediments along with the associated organic pollutants and metals. It may take several months or years for the mud component that has settled on surface layers to be removed from the system by natural processes such as, currents and tidal action.

4.1.2 Total Organic Carbon

Apart from granulometric composition, organic content in the sediment can similarly influence macrofaunal distribution and diversity (Bolam et al. 2004; Austen & Widdicombe, 2006; Martins et al. 2013). Organic matter originating from either marine or terrestrial sources is an essential food source for benthic macrofaunal communities and is thus important for ecological health. However, excessive loading of organic matter in estuarine sediments can have deleterious effects. The accumulation of organic matter in estuarine sediments doesn't necessarily directly impact the environment, but bacterial breakdown of the organic matter can (and often does) lead to hypoxic (low oxygen) or even anoxic (no oxygen) conditions. Under such conditions, anaerobic decomposition prevails, which results in the formation of sulphides such as hydrogen sulphide (H₂S). Sediments high in H₂S are characteristically black, foul smelling and toxic for most living organisms. Like fine sediments, organic carbon also

provides additional surface area for adsorption of trace metals and other contaminants, and can thus also influence levels of these contaminants in estuaries.

4.1.3 Trace Metals

Trace metals occur naturally in the environment, and some are important in fulfilling key physiological roles. Disturbance to the natural environment by either anthropogenic or natural factors can lead to an increase in metal concentrations occurring in the environment particularly sediments. An increase in metal concentrations above natural levels or at least above established safety thresholds can result in negative impacts on marine organisms, especially filter feeders like mussels that tend to accumulate metals in their flesh. High concentrations of metals can also render these species unsuitable for human consumption. Metals are strongly associated with the cohesive fraction of sediment (i.e. the mud component) and with organic matter. Metals occurring in sediments are generally inert (non-threatening) when buried in the sediment but can become toxic to the environment when they are converted to the more soluble form of metal sulphides. Metal sulphides are known to form as a result of natural re-suspension of the sediment (strong wave action) and from anthropogenic induced disturbance events like dredging activities.

4.2 Sampling Methodology

Sediment samples were collected each quarter (autumn, winter, spring, summer) for two years from 104 stations (53 intertidal and 51 subtidal) distributed on the top (intertidal) and sides (subtidal) of the various sandbanks in the Port (Figure 4.1 and Figure 4.2). Intertidal samples were collected with a hand corer (18 cm diameter) and subtidal samples collected with a stainless steel Van Veen grab. Samples were placed in sampling jars on ice immediately after collection and submitted to a SANAS accredited analytical laboratory for determination of grain size distribution, organic and trace metal concentrations.



Figure 4.1: Locations of 53 intertidal sites at which sediment samples are collected for analysis of grain size composition, organic carbon and trace metal content, benthic microalgae (microphytobenthos) and benthic macrofauna.



Figure 4.2: Location of the 51 subtidal sampling sites at which sediment samples are collected for analysis of grain size composition, organic carbon and trace metal content, benthic microalgae (microphytobenthos) and benthic macrofauna

Data on sediment grain size distribution for both intertidal and subtidal sediments were analysed using GRADISTAT (Blott & Pye, 2001). GRADISTAT software automates the process of classifying and characterising sediments both quantitatively and qualitatively.

Sediments were also analysed for concentrations of aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn) and mercury (Hg) using Nitric Acid (HNO₃) / Perchloric Acid (HClO₃) / Hydrogen Peroxide (H₂O₂) / Microwave digestion and a JY Ultima Inductively Coupled Plasma Optical Emission Spectrometer. Summary data on concentrations of trace metals in sediments at the various sampling sites are presented in the main body of the report while raw data are presented as annexures.

Trace metals were normalised against aluminium by dividing the concentration of each metal by the concentration of aluminium, a procedure commonly conducted for metal analysis (Gibbs, 1994; Summers et al. 1996). As concentrations of metals in sediments are affected by total organic content, sediment grain size, and mineralogy, correct interpretation requires normalising their concentrations rather than using their raw concentrations (Summers et al. 1996).

4.3 Results and Analysis of Data

Interpolations showing the spatial trends for the percentage of mud, TOC and normalized concentrations of trace metals in intertidal and subtidal sediments over the full extent of the Port are shown in Figure 4.3 to Figure 4.22. These interpolations provide an indication of the spatial variation in the extent of contamination of the various trace metals in the Port.

Intertidal and subtidal sediments were comprised predominantly of sandy sediments (particle size ranging between 63 µm and 2 000 µm). Higher proportions of mud were found in subtidal in comparison to intertidal sediments (Figure 4.3 and Figure 4.13). The mangrove areas of the Port had the highest average proportions of mud for both intertidal and subtidal sediments. The proportion of mud in intertidal sediments from the mangrove areas did not vary between the seasons and averaged approximately 0.6% mud content for all surveys. Subtidal sediments from the mangrove area however, exhibited small seasonal variations in the percentage of mud (spring: 3.8% ±1.3; summer: 4.8% ±2.2; autumn: 4.7% ±0.6; winter: 5.0% ±3.3).

Spatial variations in TOC in intertidal sediments in the Port are presented in Figure 4.14. TOC concentrations were generally highest in the middle of the Central Sandbank, the eastern side of the Northern Bank, Little Lagoon and the Mangroves. Over all seasons, intertidal TOC levels averaged between 1 and 2%, indicating moderate mesotrophic conditions. Similar spatial patterns in TOC levels were observed in the subtidal sediments. Areas with the highest TOC levels included the Mangroves, Little Lagoon and the eastern side of Northern Bank. TOC levels recorded at these subtidal sites were substantially higher than those recorded in intertidal sediment samples. Organic content in the subtidal sediments often exceeded 4% indicating highly eutrophic conditions. Areas with high TOC levels corresponded with those having greater percentages of fine sediments. The overall higher TOC levels recorded in the mangrove areas may be attributed to a combination of natural organic matter input from the

mangroves habitats, fine sediment characteristics and high retention rates due to the sheltered nature of the area. No seasonal trends were evident for TOC or trace metals in both the intertidal and subtidal sites.

Table 4.1: Classification levels of organic content in sediments (amended from Forbes & Demetriades 2003).

% Total organic carbon	Class	System type
< 0.5 %	Very low	Oligotrophic
0.5 - 1 %	Low	
1 - 2 %	Moderate	Mesotrophic
2 - 4 %	Medium	Eutrophic
> 4 %	High	

4.3.1 Sediment Quality Guidelines

South Africa is a signatory to the London Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter (1972) (the London Convention) and to the 1996 Protocol to the London Convention (the London Protocol). The London Convention and London Protocol regulate the deliberate disposal of waste materials in the marine environment. In South Africa, the National Environmental Management: Integrated Coastal Management Act 2008 (Act 24 of 2008) (ICMA) gives effect to the provisions of the London Convention and London Protocol. There are seven categories of waste and other material that are regulated under ICMA. Dredged material being derived mostly from Ports, forms by far the most common type. Oceans and Coasts, a branch of the Department of Environmental Affairs (DEA), is mandated with the responsibility of regulating the disposal of waste material in the marine environment in South Africa and uses a National Action list based on a corresponding list in the London Convention and London Protocol to make decisions as to whether sediment identified for dredging is of a suitable quality for unconfined open water disposal (Table 4.2).

The National Oceanic and Atmospheric Administration (NOAA) has also published a series of sediment screening values, which cover a broad spectrum of concentrations from toxic to non-toxic levels as shown in Table 4.2. The Effects Range Low (ERL) represents the concentration at which toxicity may begin to be observed in sensitive species. The ERL is calculated as the lower 10th percentile of sediment concentrations reported in literature that co-occur with any biological effect. The Effects Range Median (ERM) is the median concentration of available toxicity data. It is calculated as the lower 50th percentile of sediment concentrations reported in literature that co-occur with a biological effect (Buchman, 1999). The ERL and ERM values have been used to screen the sediment samples collected from the Port. Comparing the sediment results to the ERL guidelines provides a useful indication of areas in the Port that may be toxic to living organisms. However, this comparison does not provide an indication of whether the build-up of a trace metal is due directly to anthropogenic contamination of the environment with that particular metal or whether it is an indirect result of other environmental influences. For example, trace metals concentrations are often elevated in quiescent areas with lots of fine sediment which may be located in areas that are distant from the primary source of the contamination. Comparisons with natural background levels from areas that are

known to be unpolluted, or historical concentrations, are required to conclusively identify the source of anthropogenic enrichment. It is also important to note that the ERL guideline corresponds roughly to a 10% likelihood of toxicity, so this guideline represents a conservative (precautionary) measure (O'Connor, 2004).

Table 4.2: Summary of South African and NOAA sediment quality guidelines. Concentrations are parts per million (ppm) dry weight (mg/kg), ERL = Effects Range Low, ERM = Effects Range Median.

Metal	South Africa		NOAA	
	Special care	Prohibited	ERL	ERM
Arsenic (As)	30-150	> 150	8.2	70
Cadmium (Cd)	1.5-10.0	> 10.0	1.2	9.6
Chromium (Cr)	50-500	> 500	81	370
Copper (Cu)	50-500	>500	34	270
Mercury (Hg)	0.5-5.0	> 5.0	0.15	0.71
Lead (Pb)	100-500	> 500	46.7	218
Nickel (Ni)	50-500	> 500	20.9	51.6
Zinc (Zn)	150-750	> 750	150	410

4.3.2 Arsenic

Arsenic is notorious as a toxic element. Its toxicity, however, depends on the chemical (valency) and physical form of the compound, how it enters the body, the dose and duration of exposure and several other biological criteria (IPCS, 1980). Arsenic was commonly used as an alloying additive with lead solder, lead shot, battery grids, cable sheaths and boiler piping. Today, most arsenic originates from paints or pharmaceuticals and is commonly found in sewage. Arsenic concentrations in all intertidal samples were below the accepted NOAA and SA toxicity range for arsenic (Figure 4.5). While arsenic concentrations were found to exceed ERL guideline at two subtidal sites, it is not possible to determine the level of toxicity considering the complexity of arsenic biogeochemistry in marine and brackish water ecosystems (Figure 4.15). There are varying forms of arsenic that determine its fate in the life cycles of marine organisms and whether or not it is bioavailable (able to be taken up by organisms). Concentrations of the more toxic form, arsenite, measured in even the most heavily contaminated estuaries are well below concentrations known to be harmful to marine animals, but approach or occasionally exceed concentrations that could be toxic to sensitive species of phytoplankton (Neff, 1997).

4.3.3 Cadmium

Cadmium is a trace metal used in electroplating, in pigment for paints, in dyes and in photographic processes. The likely sources of cadmium to the marine environment are in emissions from industrial combustion processes, from metallurgical industries, from road transport and waste streams (OSPAR, 2010). A likely point source for cadmium contamination

in the marine environment is that of storm water drains. Cadmium is toxic and has a high propensity to bioaccumulate, and is thus a concern for both the marine environment and human consumption of marine organisms (OSPAR, 2010). Cadmium concentration in sediment samples from all intertidal sample sites were below the accepted NOAA and SA toxicity levels (Figure 4.6). Sediment collected from all subtidal sites along the Bayhead Canal, two sites along the Western Bank, two sites at the Yacht Basin and one site in Little Lagoon exhibited elevated cadmium concentrations (Figure 4.16). These values were in excess of the ERL, as well as SA's Special Care range (with exception of two sites along the Western Bank), so it is expected that sensitive species in these areas will show signs of toxicity. Any disturbance to the sediments at these sites would likely re-suspend, and thus increase cadmium concentrations in the surrounding environment. It is likely that increased concentrations at sites near Little Lagoon and Western Bank are related to the accumulation of mud, finer particle size sediment. The proximity to the shipping repair and maintenance industry is probably the major contributor to the elevated levels seen at the Bayhead Canal sites. At sites in the Yacht Basin it is likely that a point source for heavy metal contamination exists from the local storm water drain and 'Lavender Creek' outflow, as well as the shipping and boating industry in this area.

4.3.4 Chromium

Chromium is used mainly in metal alloys such as metal-ceramics, stainless steel, and is used for chrome plating. It has high value in the industrial world because it can be polished to a mirror-like finish, and provides a durable, highly rust resistant coating, for heavy applications. Chromium enters the environment through natural and human activities. Chromium does not bio accumulate in fish muscle, but does accumulate on the gills, causing negative health effects for aquatic animals. All intertidal sample sites were below the accepted NOAA and SA toxicity range (Figure 4.7). Twelve subtidal sites from the Bayhead Canal and the Yacht Basin exceeded the Special Care concentration limits. Three of the Bayhead Canal sites also exceeded the ERL limit (Figure 4.17). All these sites are associated with depositional areas where mud accumulates.

4.3.5 Copper

Sediment collected from all intertidal sample sites were below the accepted NOAA and SA toxicity range (Figure 4.8). Copper concentrations were highest in the Bayhead Canal, near the Little Lagoon, Western Bank and Yacht Basin (Figure 4.18). This suggests that there may be a source of copper pollution affecting the western reaches of the Port, within the Yacht Basin as well as in areas of greatest mud accumulation. Copper is used as a biocide in antifouling products as it is very effective for killing marine organisms that attach themselves to the surfaces of boats and ships. Anti-fouling paints release copper into the sea and can make a significant contribution to copper concentrations in the marine environment (Clark, 1986). The areas with elevated copper values also correspond with those with high levels of boat traffic. It is thus likely that anti-fouling paints used on boats may have been contributing copper to the system. The copper concentration at eleven sites located in the Bayhead Canal and Yacht Bank exceeded the ERL and Special Care guidelines, while two sites on Centre Bank and one in Little Lagoon only exceeded the ERL guideline (Figure 4.18).

4.3.6 Mercury

Mercury bio-accumulates in shellfish and fish and causes mercury poisoning in people who consume contaminated sea food known as Minamata disease. Historically, mercury was used in antifouling paints and more recently its presence in the environment is attributed to industrial effluents. At subtidal sites DHS 3, 26, 38 & 45 mercury levels reached ERL values (Figure 4.19), but guidelines levels were not exceeded at any intertidal sites (Figure 4.9). The subtidal sites are near to heavy shipping industry as well as areas of increased mud deposits. Due to the popularity of recreational and subsistence fishing within the Port (Guastella, 1994), these elevated concentrations are cause for concern. Like mercury, lead, nickel and zinc are known to occur in antifouling paints and follow a similar distribution pattern within the harbour (see below).

4.3.7 Lead

Lead pollution is a worldwide problem and is generally associated with mining, smelting and the industrial use of lead (OSPAR, 2010). Lead is a persistent compound which is toxic to aquatic organisms and mammals, and thus the contamination is of concern for the marine environment and human consumption (OSPAR, 2010). All intertidal sample sites were below the accepted NOAA and SA toxicity range (Figure 4.10). However, subtidal sites in the Bayhead Canal and Yacht Basin exceeded the ERL limit (Figure 4.20).

4.3.8 Nickel

Nickel is introduced to the environment by both natural and anthropogenic means. Natural means of contamination include windblown dust derived from the weathering of rocks and soils, fires and vegetation (Cempel & Nickel, 2006). Common anthropogenic sources include the combustion of fossil fuels and the incineration of waste and sewerage (Cempel & Nickel, 2006). Thus, Nickel often enters the marine environments through rain events, river outflow and runoff. Nickel concentrations in sediment from all intertidal sample sites were below the accepted NOAA and SA toxicity range (Figure 4.11). In the Bayhead Canal, however, four subtidal sites exceeded the ERL limit (Figure 4.21).

4.3.9 Zinc

Zinc concentrations in sediment from all intertidal sample sites were below the accepted NOAA and SA toxicity range (Figure 4.12). Sediment from six subtidal sites located in the upper regions of the Port exceeded ERL and Special Care ranges (Figure 4.22). These sites are located in the Bayhead Canal, Western Bank, and Yacht Basin areas, and are associated with industrial effluent, storm drain outflows, and shipping and boating repair industry, and are depositional areas with elevated mud levels.

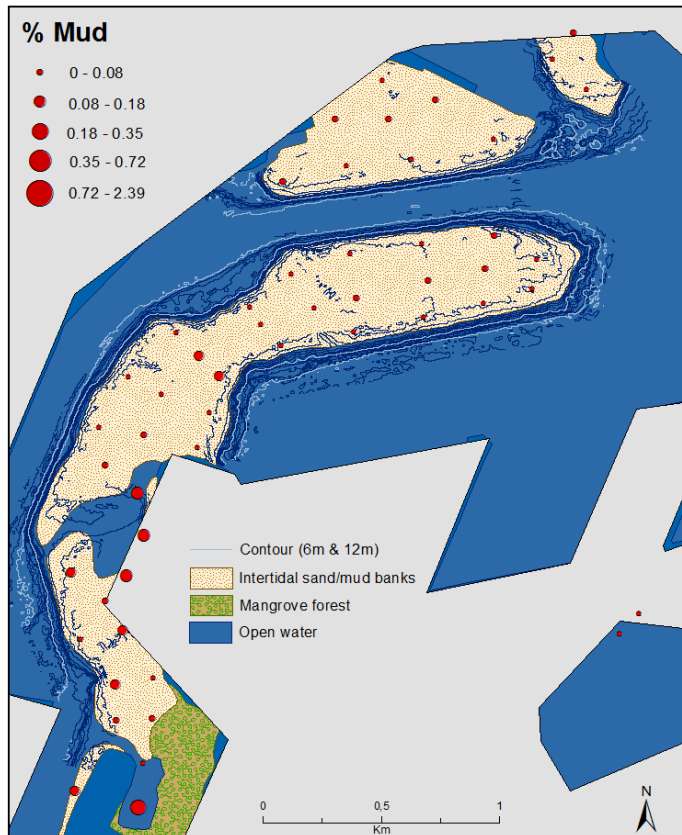


Figure 4.3: Graduated symbols (red circles) of the percentage of mud in intertidal sediment in the Port.

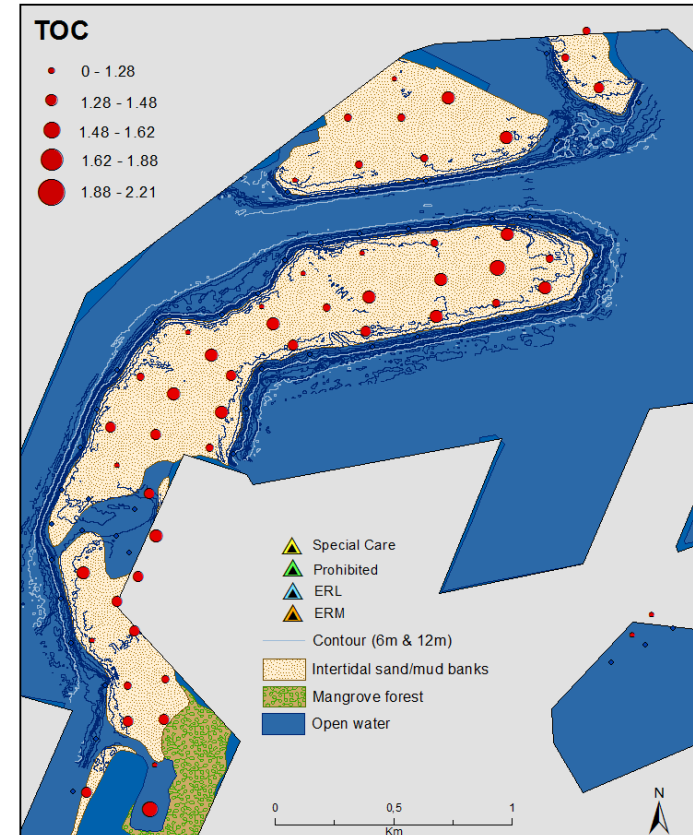


Figure 4.4: Graduated symbols (red circles) of the percentage of TOC in intertidal sediment in the Port.

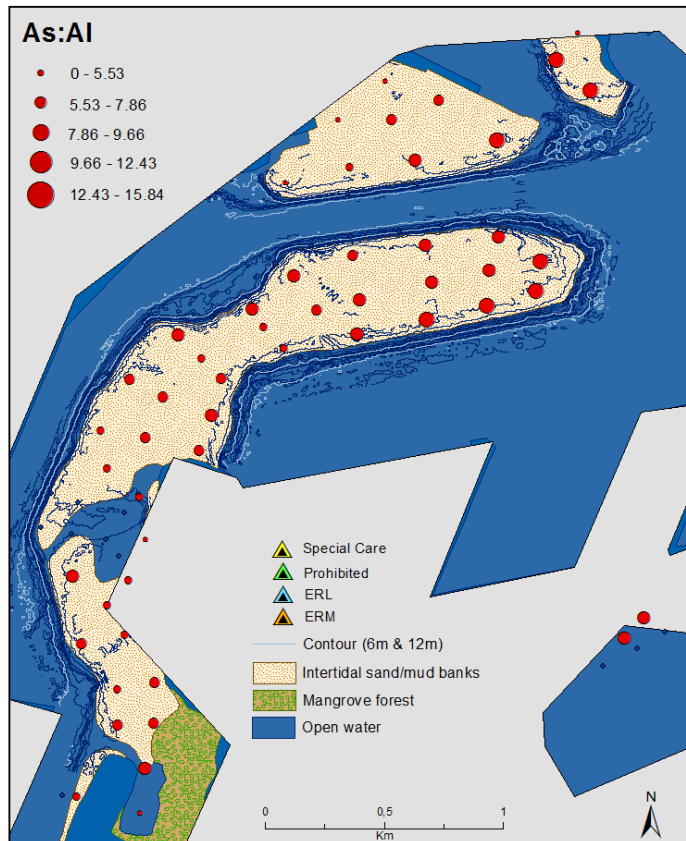


Figure 4.5: Graduated symbols (red circles) of the ratio of As:Al in intertidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

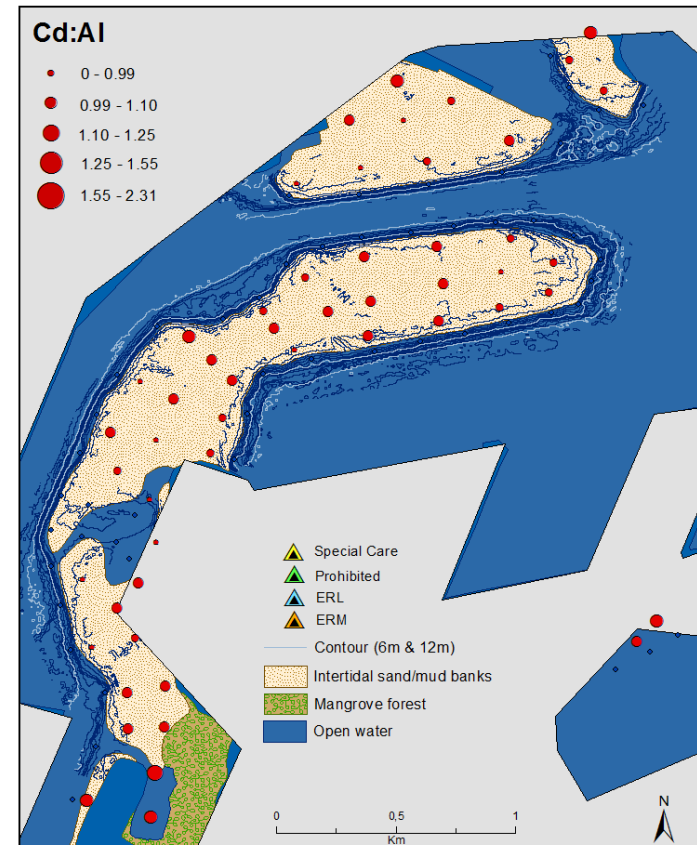


Figure 4.6: Graduated symbols (red circles) of the ratio of Cd:Al in intertidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

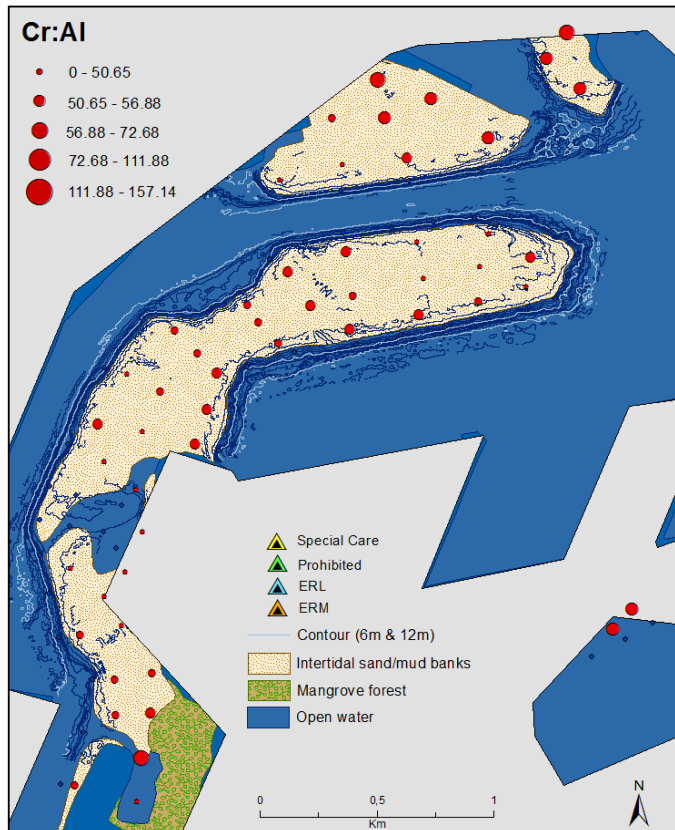


Figure 4.7: Graduated symbols (red circles) of the ratio of Cr:Al in intertidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

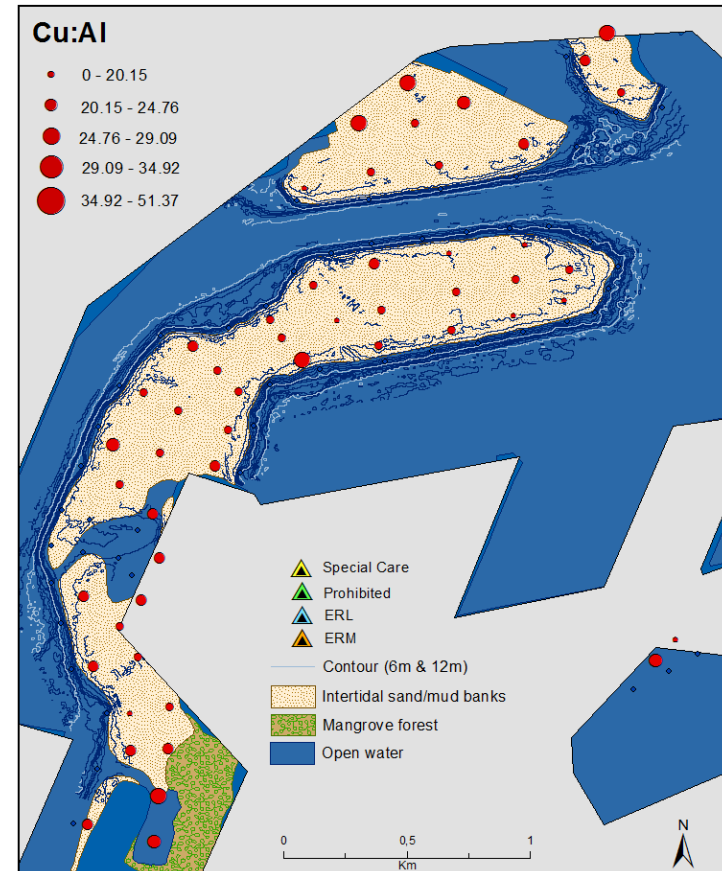


Figure 4.8: Graduated symbols (red circles) of the ratio of Cu:Al in intertidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

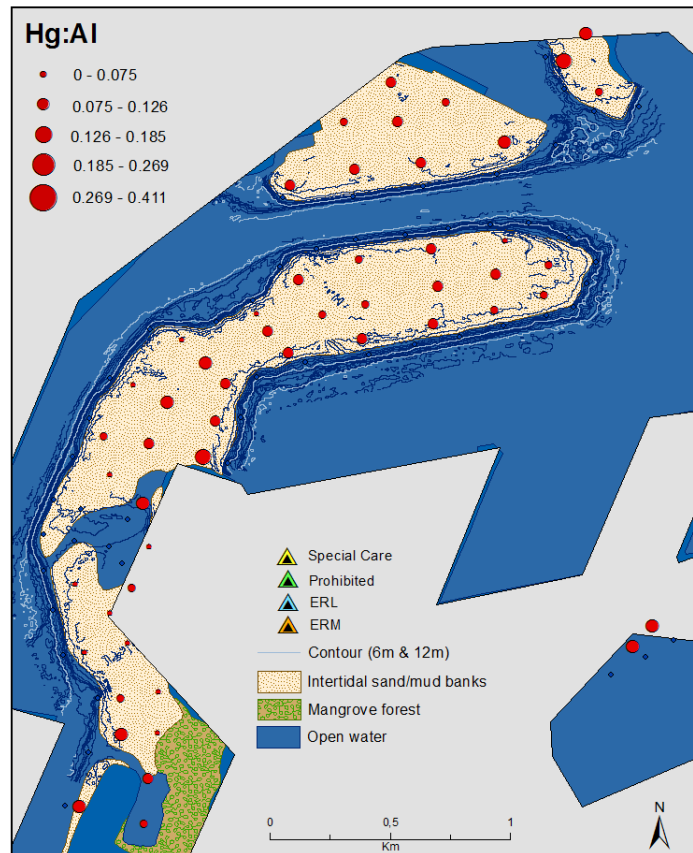


Figure 4.9: Graduated symbols (red circles) of the ratio of Hg:Al in intertidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

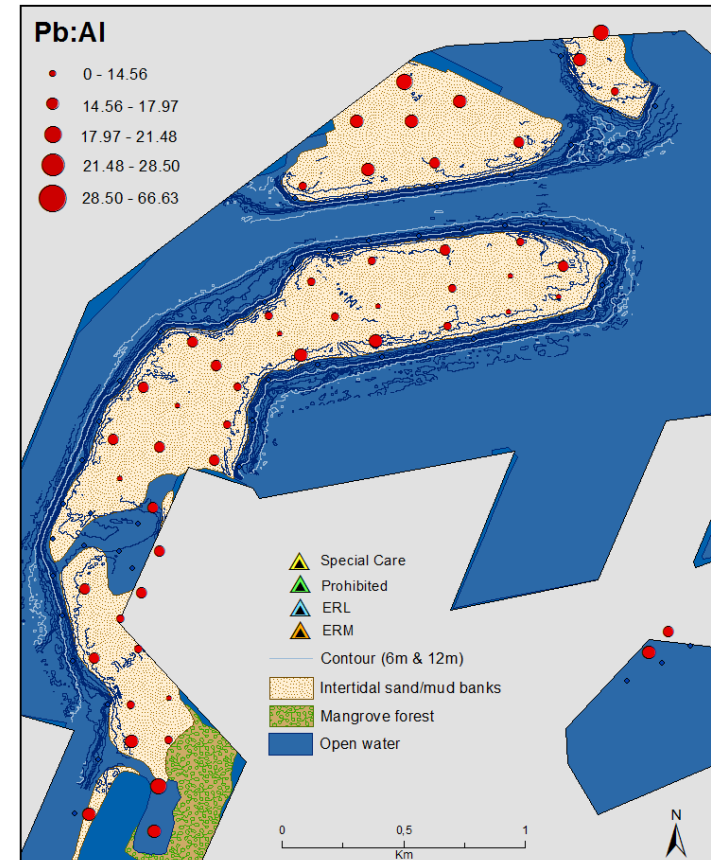


Figure 4.10: Graduated symbols (red circles) of the ratio of Pb:Al in intertidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

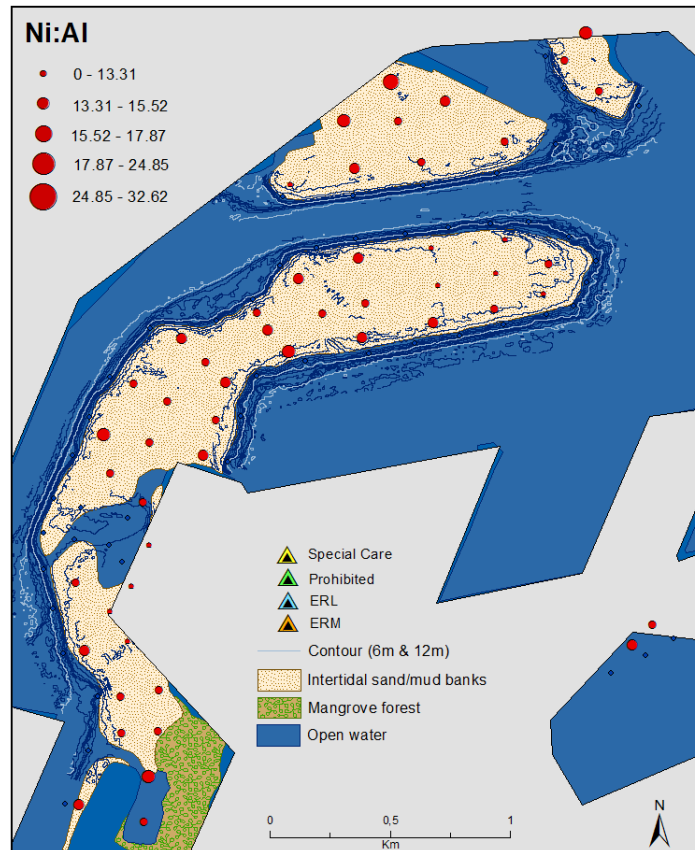


Figure 4.11: Graduated symbols (red circles) of the ratio of Ni:Al in intertidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

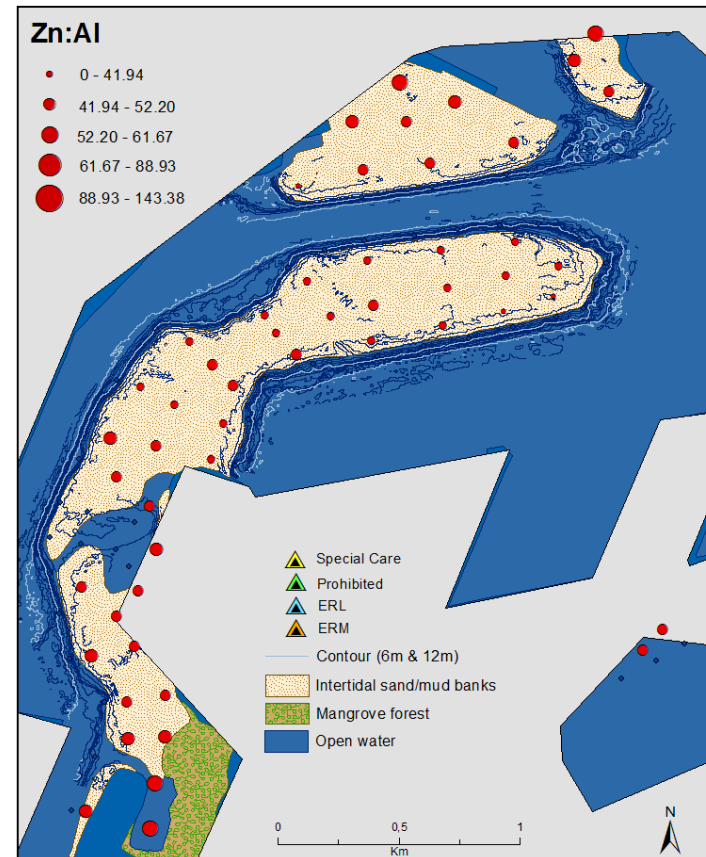


Figure 4.12: Graduated symbols (red circles) of the ratio of Zn:Al in intertidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

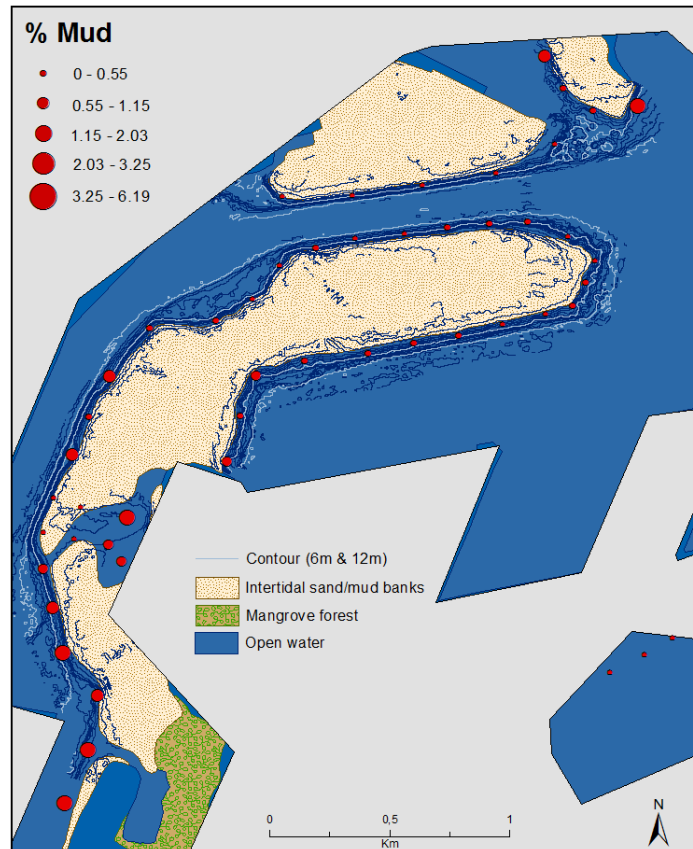


Figure 4.13: Graduated symbols (red circles) of the % mud in subtidal sediment in the Port.

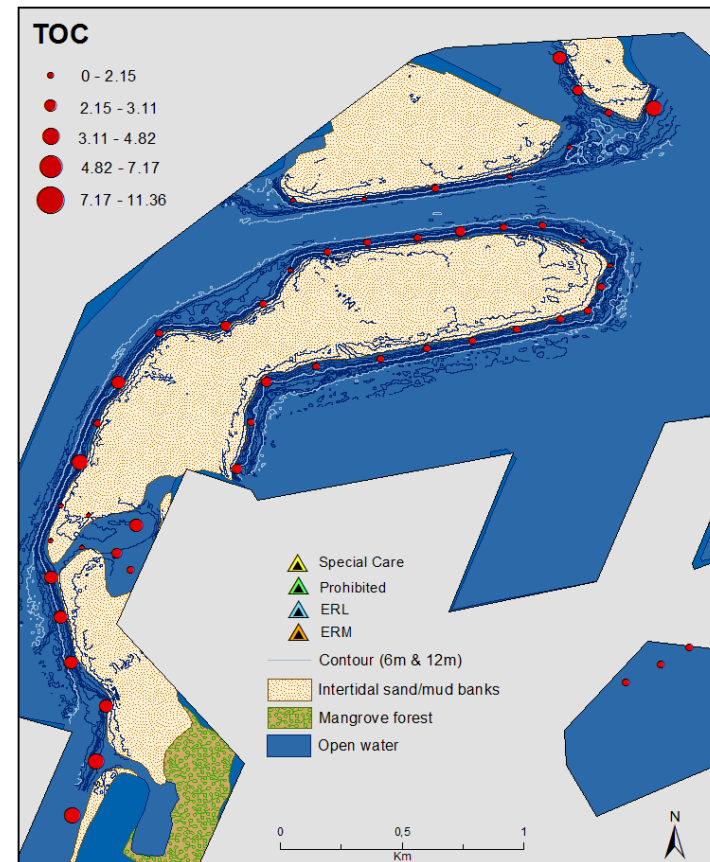


Figure 4.14: Graduated symbols (red circles) of the % TOC in subtidal sediment in the Port.

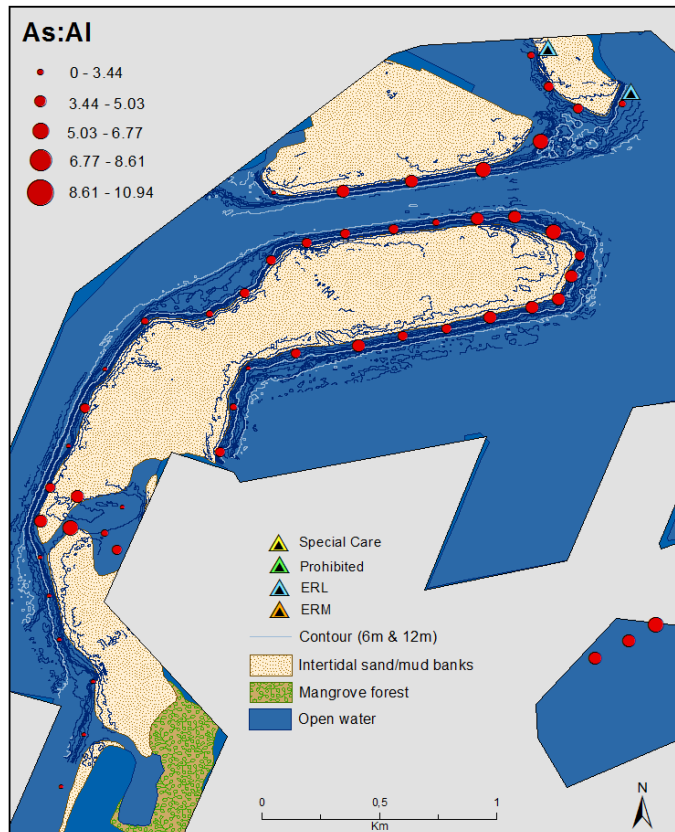


Figure 4.15: Graduated symbols (red circles) of the ratio of As:Al in subtidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

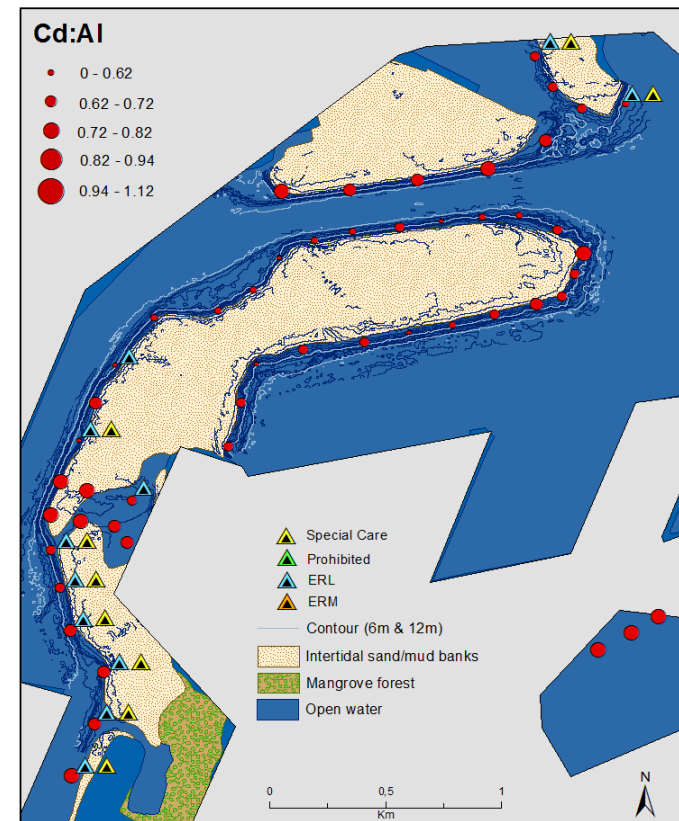


Figure 4.16: Graduated symbols (red circles) of the ratio of Cd:Al in subtidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

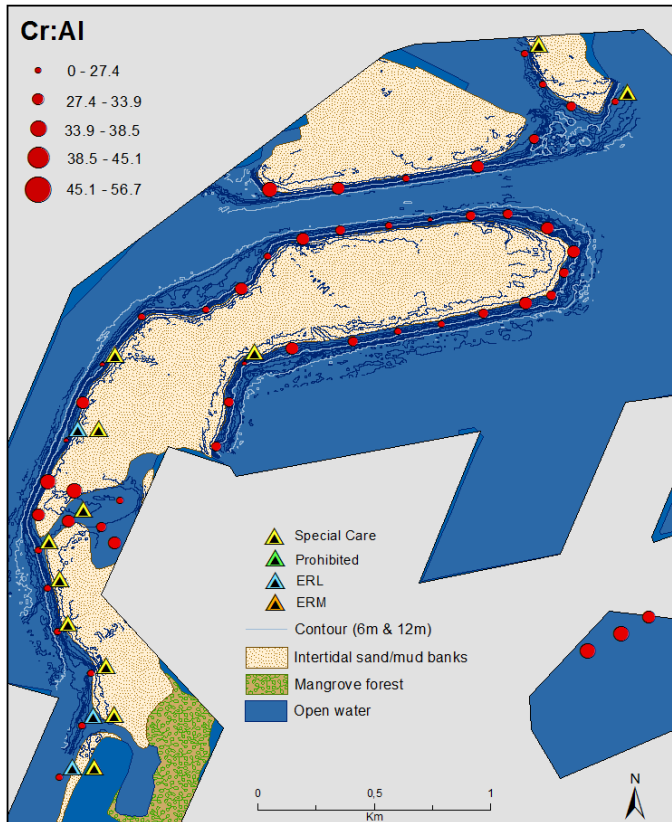


Figure 4.17: Graduated symbols (red circles) of the ratio of Cr:Al in subtidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

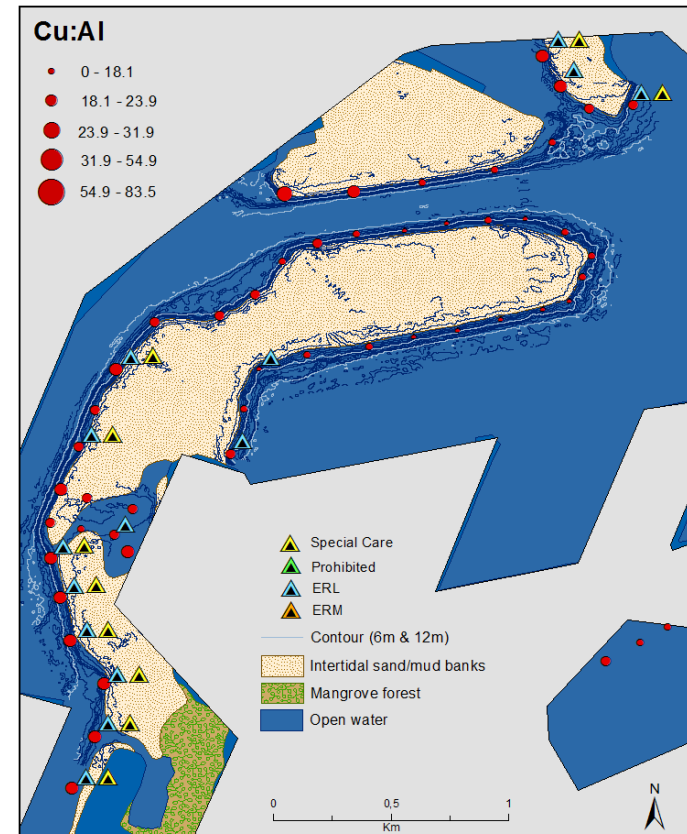


Figure 4.18: Graduated symbols (red circles) of the ratio of Cu:Al in subtidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

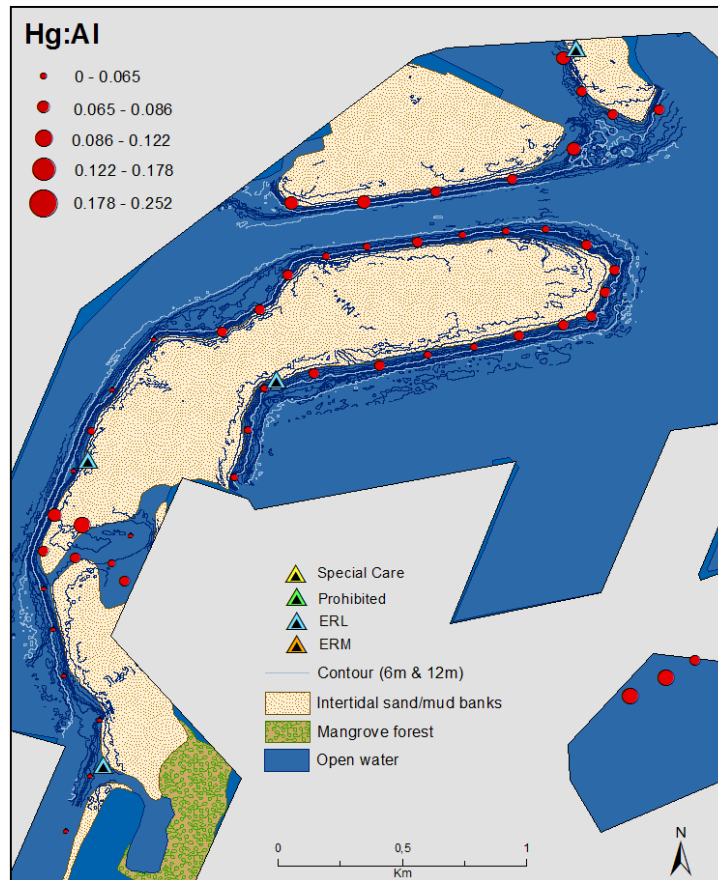


Figure 4.19: Graduated symbols (red circles) of the ratio of Hg:Al in subtidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

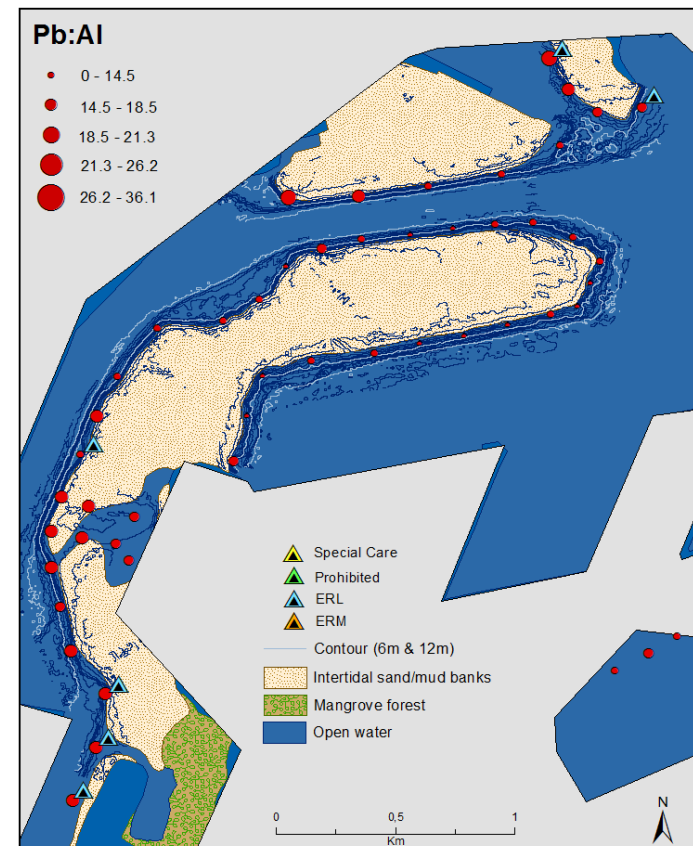


Figure 4.20: Graduated symbols (red circles) of the ratio of Pb:Al in subtidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

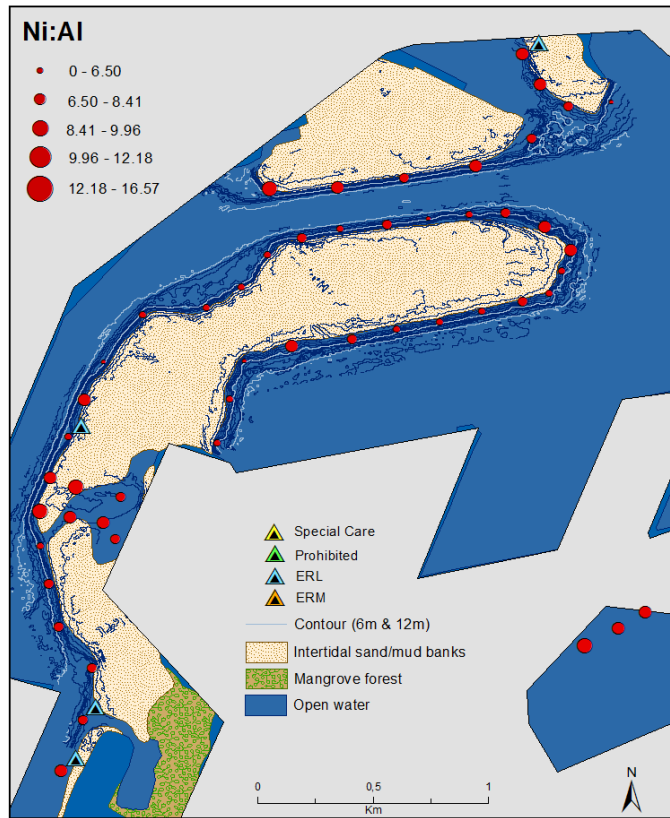


Figure 4.21: Graduated symbols (red circles) of the ratio of Ni:Al in subtidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.:

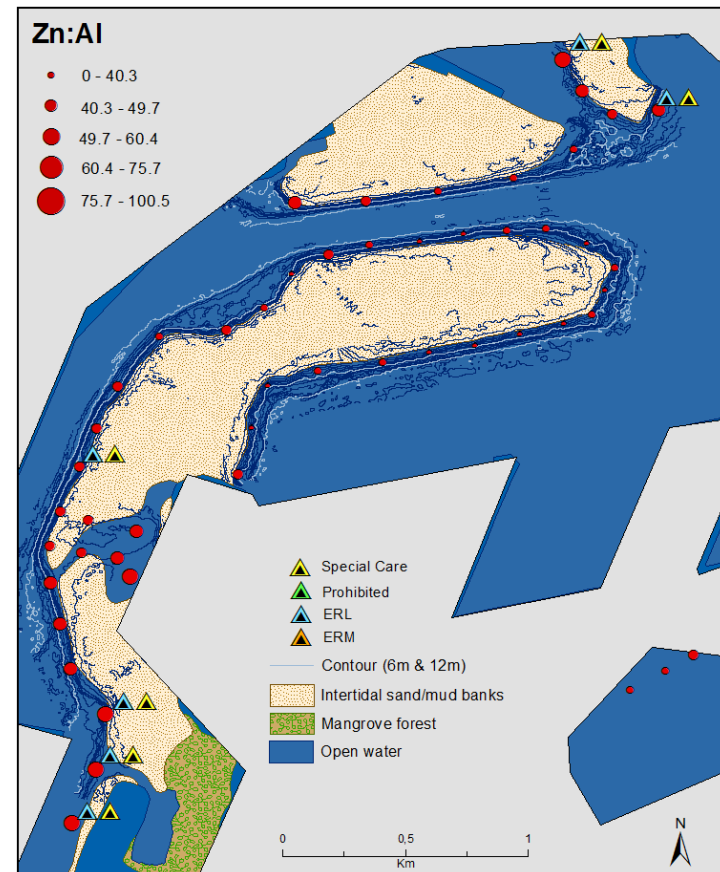


Figure 4.22: Graduated symbols (red circles) of the ratio of Zn:Al in subtidal sediment in the Port, overlaid with SA and NOAA sediment quality guidelines represented by unique symbols (coloured triangles) at site specific locations.

4.4 Comparison with Data from Previous Studies

Data from previous sediment quality surveys in the Port (CSIR, 2005; CSIR, 2011-2014; eThekweni Municipality, 2008) show patterns in trace metal concentrations, particle size and TOC that are broadly similar to those found in this study. Dominant sediment textural groups have been identified as including Medium Sand, Fine Sand and Very Fine Sand (based on the Wentworth grain size classification). In the upper regions mud is the dominate sediment type, reflecting riverine inputs and more stagnant hydrodynamic conditions in some areas (e.g. mangroves). Contaminants that are introduced into the upper regions via the river inlets, numerous storm water drains and industrial Port activities tend to remain here, thus contributing to the impaired sediment quality in this region. Weak circulation and long residence time leads to the settlement and accumulation of organic and inorganic pollutants in the sediments. Sediments in the upper regions have been found to be more organically enriched than in the lower regions. Organic matter introduced into the upper regions from river inflow, together with the higher mud fractions and the retentive nature of the area, has resulted in substantially higher TOC concentrations in this part of the Port. Anoxic sediment conditions, generally associated with high TOC concentrations, have been recorded in the Silt Canal and Congella Basin areas in previous studies. Similar spatial trends in trace metal concentrations have been observed in the Port in previous studies. Investigations in to trace metal contamination in the Port by the CSIR, (required for a permit application to dispose of dredge material), found that most metal contaminated sediments occurred in the upper regions of the Port (CSIR, 2005). Maydon Wharf, Congella Basin and the Silt Canal were highlighted as areas where trace metals concentrations repeatedly exceeded sediment quality guidelines. Most recent findings from surveys undertaken by the CSIR are presented in Table 4.3. Although the CSIR sampling focuses on the deeper channels and basins in the Port, sites located closest to each sand bank habitat were selected for comparisons. Corresponding to the findings presented in this study, the CSIR have routinely found high concentrations of chromium, copper, cadmium and zinc in sediments from the Port. Concentrations of these metals have been found to be particularly high in the upper reaches, where they often exceed guideline limits. Ship repair and maintenance in the Congella Basin, together with the polluted riverine inflow from the Silt Canal, were deemed to be the most likely sources of anthropogenic trace metal contamination in this region of the Port.

4.5 Conclusion – Sediment Analysis

Industrial effluent, sludge from sewage treatment plants, agriculture run-off, raw untreated sewage from wastewater infrastructure failure, river outflow from the Amanzimnyama and Umhlatuzana/Umbilo Canals and industry all contribute to pollution in the Port. It is evident from the data in this study and previous surveys that there are specific areas in the Port with substantially elevated levels of trace metals. These areas are located in proximity to river and storm water inflow points, heavy industry and ship repair operations. Similar findings have been reported in previous years where weak circulation and long residence time leads to the

settlement and accumulation of metals in the sediments of the upper reaches of the Port (CSIR, 2014; eThekweni Municipality, 2008).

Table 4.3: Total organic carbon and trace metal concentrations of sediment collected from 2011 to 2016 in the Port by the CSIR (CSIR, Newman et al. 2011, 2012, 2013 & 2015/2016). Orange text indicates that the concentrations exceeded the 'Special Care'

Survey period	Site area	TOC (%)	As (pp m)	Cd (pp m)	Cr (pp m)	Cu (pp m)	Hg (pp m)	Pb (pp m)	Ni (pp m)	Zn (pp m)
2011-2012	Centre Bank	0.60	17.22	7.03	30.44	<0.02	0.14	12.07	0.08	30.90
	Northern Bank	1.47	26.08	11.58	74.89	0.04	0.23	19.46	0.41	62.30
	Little Lagoon	2.43	36.88	14.02	130.99	0.44	0.02	28.97	0.29	94.32
	Mangroves	3.45	37.76	11.59	145.41	1.14	0.02	32.07	0.68	113.35
	Island View	0.52	5.95	3.16	4.54	<0.02	0.03	4.68	<0.03	11.35
2012-2013	Centre Bank	1.47	9.13	0.05	107.33	110.67	0.06	75.27	26.96	210.10
	Northern Bank	0.62	10.41	<0.02	118.38	91.04	1.18	69.49	28.42	198.14
	Little Lagoon	2.43	2.33	<0.02	19.31	14.05	<0.02	13.02	4.73	44.59
	Mangroves	3.45	5.63	0.52	124.77	99.49	0.09	94.09	26.1	245.13
	Island View	0.52	1.69	<0.02	21.86	9.98	0.05	6.97	4.50	23.30
2013-2014	Centre Bank/ Pier 2	0.38	4.19	5.67	40.25	25.77	0.05	22.33	8.95	54.45
	Northern Bank	1.63	5.74	4.89	35.50	29.87	0.05	23.17	9.18	60.51
	Little Lagoon	7.88	12.67	0.61	117.30	140.3	0.19	94.61	30.81	257.4
	Mangroves	7.08	14.12	1.30	119.00	157.09	0.21	105.83	36.46	333.42
	Island View	1.24	5.23	8.15	42.77	56.82	0.09	24.43	10.31	73.51
2015-2016	Centre Bank	0.50	4.47	0.04	26.68	25.55	0.05	16.20	6.21	50.01
	Northern Bank	0.48	2.80	0.05	27.13	25.38	0.06	15.50	5.79	43.52
	Little Lagoon	2.51	9.38	0.22	121.51	171.28	0.25	68.80	20.29	224.40
	Mangroves	9.89	8.28	0.49	133.21	193.28	0.20	74.30	22.76	277.95
	Island View	1.33	5.71	0.05	58.63	50.30	0.12	29.10	10.46	87.66

5 BENTHIC MICROALGAE (MICROPHYTOBENTHOS)

5.1 Introduction

Microalgae are photosynthetically active microorganisms. They contribute significantly to primary production in sediment and pelagic habitats, and have important trophic linkages with a variety of organisms; including macrofauna, fish, and birds. Microalgae communities in the Port occur on the sand banks as microphytobenthos and in the water column as phytoplankton. Microphytobenthos, however, is often suspended in the water column and can be as important as phytoplankton, particularly in turbid intertidal areas such as in the Port. As they play a vital functional role in estuarine systems, monitoring benthic microalgae is an important parameter for assessing ecological health. Eutrophication (or nutrient enrichment) can result in a shift in primary producer community structure that can have detrimental effects to species at higher trophic levels. In the Port, the sand bank areas provide ideal habitat for benthic microalgae colonisation during favourable environmental conditions. The Centre Bank is the single largest habitats of its type in the Port. The area thus supports a large portion of the microalgae biomass in the Port as well as consumers such as juvenile fish and invertebrates.

5.2 Sampling Methodology

Benthic microalgae samples were collected from each of the sediment monitoring sites and analysed in accordance with methods prescribed by Pinckney & Zingmark (1993). Samples were collected by slowly inserting a glass vial of known diameter (20 mm), either directly into the sand bank sediment (in the case of the intertidal samples) or into the top layer of sediment collected by an Ekman grab sampler (in the case of the subtidal samples). A core, 40 mm in length was extracted by sealing off the top of the vial with the plastic lid and removing the tube from the sediment (Figure 5.1). Samples were then placed on ice in a dark container and submitted to an accredited laboratory for further analysis.

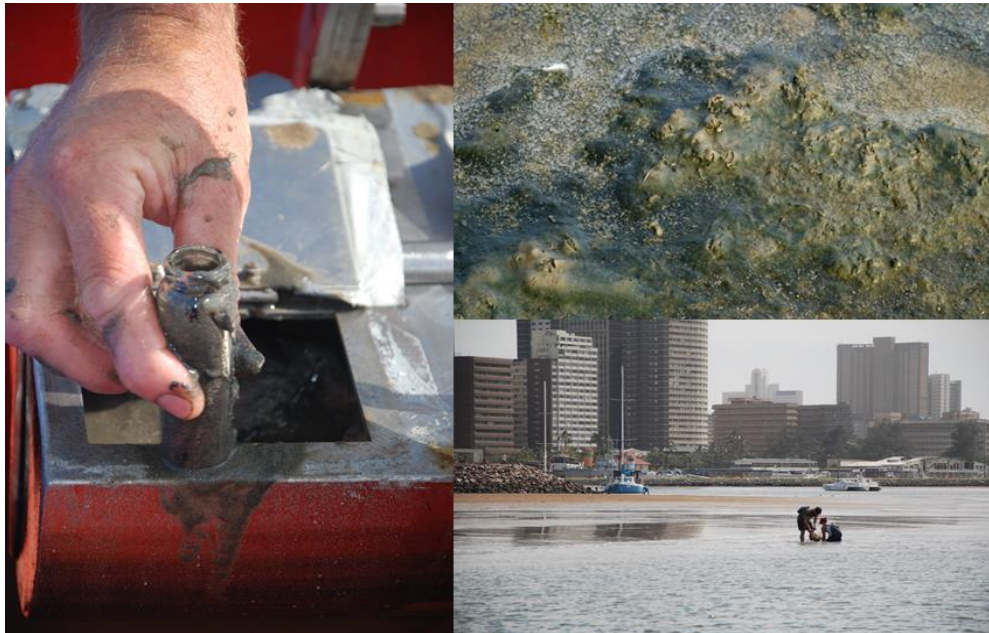


Figure 5.1: Sampling subtidal microphytobenthos (left), intertidal microphytobenthos on the Centre Sand Bank (top right) and intertidal microphytobenthos at the Northern Sand Bank (bottom right).

In the laboratory, the biomass of the microalgae was estimated as total chlorophyll (Chl-a) according to the methods of Whitney & Darley (1983), Dandonneau & Neveux (2002) and Seuront & Leterme (2006). Chlorophyll was extracted from the sediment samples through addition of 8-10 mL of 90% acetone. These samples were then centrifuged for approximately 5 minutes and the supernatant containing the chlorophyll pipetted into microfuge tubes. The extracts in the microfuge tubes were analysed spectrophotometrically using standard methods of chlorophyll concentration determination and employing the equation given by Lorenzen (1967), which yields results of chlorophyll per m^2 , thus giving an indication of microalgal biomass at each site. The spectrophotometric method allows for partitioning of the ~90% acetone pigment extract with hexane to eliminate interference from degraded pigments that are common in sediment samples (Cahoon & Cooke, 1992).

5.3 Results and Analysis of Data

Mean chlorophyll a concentrations for each intertidal and subtidal sediment sample for each season are shown in Figure 5.2. Analysis of the intertidal sediments showed peaks in chlorophyll a at the mangrove sites and in the shallow regions of both the Centre and Northern Banks. Subtidal chlorophyll a concentrations were on the whole considerably lower than those in intertidal sediments. Higher chlorophyll a concentrations were recorded in the subtidal sediments at Little Lagoon and at the mangrove sites. Microphytobenthos biomass recorded in winter was considerably lower in both intertidal and subtidal sediments than the other seasons, indicating seasonal variation in benthic microalgae biomass.

5.4 Comparison with Data from Previous Studies

A number of studies have looked at phytoplankton communities in the Port for the monitoring of water quality, identification of eutrophication conditions and the possible formation of harmful algal blooms (Pillay et al. 2003; Deyzel et al. 2010; CSIR, 2011, 2013 & 2014, Moodley, 2014). Few studies, however, have explicitly focused on microphytobenthos biomass on the sand banks areas in the Port, making historical comparisons difficult. Nonetheless, the Central Sandbank has been identified for its ecological value in supporting diverse and highly productive microphytobenthic communities. Pillay et al. (2003) observed high benthic algal diversity and biomass in the intertidal Mangrove and Centre Bank habitats suggesting relatively healthy surface sediment conditions. Forbes & Demetriades (2010) further highlighted the importance of intertidal microphytobenthos as drivers of the ecological interactions within the Port. Centre Banks' large intertidal area, coarse sediment and relatively stable conditions provide favourable micro-habitats for microphytobenthos communities to develop. In the upper regions of the Port, in the Silt canal area, however, Moodley (2014) found low benthic diatom diversity and substantial spatio-temporal variations between sample sites. These findings indicated poor quality water was entering the Port via the catchment river systems and the suggested the need for remedial measures to be taken.

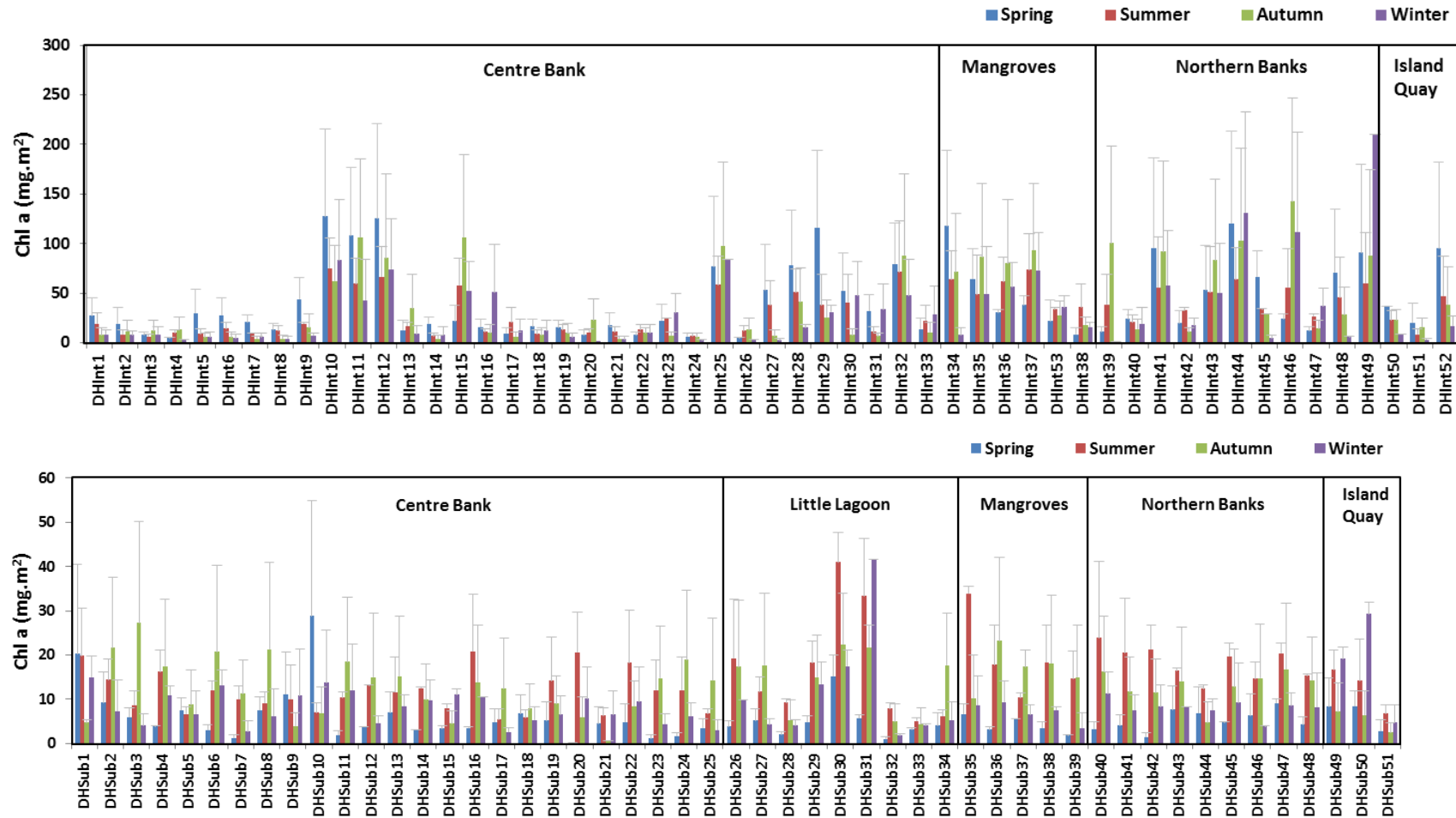


Figure 5.2: Mean chlorophyll a concentrations in 53 intertidal (DHInt1-DHInt53, top) and 51 subtidal (DHSub1-DHSub51, bottom). Samples in different seasons – Spring, Summer, Autumn and Winter – are displayed separately.

5.5 Conclusion – Benthic Microalgae

Biomass (as chlorophyll a) and light availability are major determinants of benthic primary production (MacIntyre et al. 1996). Microphytobenthos may also contribute significantly to production in the water column when sediment is resuspended by currents or other forms of disturbance, such as propeller wash. These algae and cyanobacteria are an important food source for deposit-feeding and suspension-feeding macrofauna as well as for meiofauna and microfauna. An abundance of microphytobenthos results in a greater diversity of species higher up the food chain and play a significant role in system productivity and trophic dynamics. In addition, microphytobenthos alter sediment properties both directly (by carpeting the sediment and decreasing the likelihood of particles being stirred up by currents), and indirectly by modifying the activities of benthic infauna. In the Port, chlorophyll a concentrations were higher at intertidal sites than at subtidal sites. Since more light is available in shallow water, this indicates a positive relationship between microphytobenthos and available light. Algae require light to photosynthesize, thus it is intuitive that microphytobenthos biomass will be higher in the warm months of spring, autumn and summer, which was the trend observed in the data for the Port. As microphytobenthos is an important food source for species at higher trophic levels, anthropogenic disturbance of these algae in sensitive areas of high diversity should be kept to a minimum.

The extension of the Central Sandbank will create additional shallow intertidal and subtidal habitat in the Port and is likely to increase overall microphytobenthos biomass in the Port, thus benefitting higher trophic levels. The development of microphytobenthic communities would facilitate the successful establishment of pioneer benthic invertebrate communities and will provide a readily accessible food resource for fish and birds in the Port. Establishment of the benthic invertebrate community would likely occur in relatively quickly after the establishment of the benthic microalgae community. It is important, however, for successful establishment of a microalgal community that the sediment characteristics of the newly established sandbank be within the recommended guidelines stipulated in the Sediment section of the CSMP. Stable sand bank conditions and relatively coarse sediments characteristics, resembling that of the existing Centre Bank habitat, are important for the creation of micro-habitats where microphytobenthos communities can establish.

6 MACROFAUNA

6.1 Introduction

Macrofauna (animals larger than 0.5 mm) living within sandy and muddy substrata play an important role in the reworking of sediments and assist with enhancing sediment porosity. This increases the exchange of oxygen and nutrients within the substrate. Macrofaunal communities are also an important source of food for many marine and estuarine species. Numerous fish, birds and invertebrates depend on these infaunal communities as they constitute a major part of their diets. The macrofaunal communities within estuaries often have important ecological linkages with their neighbouring habitats in that certain species from other areas depend on the health of these habitats for their survival (e.g. trophic subsidy). Degradation or loss of adjacent habitats can, therefore, have far reaching detrimental effects on ecologically connected environments.

It is important to monitor biological components of the ecosystem in addition to physico-chemical and eco-toxicological variables, as biological indicators provide a direct measure of the state of the ecosystem in space and time. Benthic macrofauna are the biotic component most frequently monitored to detect changes in the health of the marine environment. This is largely because these species are short lived and, as a consequence, their community composition responds rapidly to environmental changes (Warwick, 1993). Given that they are also relatively non-mobile (in comparison to fish and birds) they tend to be directly affected by pollution and are easy to sample quantitatively (Warwick, 1993). Furthermore, they are scientifically well-studied compared to other sediment-dwelling components (e.g. meiofauna and microfauna) and taxonomic keys are available for most groups. In addition, benthic community responses to a number of anthropogenic influences have been well documented.

Organic matter is one of the most important pollutants affecting marine life and it can lead to significant changes in community composition and abundance, particularly in semi-enclosed or closed bays where water circulation is restricted (e.g. Durban Bay). High organic loading often leads to eutrophication, which may bring about a number of community responses amongst the benthic macrofauna. These include increased growth rates, disappearance of species due to anoxia, and changes in community composition. A reduction in the number of species found in a habitat and even complete disappearance of all benthic organisms may result from repeated hypoxia (Warwick, 1993). The community composition of benthic macrofauna is also likely to be impacted by increased levels of other contaminants, such as trace metals and hydrocarbons, found in the sediments. Furthermore, areas that are disturbed by mechanical means are likely to be inhabited by a greater proportion of opportunistic pioneer species.

Patterns of colonisation and succession of the new sand bank extension at Centre Bank is likely to follow those of disturbed habitats. It has been shown that species with a high fecundity, rapid growth rate and short life-cycle are able to rapidly invade and colonise

disturbed areas (Newell et al. 1998). These species are known as “r-strategists”, pioneer or opportunistic species and their presence generally indicates unpredictable short-term variations in environmental conditions as a result of either natural factors or anthropogenic activities. In stable environments, the community composition is controlled predominantly by biological interactions rather than by fluctuations in environmental conditions. Species found in these conditions are known as “K-strategists” and are selected for their competitive ability. K-strategists are characterised by long life-spans, larger body sizes, delayed reproduction and low mortality rates. Intermediate communities with different relative proportions of opportunistic species and K-strategists are likely to exist between the extremes of stable and unstable environments. Numerous experimental studies have shown relatively rapid rates of initial colonisation of disturbed sediment habitats. Initial colonisation has been documented to occur as rapidly as within a single day (Botter-Carvalho et al. 2011), however, population numbers of opportunistic species generally only peak after six months. The “Recovery” of a macrofaunal community, in terms of abundance, biomass, species richness and its functional role being equivalent to that prior to disturbance, has been found to range from 1 month to more than a year (Newell et al. 1998; Desprez, 2000; Kotta et al. 2009).

One of the main aims of this monitoring study is to assess intertidal and subtidal sand bank macrofaunal communities, so as to formulate a baseline to act as an end-reference point for the planned developments in the Port. The use of dredge material to create an extension of the existing Centre Bank will create additional shallow intertidal and subtidal sand bank habitats. Numerous studies in the United States have shown the successful use of dredged material in creating new naturally functioning mudflats (Ray, 2000) and saltmarshes (Streever, 2000) systems. However, there have been concerns over the ecological consequences of using fine sediments in “beneficial schemes” for creating intertidal habitats. Bolan et al. (2004) found that diverse infaunal communities are able to successfully establish in newly created intertidal habitats where dredge material was used. The rapid recolonization observed in their study was attributed to the similarity in dredge sediments to that of the reference sediments, being mainly the silt/clay and organic carbon fractions. The rate of recolonisation is however, dependent of the spatial and temporal extent of the disturbance when creating the new habitat.

6.2 Sampling Methodology

Benthic macrofauna samples were collected from the same stations as for sediment and benthic microalgae monitoring activities. Samples were collected quarterly in autumn, winter, spring and summer over a period of two years. Intertidal samples were collected at spring low tide by inserting a large (18 cm diameter) corer into the sediment to a depth of 30 cm, plugging the open end, extracting the core and transferring the contents to a 0.5 mm mesh bag. Three cores equating to a surface area of 0.3 m² were taken and pooled at each sampling station. The mesh bag was agitated until all the fine sediment was removed and the remaining contents placed in a sample jar. 5% formalin was added as a preservative. Subtidal samples were collected at corresponding times (autumn, winter, spring and summer) using a Van Veen grab with a bite of 0.085 m² deployed from a small inflatable boat. Two grabs equating to a surface area of 0.170 m² were taken and pooled at each subtidal sampling station. In all

cases, macrofauna from the samples were extracted from the residual sediment in the lab, identified to species level, counted and weighed (wet weight). Subtidal stations were located at 3-8 m depth on the sides of the sand banks.



Figure 6.1: Subtidal macrofauna sampling –Grab with sample (left), Examples of macrofauna specimens collected (right).

Given the complexity inherent in environmental assessments, numerous indices based on benthic invertebrate fauna information, were used to describe spatial and seasonal variations of the macrofaunal communities in the Port. The community composition, diversity, species abundance and biomass of soft bottom benthic macrofauna samples collected in Durban Bay from October 2014 to September 2016, are considered in this report.

6.2.1 Diversity Indices

Diversity indices provide a measure of diversity, i.e. the way in which the total number of individuals is divided up among different species. Understanding changes in benthic diversity

is important because increasing levels of environmental stress generally decreases diversity. Two different aspects of community structure contribute to community diversity, namely species richness and equability (evenness). Species richness refers to the total number of species present while equability or evenness expresses how evenly the individuals are distributed among different species. A sample with greater evenness is considered to be more diverse. It is important to note when interpreting diversity values that predation, competition and disturbance all play a role in shaping a community. For this reason, it is important to consider physical parameters as well as other biotic indices when drawing a conclusion from a diversity index.

The Shannon-Weiner diversity index (H') was calculated for each sampling location using PRIMER V 6:

$$H' = - \sum p_i (\log p_i) \quad 1$$

The diversity (H') value for each site was plotted geographically and this was used to interpolate values for the entire system using ArcGIS in order to reveal any spatial patterns.

6.2.2 Statistical Analysis

Both univariate and multivariate statistical analyses were used to investigate patterns in macrofauna community structure. All univariate analyses were performed using STATISTICA 12. Analysis of Variance (ANOVA) and Kruskal-Wallis Tests were conducted to determine whether macrofaunal abundance, biomass and species richness in the intertidal and subtidal habitats differed according to season (autumn, winter, spring and summer) and sand bank sites (Centre Bank, Little Lagoon, Mangroves, Northern Banks, Island View). All data were tested for normality and equal variance using the Shapiro-Wilkson Test and Levene's equal variance test respectively. If these criteria were not met the non-parametric Kruskal-Wallis Test was used.

The multivariate analysis was conducted using PRIMER v.6 (Plymouth Routines in Multivariate Ecological Research) (Clarke & Warwick, 2001). Species did not occur across all sites resulting in a high number of zeros in the data set. Fourth root transformation of the data was therefore required to reduce the weight of exceptionally abundant species and to achieve a balance in contribution between the rarer and more common species. All analyses were thus conducted using Bray-Curtis dissimilarities on fourth-root transformed abundance data. Differences in community species composition were examined using the non-metric multi-dimensional scaling (MDS) ordination technique. This analysis places sites in a multi-dimensional plot where their orientation is based on their similarity in species composition. Sites of similar species composition are placed closer together, while those of differing composition are positioned further apart. Stress level values, which indicate the level of

¹ Where p_i is the proportion of the total count arising from the i th species. This is the most commonly used diversity measure and it incorporates both species richness and equability.

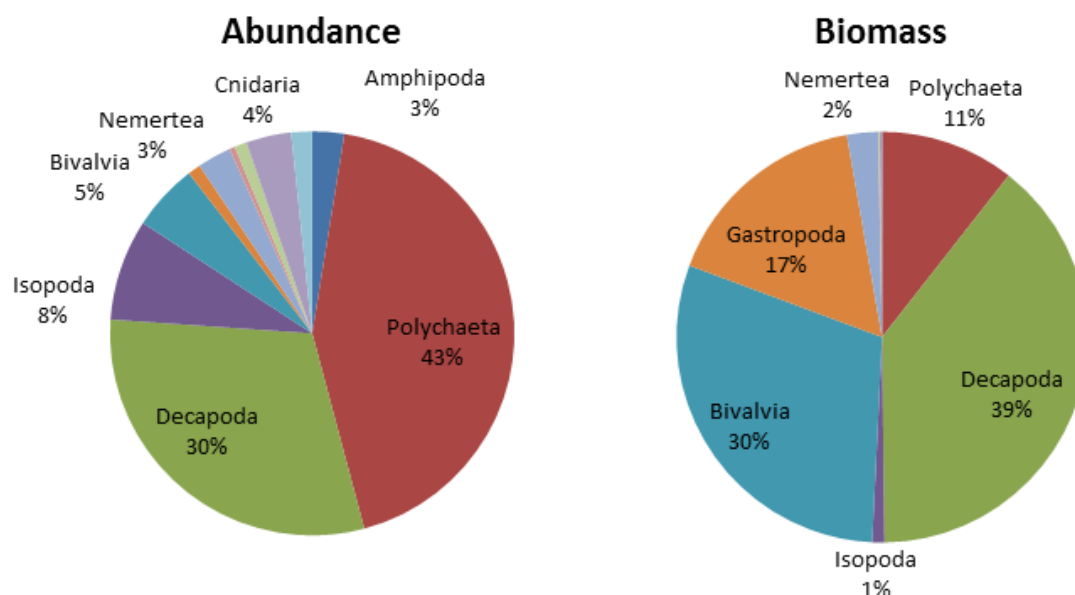
accuracy when converting the ordination into a two dimensional format, that are greater than 0.2 are regarded to be high (Clark & Warwick, 2001). Analysis of Similarity (ANOSIM) was also used to statistically investigate the degree of similarity in the assemblage structuring. The ANOSIM test produces a probability value (P) and an R statistic value that ranges between 0 and 1, with 0 indicating 100% similarity and 1 indicating 100% dissimilarity. The R statistic, which measures the difference between assemblages, is considered to be more important than the P value as this can be influenced by the sample size (Clarke & Gorley, 2006). If an R statistic value was > 0.5 the two compared sites were considered to be significantly different. Similarity percentages routine (SIMPER) analysis was used to identify species which contributed to the Bray-Curtis similarity between samples within groups and the dissimilarity between samples from different groups (Clarke & Gorley, 2006). The SIMPER analysis allows for the identification of 'indicator species' which characterise a site and the 'discriminatory species' which differentiates sites (Clarke & Gorley, 2006). Indicator species contribute to the similarity in assemblages between sites by being abundant in all of the sites and having high Similarity/Standard Deviation ratio. Discriminatory species are abundant in one site and infrequent in the others and having a high Dissimilarity/Standard Deviation ratio (Clarke & Warwick, 2001).

6.3 Results and Analysis of Data

A total of 155 species of macrofauna from both the intertidal and subtidal habitats were recorded in this study. The intertidal community composition was more variable than the subtidal community, with generally lower abundance, biomass, as well as number of species. To date a total of 9384 intertidal and 12115 subtidal animals have been collected and identified with a total biomass of 769.0 g and 965.81 g, respectively. Overall, the subtidal macrofaunal community had a greater number of species compared to the intertidal community with 134 and 95 species respectively.

Taxonomic contributions to community composition of intertidal and subtidal macrofauna abundance and biomass over the four seasons are shown in Figure 6.2. Overall, Polychaetes were the most abundant taxonomic group in both intertidal and subtidal habitats, followed by Decapoda. Nemertea made a substantial contribution in the subtidal community, while Bivalvia and Isopoda both contributed notably to community composition in both habitats. In the intertidal community Decapoda was the dominant taxon contributing most to total biomass followed by Bivalvia and Gastropoda. The dominate taxon in the subtidal community was Bivalvia followed by Decapoda and Gastropoda. Polychaeta, Bivalvia, Echinodermata and Gastropoda were slightly more dominant in the subtidal community than the intertidal. Descriptions of all taxa collected can be found in Annexure 3.

Intertidal



Subtidal

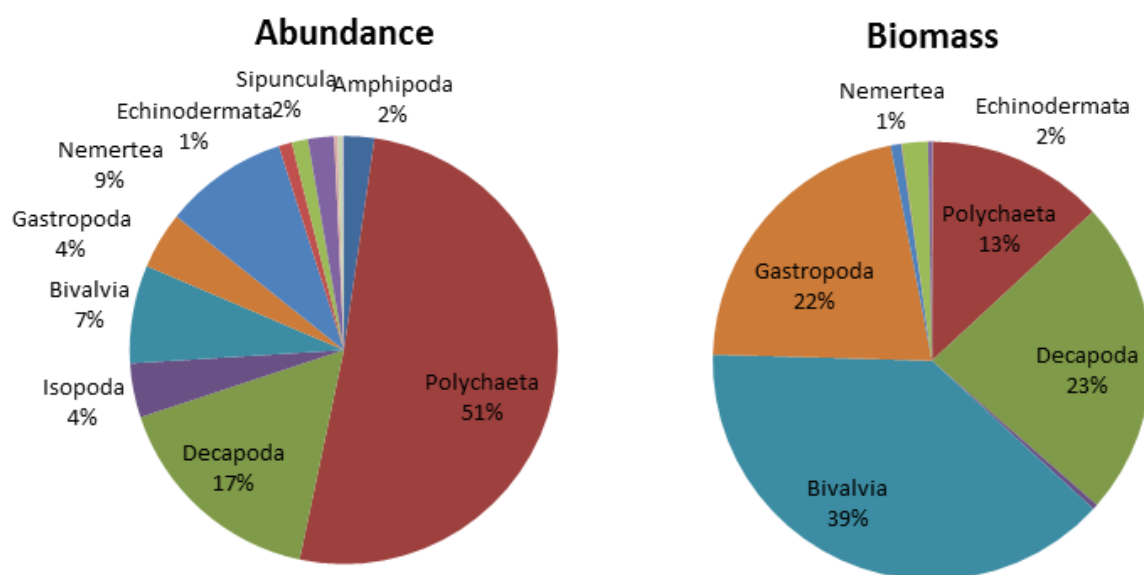


Figure 6.2: Taxonomic composition of intertidal and subtidal macrobenthic communities in the Port based on abundance and biomass data across the seasons.

6.3.1 Species Diversity

Variations in species diversity (represented by the Shannon Weiner Index, H') for intertidal and subtidal sites in the Port are presented in Figure 6.3 and Figure 6.4. Intertidal diversity was highest at sites DHI 28 and 29 in Little Lagoon and DHI 40 and 44 on Northern Bank. Interestingly, intertidal diversity was found to be lowest at sites located around the edges of

Centre Bank and Northern Bank, while subtidal diversity was lowest at sites located in the Mangroves. Lower diversity at these sites was thought to be linked to the high proportion of fine sediments, which contains elevated levels of contaminants (trace metals, organic material, etc.). It is well known that high levels of disturbance associated with pollution can allow a small number of opportunistic, short-lived or r-selected species to colonise the affected area and prevent a more diverse community comprising longer living k-strategist species from becoming established

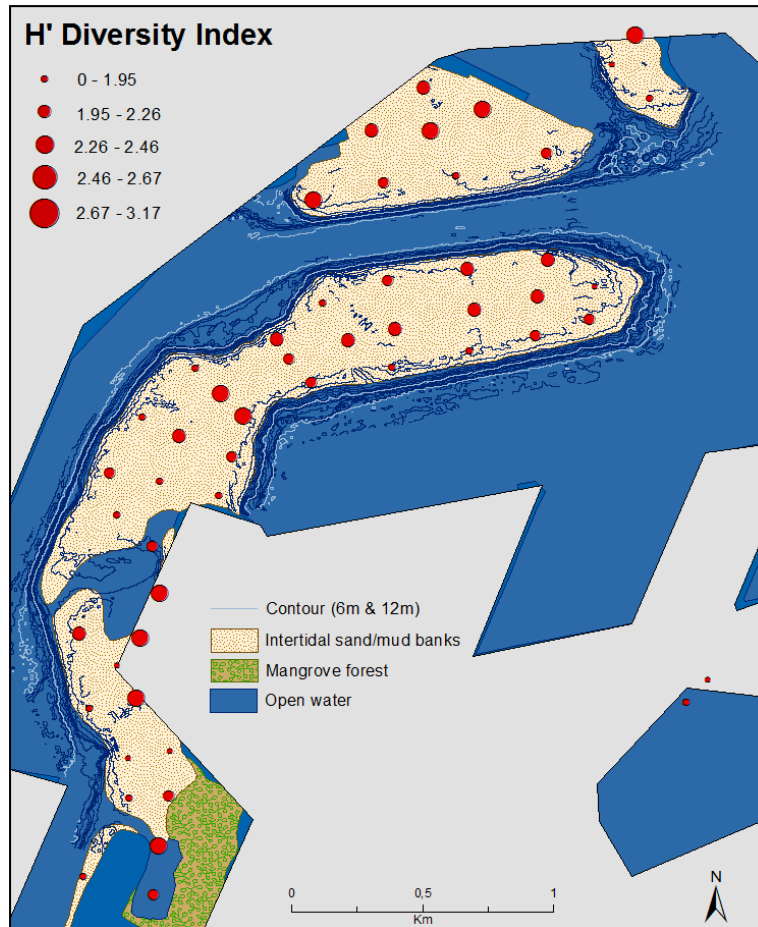


Figure 6.3: Graduated symbols (red circles) of the variation in the diversity of the intertidal benthic macrofauna in the Port as indicated by the 2016 survey results.

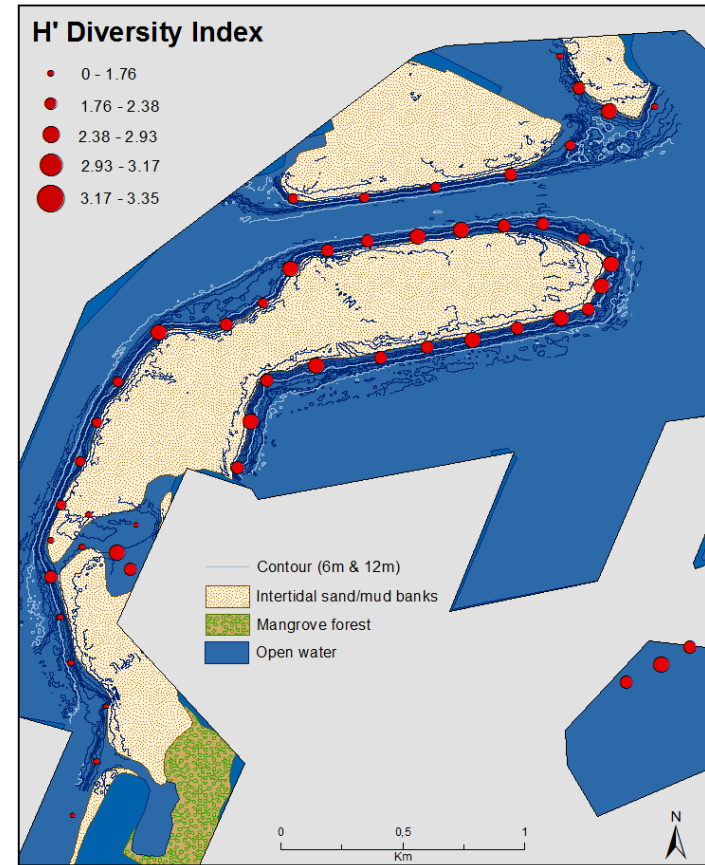


Figure 6.4: Graduated symbols (red circles) of the variation in the diversity of the subtidal benthic macrofauna in the Port as indicated by the 2016 survey results

6.3.2 Spatial Trends in Macrofaunal Communities

Spatial variations in the contribution by various taxonomic groups to mean abundance and biomass per m^2 in the intertidal and subtidal habitats are shown in Figure 6.5 and Figure 6.6. Mean abundances did not vary much between intertidal habitats in the different part of the Port, but abundance was highest at the Mangroves and Little Lagoon. Polychaeta was the dominant taxon at Little Lagoon (53%), Mangroves (69%) and Northern Banks (43%), while Decapoda (43%) and Isopoda (41%) were dominant at Centre Bank and Island View, respectively. Decapoda was the next most important taxon after Polychaeta at Little Lagoon (25%) and Northern Banks (26%), whereas, at the Mangroves, Bivalvia (15%) was the second greatest contributor to mean abundance. Intertidal biomass estimates showed contrasting patterns to intertidal abundance. Mean biomass was considerably higher in the Mangroves (40.7 g/m^2) than other sand bank habitats and lowest (6.4 g/m^2) at Island View. Decapoda was the dominant contributor to total biomass at Centre Bank, Northern Bank and Island View, while Bivalvia were dominant at Little Lagoon and the Mangroves. Gastropoda made an important contribution to mean biomass at Centre Bank (28%) and Northern Bank (27%). Polychaeta contributions to mean biomass remained relatively constant across all sand bank habitats.

Unlike intertidal trends, subtidal mean abundance was highest in the Mangroves (469.5 indiv./m^2), while there was little variation between the other sand bank habitats. Polychaeta dominated the subtidal communities apart from at the Mangroves where Decapoda were dominant (59%). Mean subtidal biomass estimates showed similar trends to mean abundance. Mangroves had considerably higher mean biomass (72.8 g/m^2) than other sand bank habitats. Centre Bank (13.2 g/m^2), Northern Bank (13.8 g/m^2) and Island View (12.7 g/m^2) had equally low biomass estimates. Decapoda dominated mean biomass estimates at the Mangroves (45%) and Northern Bank (29%), while Bivalvia were dominant at the Centre Bank (39%) and Little Lagoon (48%). Contributions of Polychaeta to mean biomass were high at Centre Bank (25%) and Northern Bank (26%) and lowest at Little Lagoon (6%) and the Mangroves (4%).

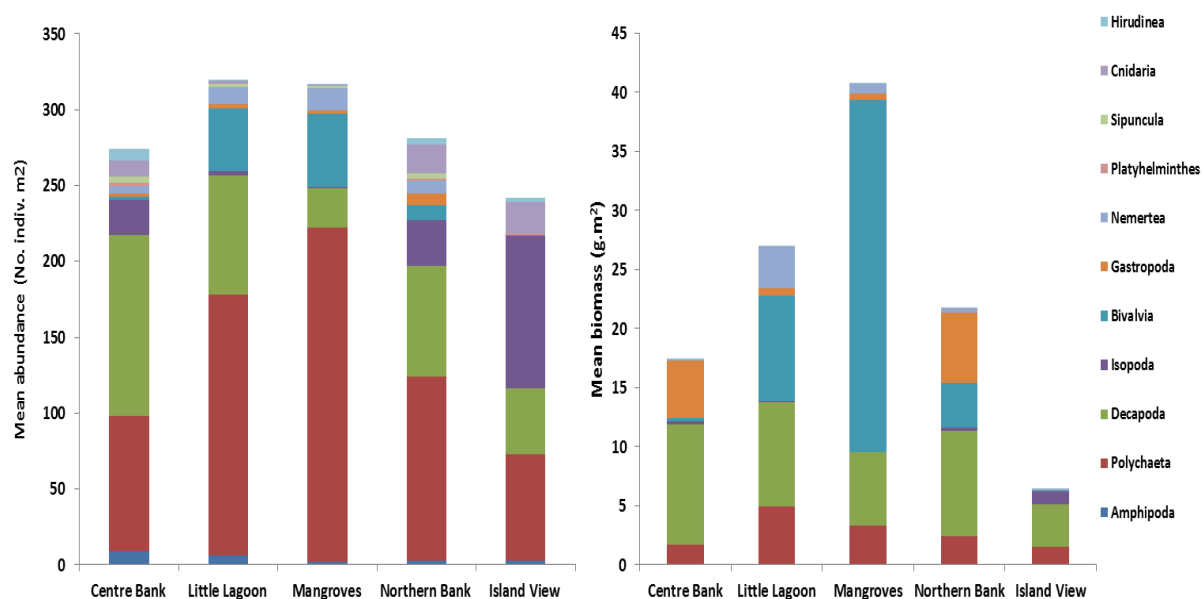


Figure 6.5: Contribution to mean abundance and biomass of intertidal macrofauna according to taxon for each sand bank habitat across the seasons.

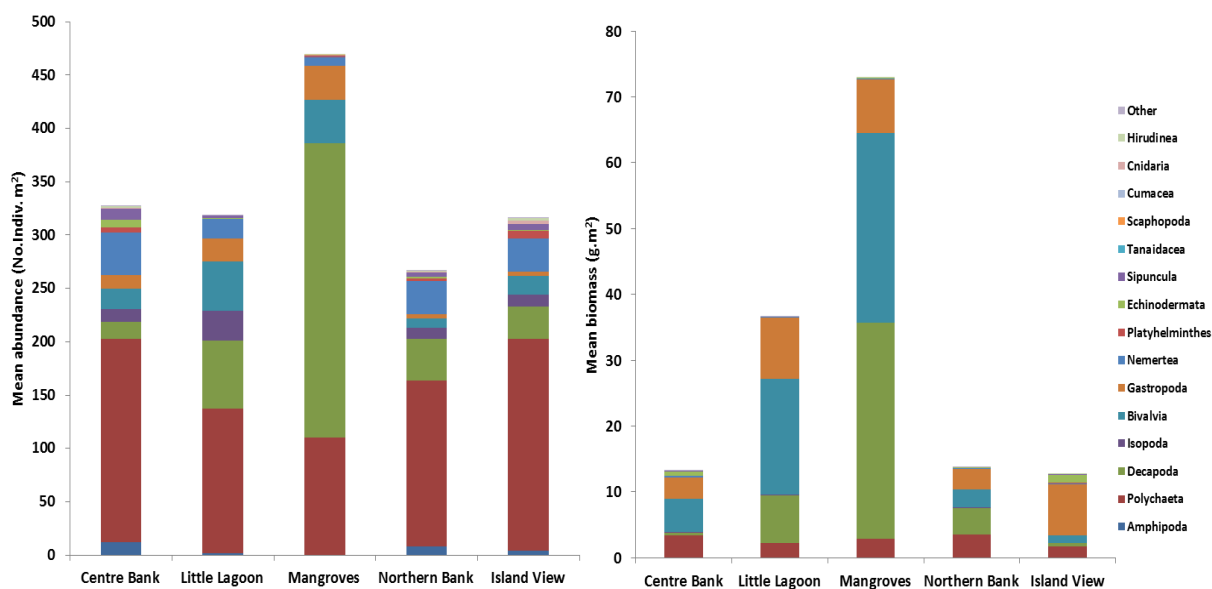


Figure 6.6: Contribution to mean abundance and biomass of subtidal macrofauna according to taxon for each sand bank habitat across the seasons.

6.3.3 Functional Feeding Groups

Spatial contribution of the different trophic (feeding) groups to mean abundance and biomass per m^2 in the intertidal and subtidal habitats are presented in Figure 6.7 and Figure 6.8. Detritivores (those that feed on particulate organic matter in or on the surface of the sediment) and predators dominated intertidal and subtidal abundance estimates at all sand banks sites. The contribution by detritivores to mean abundance was lowest at Little Lagoon and the Mangroves, whereas filter feeders (those that feed by filtering particulate matter out of the water column) were substantially greater. Intertidal and subtidal biomass estimates at Centre Bank, Northern Bank and Island View followed similar trends to abundance with Detritivores being the dominant feeding group. However, at Little Lagoon and the Mangroves, filter feeders, being mainly Bivalvia, had far greater contributions to mean biomass. The contribution by Grazers and Scavengers to subtidal abundance and biomass on subtidal habitat at Centre Bank and Island View was more important than at other sites in the Port.

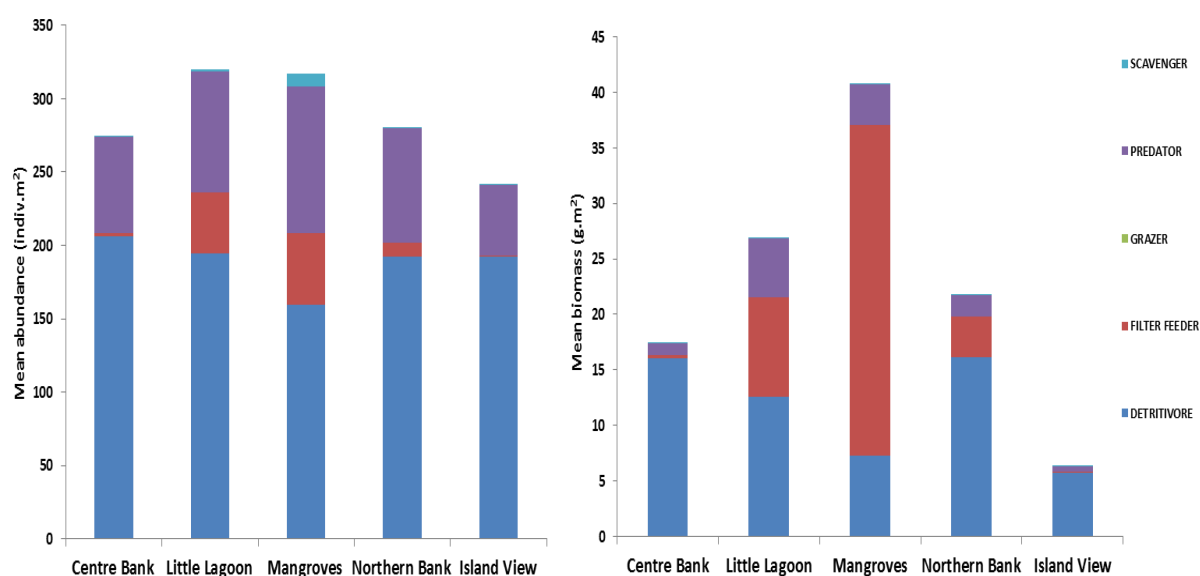


Figure 6.7: Contribution to mean abundance and biomass of intertidal macrofauna according to functional feeding group for each sand bank habitat across the seasons.

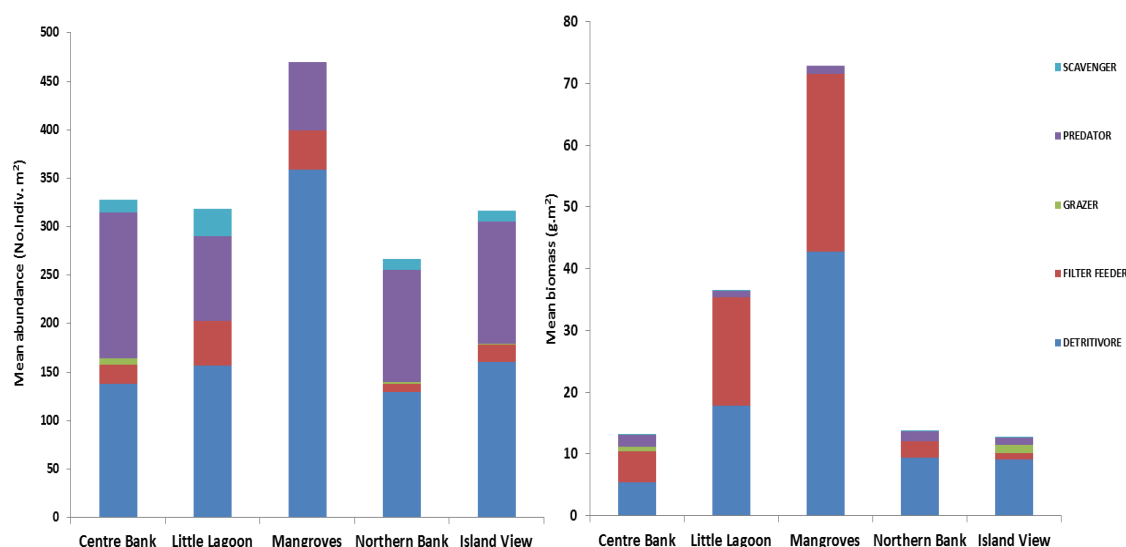


Figure 6.8: Contribution to mean abundance and biomass of subtidal macrofauna according to taxon for each sand bank habitat across the seasons.

6.3.4 Univariate Analysis of Spatial Patterns

Univariate ANOVA analyses of the combined seasonal data were used to investigate spatial patterns in intertidal and subtidal abundance, biomass and species richness, results for which are shown in Figure 6.9 and Figure 6.10. Overall, the five sand bank habitats (Centre Bank, Little Lagoon, Northern Bank, Mangroves and Island View habitats) were significantly different in terms of intertidal species richness ($F_{4, 404} = 4.745$, $P < 0.001$) and biomass ($F_{4, 404} = 9.607$, $P < 0.001$). All intertidal areas had a significantly greater average number of species than Island View, with the higher species richness recorded at the Little Lagoon and Centre Bank. Significant spatial differences in average biomass were found when comparing Little Lagoon and the Mangroves to other sand bank sites. The Mangroves had significantly greater biomass than the Centre Bank, Northern Bank and Island View, while Little Lagoon estimates were significantly greater than Centre Bank and Island View. No significant differences in intertidal abundance estimates were found, but abundance was slightly higher (but not significantly so) at Little Lagoon compared with the other sand bank sites.

Combining subtidal community estimates across seasons revealed significant spatial differences in species richness ($F_{4, 380} = 10.760$, $P < 0.001$), biomass ($F_{4, 380} = 20.565$, $P < 0.001$) and abundance ($F_{4, 380} = 4.194$, $P < 0.001$). Average species richness at Centre Bank was significantly greater than Little Lagoon, Mangroves and Northern Bank, while Island View was significantly greater than the Mangroves. Analysis of subtidal biomass estimates revealed a significant difference between the Mangrove and other sandbanks, while all other sandbanks showed similar patterns in biomass. Similar patterns were found with average abundance estimates with the Mangrove habitat found to be the most important. Mangrove

abundance estimates were significantly greater than the Centre Bank, Little Lagoon and Northern Bank sites, while all other areas showed similar patterns in abundance.

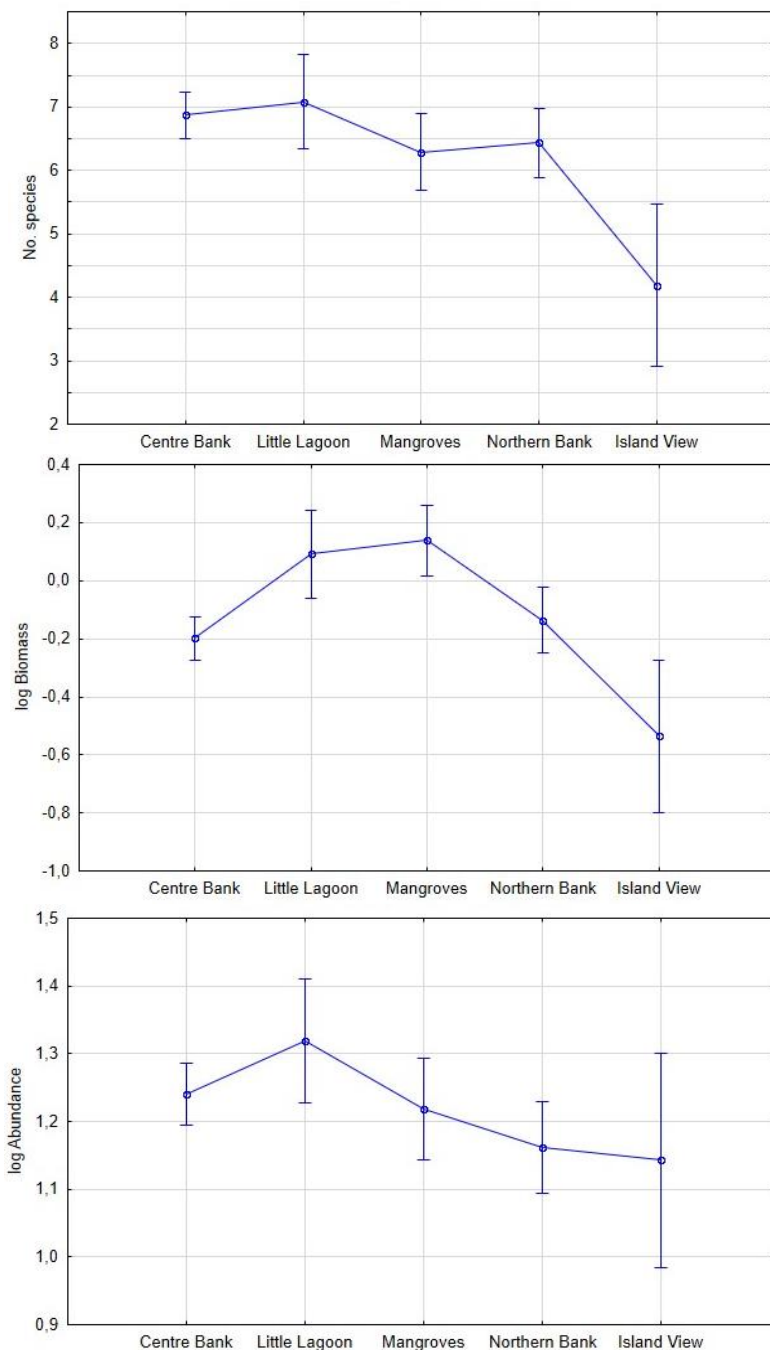


Figure 6.9: Comparison of average number of species (top), biomass (middle) and abundance (bottom) of intertidal macrofauna at the five a priori defined sandbank areas within the Port. (Error bars show 95% confidence intervals of the mean, non-overlapping bar indicate significant differences).

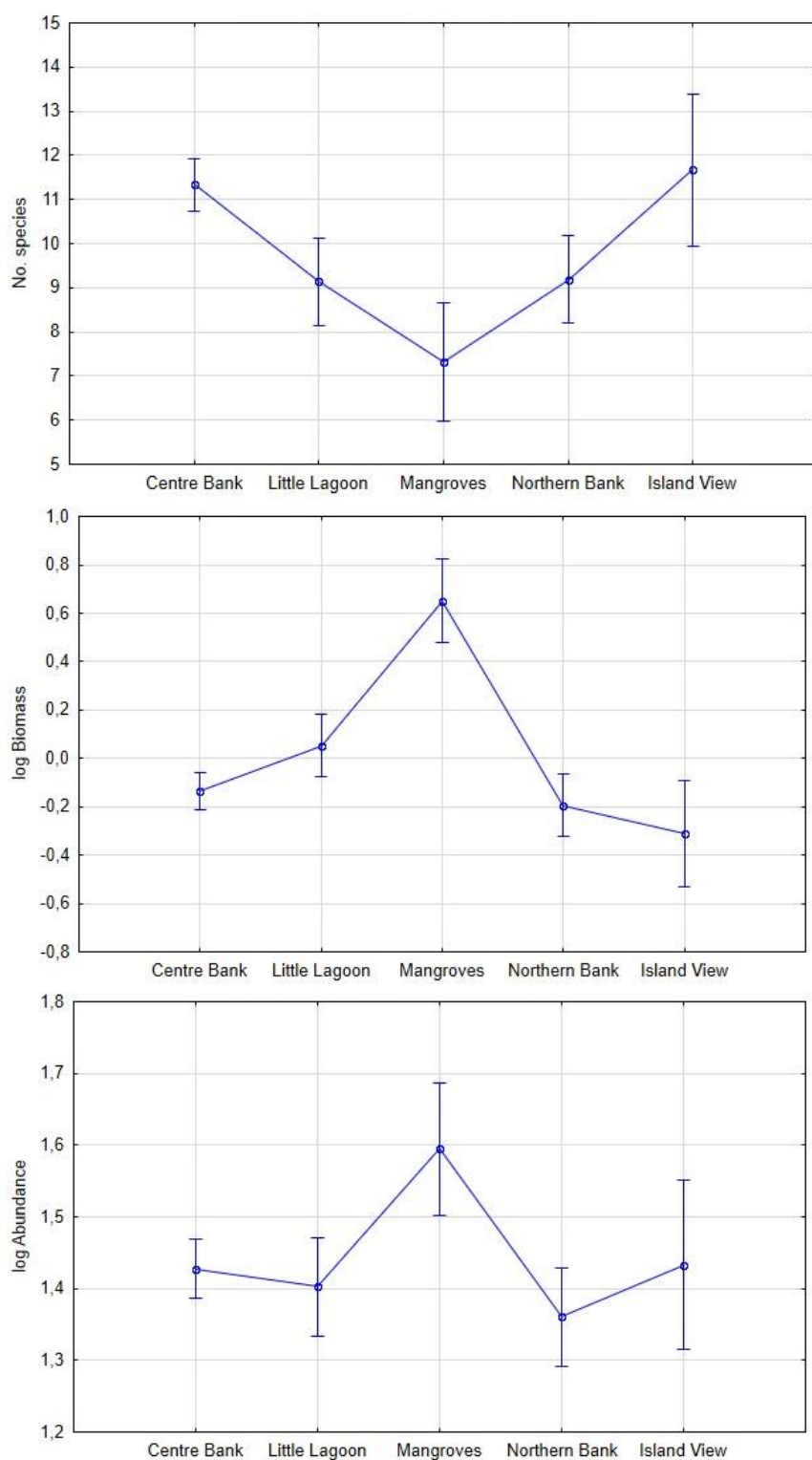


Figure 6.10: Comparison of average number of species (top), biomass (middle) and abundance (bottom) of subtidal macrofauna at the five a priori defined sandbank areas within the Port. Multivariate analysis of spatial patterns

MDS ordination plots prepared from the macrofauna abundance data for the intertidal and subtidal habitats are presented in Figure 6.11 and Figure 6.12. ANOSIM analysis indicated significant differences between sand banks ($p < 0.001$) and a reasonable degree of dissimilarity between communities (Global $R = 0.487$). Pair wise analysis between sand bank habitats indicated significant differences between Centre Bank and the Mangroves ($R = 0.797$, $p < 0.001$), Little Lagoon and Island View ($R = 0.982$, $p < 0.05$), and the Mangroves and Island View ($R = 0.967$, $p < 0.05$). The MDS ordination supported the ANOSIM results with the Mangroves and Little Lagoon sites forming separate clusters, although there was some overlap between Centre Bank and Northern Bank sites. The separate grouping of some Centre Bank sites (DHI10-15, 15, 25 & 44) is likely related to them being located in the middle of the sand banks and thus exposed for the longest period over each tidal cycle. Similarly, the separate grouping of the Northern Banks sites (DHI 42, 44, 45, 47, 50) is likely associated with them all being in close proximity to storm water inflow points.

As observed in the intertidal habitat, there was an overall significant dissimilarity between subtidal sandbank communities (Global $R = 0.557$, $p < 0.05$). Sand bank habitats which showed significant differences were Centre Bank and Little Lagoon ($R = 0.662$, $p < 0.001$), Centre Bank and the Mangroves ($R = 0.938$, $p < 0.001$), and the Mangroves and Northern Bank ($R = 0.565$, $p < 0.05$). MDS ordination plots showed separate grouping of the Mangrove sites from the remaining sand bank sites. Except for a few outliers, grouping of Centre Bank sites was also observed. Overlap of some Northern Bank and Island View sites in the Centre Bank grouping is likely due to similarity in sediment characteristics and physico-chemical conditions in the lower regions, as mentioned in previous chapters.

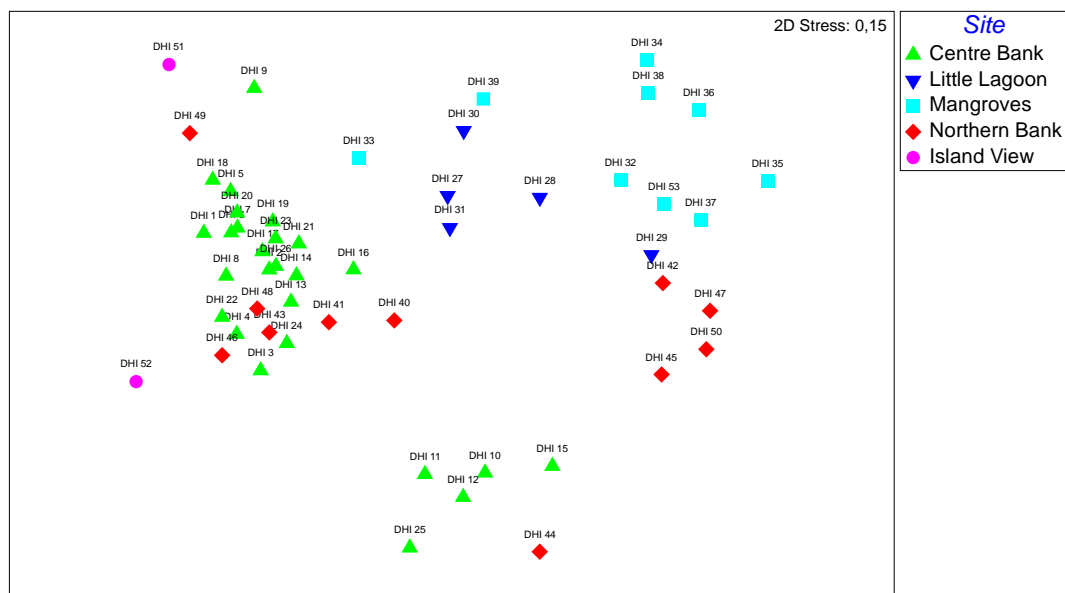


Figure 6.11: Multidimensional Scaling (MDS) Plot showing differences in community structure amongst intertidal macrofaunal assemblages in Durban Bay (Port) in the period October 2014 to September 2016 (sites were averaged across seasons).

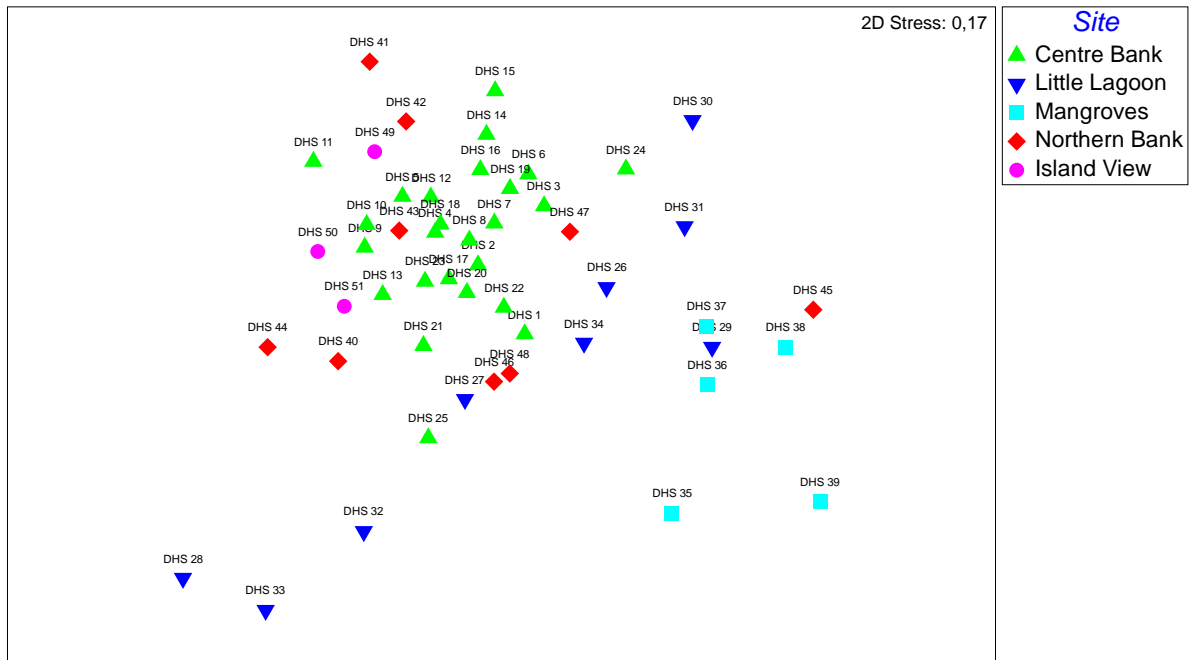


Figure 6.12: Multidimensional Scaling (MDS) Plot showing differences in community structure amongst subtidal macrofaunal assemblages in Durban Bay (Port) in the period October 2014 to September 2016 (sites were averaged across seasons).

6.3.5 Indicator and Discriminating Species

A SIMPER analysis was performed to identify indicator and discriminatory species in the intertidal and subtidal communities of each sand bank habitat. Indicator species contribute to the similarity in assemblages between sites by being abundant in all of the sites and having high Sim /SD values. *Glycera natalensis* was the most common intertidal species contributing between 9.2-11.1% to the similarity between sand banks, while Nemertea was the most common subtidal species with contributions ranging from 5.1-7.3%. Decapods *Callichirus kraussi* (Av. Sim: 5.7; Sim/SD: 2.5) and *Spiroplax spiralis* (Av. Sim: 5.4; Sim/SD: 2.3) were the best intertidal indicator species for Centre Bank, whereas the best subtidal indicators were polychaetes *Glycera natalensis* (Av. Sim: 3.4; Sim/SD: 6.9) and *Glysera subaenea* (Av. Sim: 2.7; Sim/SD: 6.4). The Mangrove sites had distinctly different indicator species, the bivalve *Dosinia hepatica* (Av. Sim: 5.8; Sim/SD: 5.2), and polychaete *Glycera tridactyla* (Av. Sim: 4.5; Sim/SD: 7.4) for the intertidal habitat. The most reliable indicator species for the subtidal mangrove habitat were the bivalve *Theora lata* (Av. Sim: 3.4; Sim/SD: 10.1) and gastropod *Notomastus latericeus* (Av. Sim: 4.8; Sim/SD: 12.3). Intertidal isopod *Excirolana latipes* (Av. Sim: 11.2; Sim/SD: 6.9) and subtidal bivalve *Fulvia laevigata* (Av. Sim: 2.8; Sim/SD: 18.1) were considered the most reliable indicator species for Island View.

The average dissimilarity between communities ranged from 51-73% for the intertidal and 42-60% for the subtidal communities. Both the intertidal and subtidal macrofaunal assemblages at Mangroves and Island View were most dissimilar. The best discriminating species between the intertidal communities were *Excirolana latipes* (Av. Diss: 4.8; Diss/SD: 4.5) and *Dosinia hepatica* (Av. Diss: 3.6; Diss/SD: 5.5), and for the subtidal communities were *Paratyloidioplax blephariskios* (Av. Diss: 3.8; Diss/SD: 6.1) and *Jasmineira elegans* (Av. Diss: 2.0; Diss/SD: 7.8). Intertidal assemblages of Mangroves and Little Lagoon were least dissimilar, reliable discriminators being *Orbinia bioreti* (Av. Diss: 1.9; Diss/SD: 1.5) and *Callichirus kraussi* (Av. Diss: 1.9; Diss/SD: 1.5). Least dissimilar subtidal assemblages were Centre Bank and Island View. Discriminating species were gastropod *Polinices mamilla* (Av. Diss: 1.0; Diss/SD: 3.2) and brittle star *Capitella capitata*. (Av. Diss: 1.0; Diss/SD: 1.9).

6.3.6 Seasonal Trends in Macrofaunal Community Composition

Variations in seasonal contribution of various taxonomic groups to mean abundance and biomass per m² in the intertidal and subtidal habitats are presented in Figure 6.13 and Figure 6.14. Overall, mean intertidal abundance was highest in autumn 2016 (425 indiv./m²) and lowest in spring 2015 (185 indiv./m²). In spring of 2014 and summer of 2015, Decapoda were the dominant taxon in the intertidal macrofaunal community, followed by Polychaeta and Isopoda. In all other seasons, however, Polychaeta dominated. The contribution by Polychaeta to mean abundance was highest in the summer (51%) and autumn (50%) 2016 surveys. The contributions of Decapoda to community composition in spring 2015 (35%) and summer 2016 (19%) were notable lower than the previous corresponding spring 2014 (51%) and summer 2015 (36%) surveys. Isopoda contributions remained largely constant across all seasons. Mean intertidal biomass estimates were highest in both winter 2015 (34.5 g/m²) and winter 2016 (36.4 g/m²) surveys. Decapoda, Bivalvia and Gastropoda were the dominant contributors to mean biomass in the intertidal community. Bivalvia and Gastropoda contributions were greatest in both the autumn and winter seasons respectively. Polychaeta contributions were highest in summer 2015 (11%) and summer 2016 (20%) and decreased in the following autumn 2015 (8%) and autumn 2016 (10%) surveys. All other taxa had fairly similar contributions to community composition.

Subtidal macrofaunal abundance was lowest in the autumn 2015 (237 indiv./m²) and highest in the following autumn 2016 (511 indiv./m²) survey. Similar to the intertidal habitat, Polychaeta and Decapoda dominated the subtidal communities for each season. Bivalvia and Nemertea were the next higher contribution to mean abundance for each the season, peaking in the autumn and winter surveys. Isopoda contributions remained relatively constant across seasons. Mean biomass was lowest in spring 2014 (11.7 g./m²) and highest in autumn 2016 (48.8 g./m²). Decapoda, Bivalvia and Gastropoda were the dominated contributors to taxonomic composition; however, they varied considerably between seasons. Polychaeta contributions were highest in both the spring 2014 (22%) and spring 2015 (21%) surveys.

6.3.7 Univariate Analysis of Seasonal Patterns

Univariate analysis of combined data from each site (ANOVA) was used to investigate seasonal effects on intertidal and subtidal abundance, biomass and species richness estimates (Figure 6.15 and Figure 6.16). Significant seasonal effects were found for intertidal species richness ($F_{3,404} = 4.745$, $P < 0.001$), biomass ($F_{3,404} = 9.544$, $P < 0.001$) and abundance ($F_{3,404} = 14.916$, $P < 0.001$). Intertidal species richness and abundance patterns followed similar trends with significantly lower values in spring than all other seasons. Both were found to be highest in autumn but not significantly different to summer and winter. Biomass estimates however, were significantly higher in autumn and winter when compared to spring and summer.

Unlike in the intertidal community, no significant seasonal differences were found in terms of abundance, however, there were significant differences in species richness ($F_{3,381} = 2.940$, $P < 0.001$) and biomass ($F_{3,381} = 5.606$, $P < 0.001$). Overall, species richness and biomass estimates for the subtidal communities were both highest in summer with significant lower species richness between winter and biomass estimates in spring.

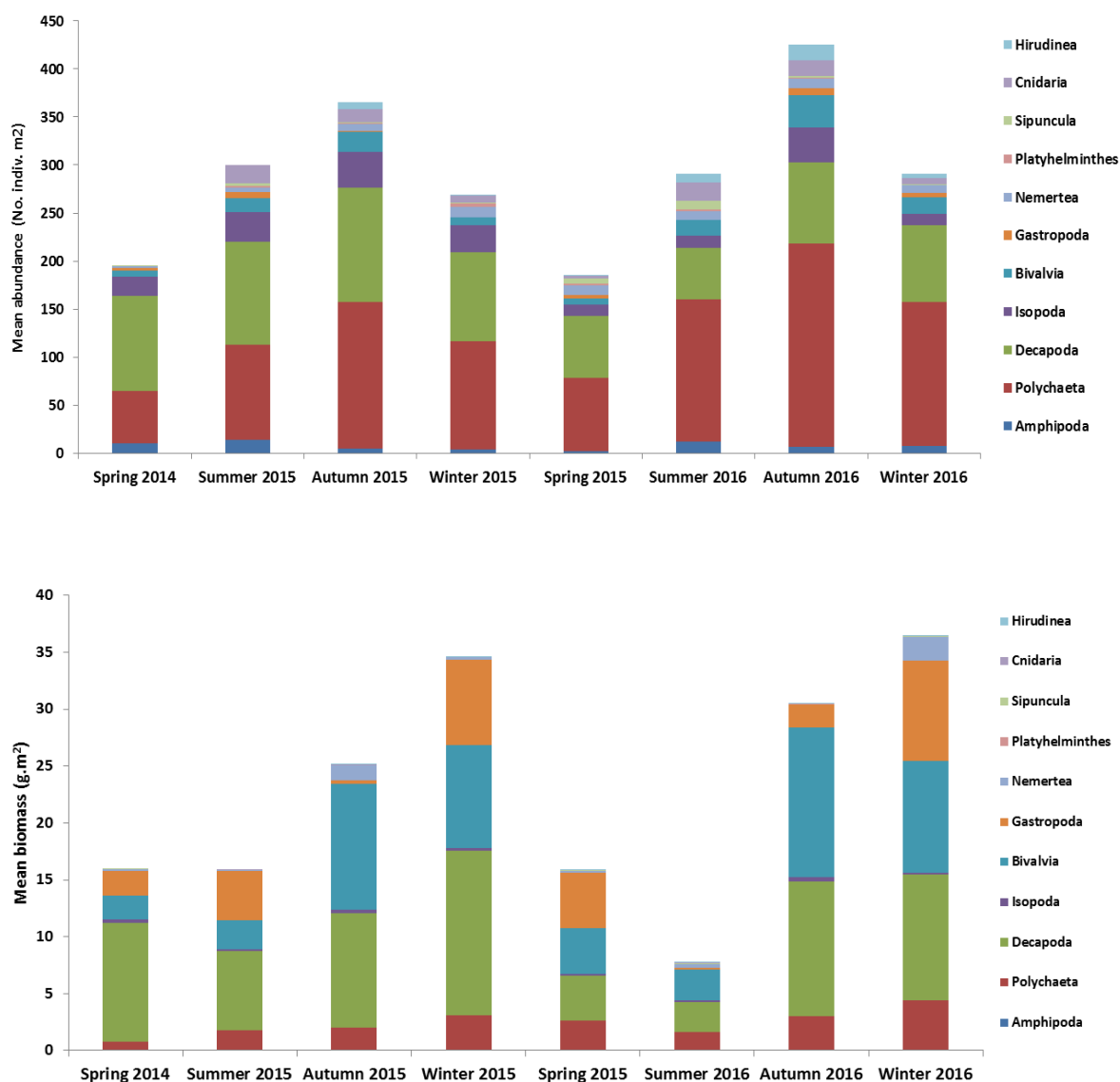


Figure 6.13: Contribution to mean abundance and biomass of intertidal macrofauna according to taxon for each season.

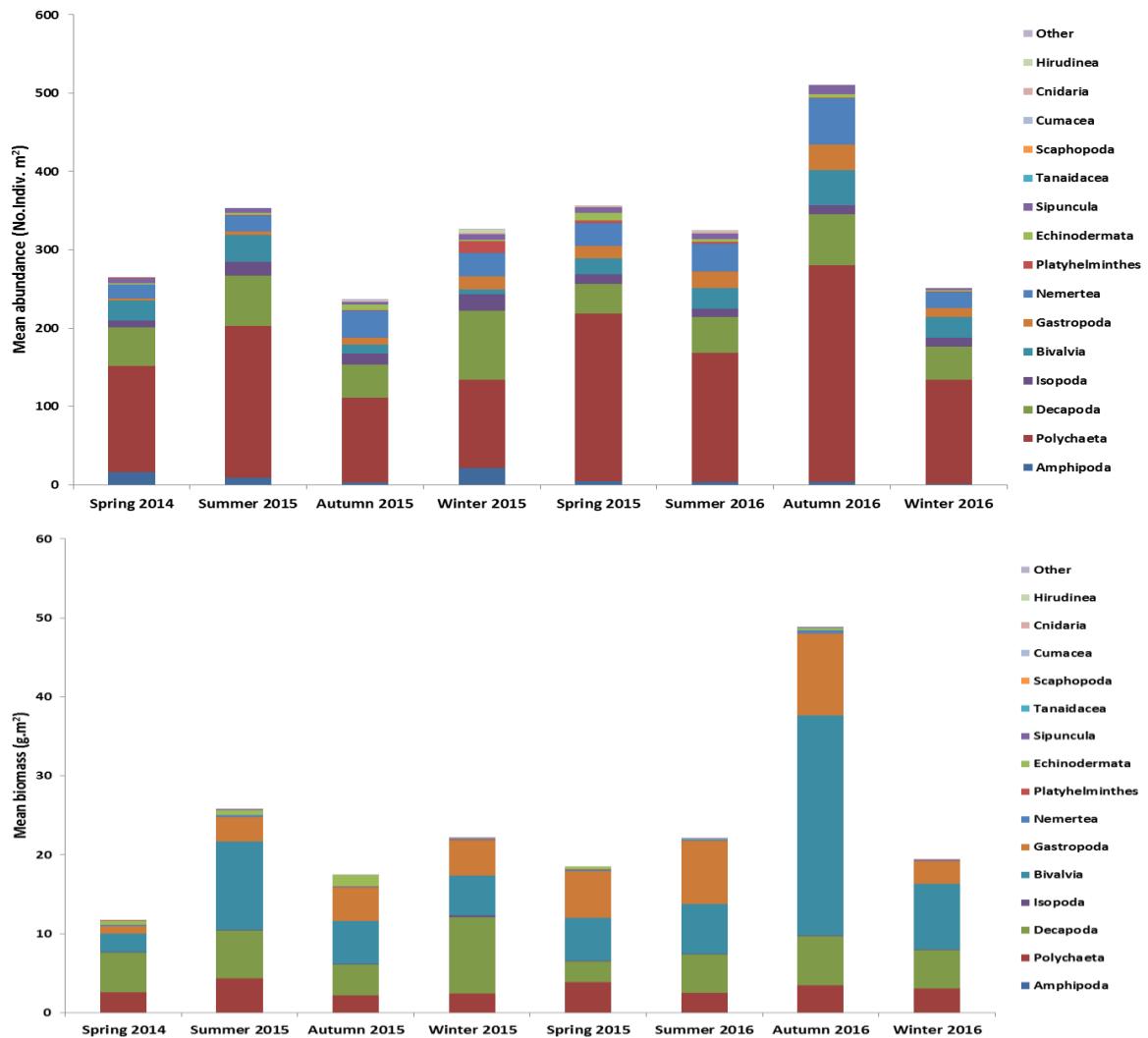


Figure 6.14: Contribution to mean abundance and biomass of subtidal macrofauna according to taxon for each season.

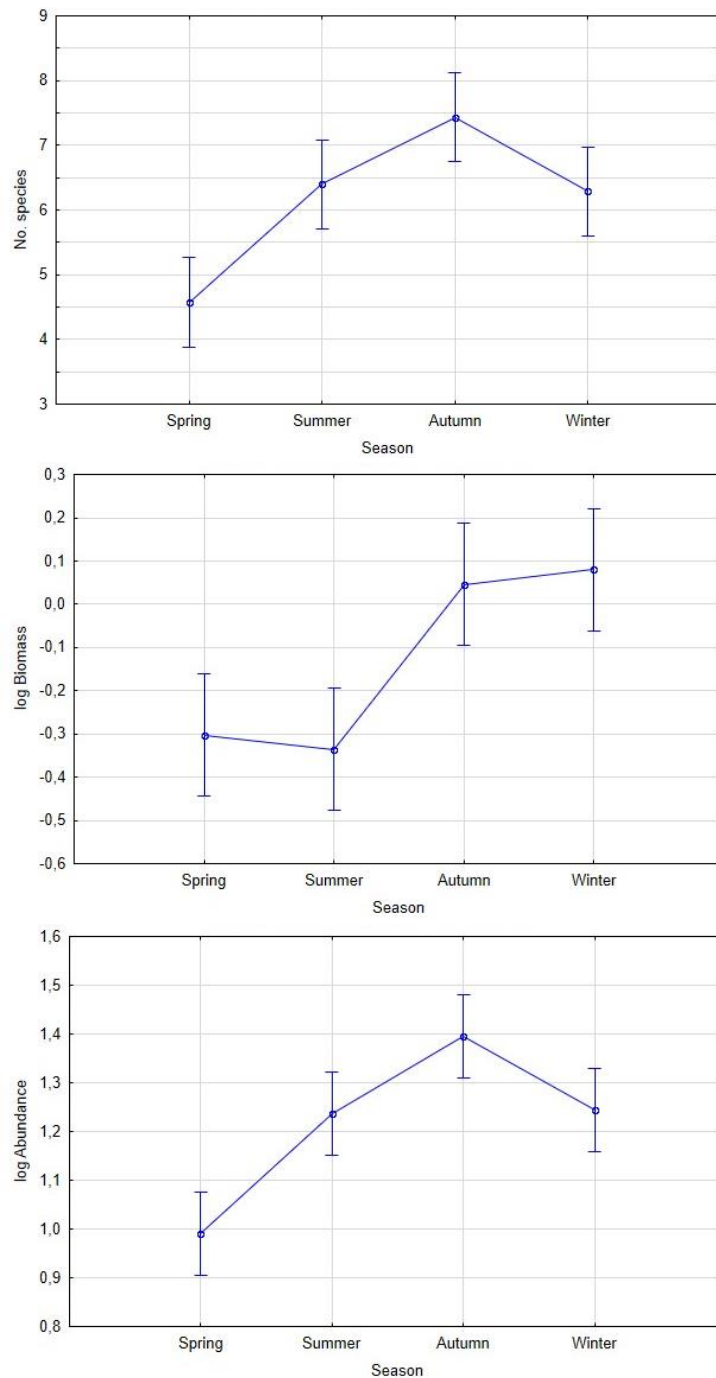


Figure 6.15: Comparison of average number of species (top), biomass (middle) and abundance (bottom) of intertidal macrofauna for each season within the Port. (Error bars show 95% confidence intervals of the mean, non-overlapping error bars indicate significant differences).

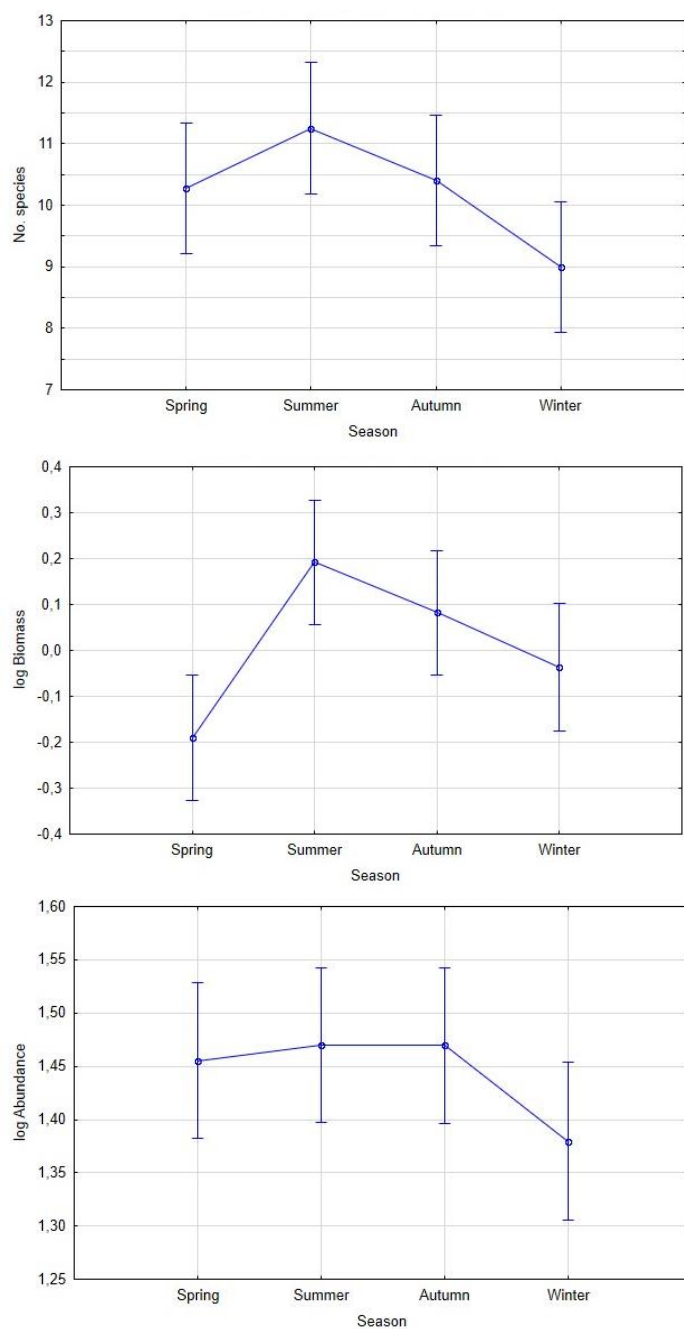


Figure 6.16: Comparison of average number of species (top), biomass (middle) and abundance (bottom) of subtidal macrofauna for each season within the Port. (Error bars show 95% confidence intervals of the mean, non-overlapping error bars indicate significant differences).

6.3.8 Univariate Analysis of the Interactive Effect

Univariate analysis of the interactive effect between Area x Season for intertidal and subtidal abundance, biomass and species richness using ANOVA are given in Figure 6.17 and Figure 6.18. Overall, the interactive effect was found to be insignificant for both intertidal and subtidal communities. However, plots of the means and associated confidence intervals revealed some differences between seasons within each site.

Average species richness in the intertidal habitat was highest during autumn for most sites, with significantly greater number of species at the Mangroves compared to spring and summer. At Centre Bank species richness during spring was significantly less than all other seasons, while Northern Banks spring numbers were significantly lower than autumn. The seasonal pattern of intertidal macrofaunal biomass at the different sand banks followed similar trends to species richness. At the majority of sites, average biomass estimates were highest in autumn, with significant differences to summer and spring estimates at the Centre Bank and Mangroves sites. Winter biomass estimates were also significantly greater at Centre Banks when compared to summer and spring. Intertidal abundance was highest in autumn and lowest in spring for a majority of sites. What is clear from the plot of mean abundance and associated confidence intervals, is that the autumn abundance estimates at the Little Lagoon, Mangroves and Northern Bank sites (and in the case of the Centre Bank, also winter and summer) were significantly greater than that recorded in spring. Overall, there was little seasonal variation at Little Lagoon.

In the subtidal habitat, there were no significant differences in species richness, biomass and abundance between seasons within each site. Although not significant, the Mangroves had the lowest average species richness while Centre Bank and Island view had the highest. Biomass estimates show contrasting patterns with the highest estimates at the Mangroves, however, there was no significant seasonal variation. Abundance estimates corresponded with the biomass trends with the highest average abundance at the Mangroves.

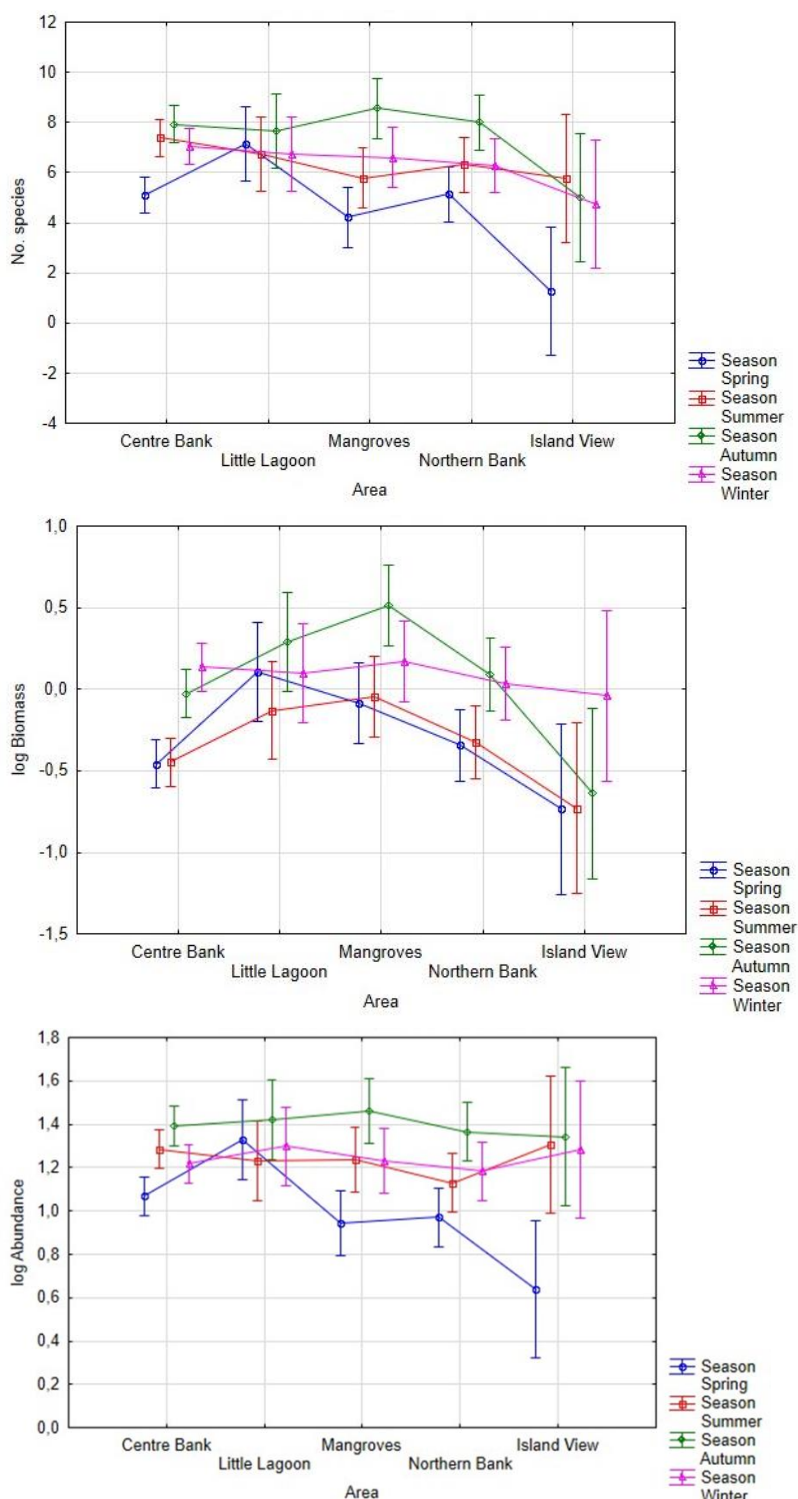


Figure 6.17: Comparison of average number of species (top), biomass (middle) and abundance (bottom) of intertidal macrofauna at the five a priori defined sandbank areas within the Port for each season. (Error bars show 95% confidence intervals of the mean non-overlapping error bars indicate significant differences).

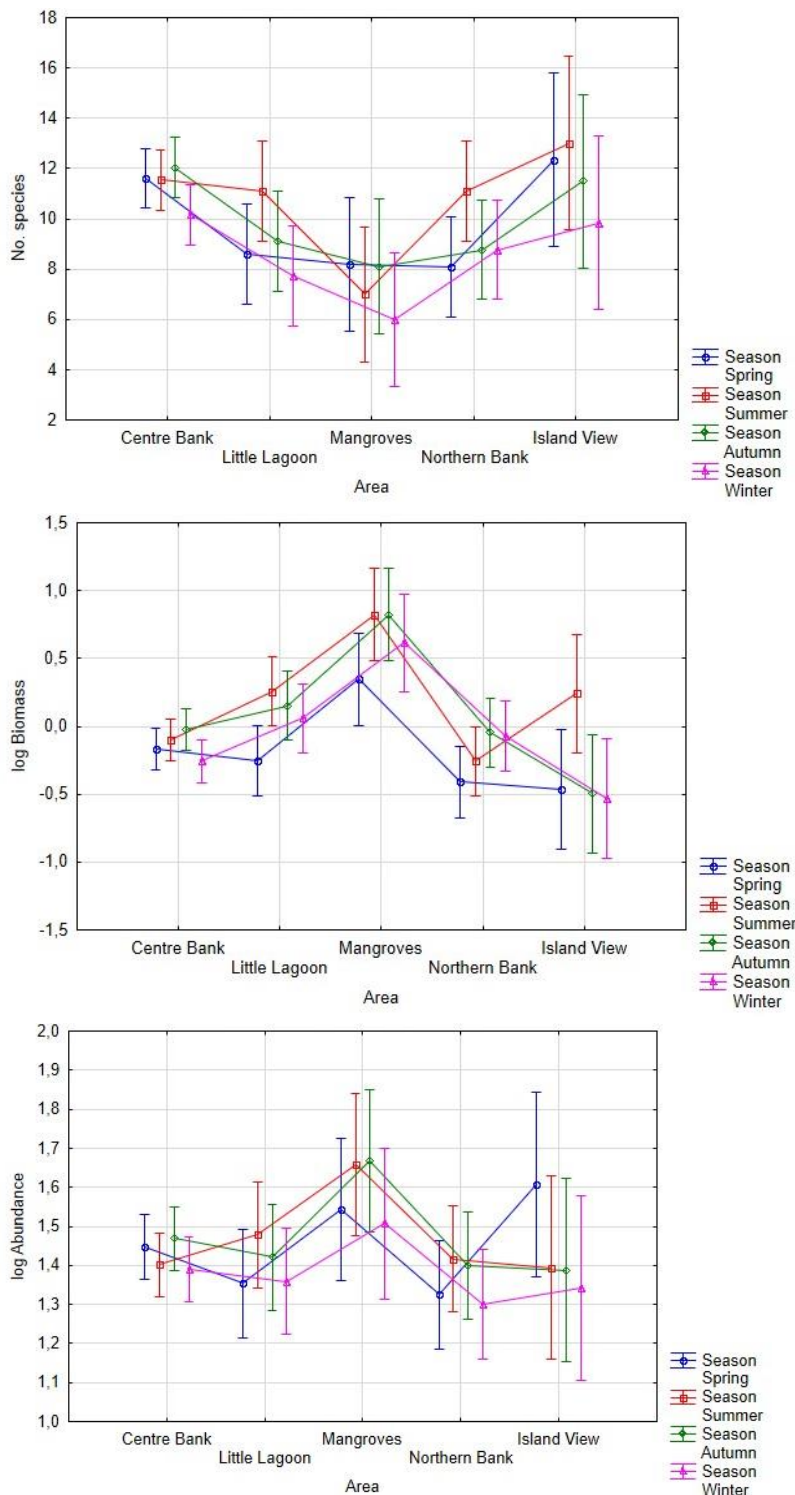


Figure 6.18: Comparison of average number of species (top), biomass (middle) and abundance (bottom) of subtidal macrofauna at the five a priori defined sandbank areas within the Port for each season. (Error bars show 95% confidence intervals of the mean, non-overlapping error bars indicate significant differences).

6.4 Comparison with Data from Previous Studies

The first biological survey of Durban Bay was carried out in 1950-1952 by Day & Morgan (1956). They reported that ecological divisions in the Port were regulated by substratum (consisting of clean sand, various grades of muddy sand, and hard man-made substrates) rather than by differences in salinity or temperature. A general reduction in diversity and abundance of algae, invertebrates and fish compared to what would have been expected under natural conditions was reported. Clean sand contained little organic matter and did not support a great diversity of fauna. This sediment type was dominated by burrowing animals such as isopods and the sand prawn *Callichirus kraussi* (formerly named *Callianassa kraussi*). Muddy sands, on the other hand, were rich in organic matter and were associated mostly with mangrove habitats in the Bay. Muddy sands were rich in invertebrate fauna, including many species of polychaetes, amphipods, tanaeids, isopods, mysids, brachyurans and echinoderms. Small crabs and whelks were found on the sediment surface. The eel grass *Zostera capensis* was also present on the intertidal banks (albeit in poor condition) in these early days but had completely disappeared by 1955 along with the rich fauna associated with it (Day & Morgan, 1965).

In the past, relatively more sampling has been conducted in sand-flat habitats than in the deeper subtidal areas of Durban Bay, partly because the ecological role that the sand banks play has been recognised as being disproportionately important. The benthic fauna in the deeply dredged channels is reportedly depauperate, consisting of a few species of coelenterates, amphipods, isopods, polychaetes, annelids and crabs (Hay, 1995). Results show very low abundance (<50 indiv./m²) and low levels of diversity (<6 taxa/m²) of invertebrates in these areas (Angel & Clark, 2008). This is likely due to the periodic dredging operations required to maintain the operating depth of the Port, disturbance caused by ship propellers and the anoxic conditions that are characteristic of much of the deeper sediments in the Harbour (CSIR, 2008).

Recent surveys show that a total of approximately 85 invertebrate species were recorded in the soft-sediment habitats of the Port (Pillay, 2002; Angel & Clark, 2008; CSIR, 2008; CSIR, 2011). Overall, diversity was highest among the polychaetes with 27 taxa recorded, followed by the malacostraca with 18 taxa. Other important classes well represented in the fauna included the gastropods and bivalves. Highest diversity and biomass of invertebrates is undoubtedly attained at the remaining intertidal and shallow subtidal sand-flat habitats that have not been dredged and are comparatively well oxygenated. Newman et al. (2008) recorded an average of 11 taxa per square meter of sandbank, while Pillay (2002) recorded a total of 38 taxa at Little Lagoon (a shallow subtidal flat opposite Bayhead) alone, representing highest diversities in Durban Bay at the time. Densities of organisms at Little Lagoon are high, with an average density of 2 888 indiv./m² recorded by Newman et al. (2008), while Pillay (2002) recorded 3 226 individuals of *Halmyrapseudes cooperi* per square metre and 578 indiv./m² of *Prionospio sexoculata*. Average densities were also high for the intertidal flats, with Centre Bank reportedly supporting an average density of 902 indiv./m² (CSIR, 2008). Intertidal sand-flats are also well recognised for the abundance of Callianassid prawns

(*Callichirus kraussi*) that occur in these areas (Newman, 2008; CSIR, 2011). Macrofauna residing in these sand-flats support important assemblages of fishes and birds (Allan et al. 1999; McInnes et al. 2005; CSIR, 2008).

6.5 Conclusion – Macrofauna

Heterogeneity at both temporal and spatial scales is a widely-accepted characteristic of soft-bottom benthic communities. Varying sediment characteristics, organic content, environmental disturbances, coupled with differing species succession rates creates uneven distributions in soft-bottom macrofaunal communities (Grassle & Sanders, 1973; Grassle, 1989; Pacheco et al. 2010; Alves et al. 2014). Across the sand bank habitats in the Port, spatial variability of the macrofaunal assemblages was indicated by significant differences in abundance, biomass and species richness between particular habitats. Macrofaunal communities of the Mangroves and Centre Bank revealed the greatest dissimilarities from the other sand bank habitats. The significant differences found between the Centre Bank and the Mangrove communities are likely due to combination of differences in sediment grain size, pollutants, amount of organic matter and the nutrient retentive nature that may offset the negative effects on macrofauna by possible pollution.

The differences in the sediment grain size characteristics between areas account for much of the variations in the structure and diversity of the macrobenthic communities. The Mangroves had the highest mud fractions for both intertidal and subtidal sediments (see Sediments Chapter) with anoxic condition observed when sampling, while Centre Bank sediments characteristics were coarser appearing to be cleaner and more aerated. The differences in the granulometric properties of the sediments directly influence the diversity and abundance of macrofauna in the community. However, various biological and environmental factors such as, predation, organic content and disturbance can further influence community structure and distribution. Predation in the Mangroves by fish and birds is likely to be high, while organic loading from the Amanzimnyama and Umhlathuzana/Umbilo canals would further influence assemblage structure. Significant seasonal differences were found between the wet and dry seasons, particularly in the intertidal communities where abundance, biomass and species richness were significantly greater in autumn and winter. Freshwater inflow and the subsequent organic matter and sediment loading from seasonal rainfall may explain the differences observed between seasons. Seasonal variations in microphytobenthos, an important food source (see Chapter 5), and the seasonal migrations of predators is also likely to influencing factors.

Formulating an ecological baseline to serve as a benchmark against the impacts of any disturbance associated with proposed developments is a core focus of this study. The approach that seems to have gained greatest favour in recent years is one known as the test for bioequivalence and was developed by researchers in New Zealand - McDonald & Erickson (1994). In terms of this approach, an area is defined as being bioequivalent if the mean density of a particular organism(s) at an impacted site falls within a predefined percentage of the mean density at the reference site for a defined time interval. Conversely, a site is said to be

impacted or disturbed if the selected variable(s) do not fall within that predefined range. This approach acknowledges the physical nature of the environment to play a role in the recovery of the macrofaunal communities, but it focuses mostly on the biological aspects (such as recruitment success, competition, predation etc.) which can play a major role in the recovery of the communities even when the physical nature of the environment is back to its original structure (Kenny & Rees, 1996).

The level at which two sites can be considered “functionally equivalent” has been subject to much debate in the literature, and is undoubtedly site specific. However, a value of 80% sustained over a period of about three to five years is now fairly widely accepted (McDonald & Erickson, 1994). This means that the species number, abundance and/or biomass of the communities of the proposed sand bank extension should at least reach 80% similarity to that of the existing Centre Bank and must remain at this level for a period of at least three to five years.

There is a readily available source of larval recruitments from the existing adult populations on Centre Bank to colonise the newly created sand bank extension. Given the limited spatial variation in environmental conditions and community composition of Centre Bank, it is expected that colonisation rates of the new sand bank habitat will occur in quick succession after development. To further promote colonisation it is advised that any sediment removed from the Centre Bank during the construction phase be used as surface deposits in creating the sand bank extension. The sediment material will likely contain residual macrofauna species thereby accelerating colonisation rates. The success of macrofaunal colonisation of the new sand bank extension is, however, largely dependent on the similarity in the granulometric properties and physico-chemical properties of the material used to that of the existing Centre Bank. It is important that in order for the successful establishment of the macrofaunal communities that the sediment characteristics of the new extended areas be within the recommended guidelines stipulated in the Sediment section of the CSMP.

7 FISH

7.1 Introduction

The fish fauna of the KwaZulu-Natal (KZN) coast is largely a subset of the Indo Pacific fauna (~74 %), with a number of circumglobal species (~8 %) (Van der Elst, 1988). A significant number of endemic species are also found off the KZN coast (~16 %), but that are mostly extensions of species that inhabit cooler temperate regions off South Africa's east coast. Van der Elst (1988) estimates that there are at least 1 192 species belonging to 150 families present in the region. A large number of these species are tropical reef associated (although the soft sediment habitats may well be essential for certain life history stages), whilst many others occur in the pelagic realm, or in deeper shelf waters.

The fish fauna in the Port was considered to be very diverse in the 1950s when a total of 186 species were recorded by Day & Morgan (1956). The most-common fish species recorded during this time were *Terapon jarbua*, *Mugil cephalus*, *Liza dumerili*, *Ambassis dussumieri* and *Leiognathus equulus*. Many of these species are recognised as being dependent on estuaries, and the Bay was found to be an important nursery area for these fishes. The two recent surveys of fish in the Port conducted by Angel & Clark (2008) and Newman et al. (2008) recorded far fewer species, at 29 and 34 species respectively. Despite this, they still confirmed the findings of previous studies, in that the majority of fishes in the Bay were estuary dependent (Day & Morgan, 1956; Cyrus & Forbes, 1996; Forbes et al. 1996). The survey undertaken by Angel & Clark (2008) yielded a total of 696 fish from 19 gill and seine net samples. The most common species in terms of abundance were the Ambassids (29.9%), mostly comprised of bald glassies (*Ambassis dussumieri*), Leiognathids (10.5%), mostly the common ponyfish (*Leiognathus equulus*), and five species of Mugilids (8.2%) consisting mainly of groovy mullet (*Liza dumerili*). These three families contributed nearly half the fish sampled (48%). The majority of species caught were similar to those recorded by Hay et al. (1995), Day & Morgan (1956), Whitfield (1998) and Newman et al. (2008). Most of the species are either listed as 'Least Concern' on the IUCN Red List (2013) or have not been assessed.

Forbes & Demetriades (2003) highlighted the importance of the shallow sand bank habitats in the Port as a nursery area for fish, and highlighted Little Lagoon as being particularly important in this respect. At least 36 species of fishes have been recorded in Little Lagoon, the most abundant species being *Ambassis dussumieri* (>80%). Other notable species that occurred at considerably lower numbers (<5%), were *Thryssa vitirostris*, *Gerres filamentosus*, *G. longirostris*, *Leiognathus equulus*, *Liza dumerili* and *Sillago sihama*. The majority of these species are estuary-dependent, and it is well recognised that Little Lagoon provides a valuable nursery habitat for many juvenile fishes (Cyrus & Forbes, 1996; Forbes & Demetriades, 2003). CSIR (2008) reiterated the importance of the shallow sand bank habitats nursery function and suggested that habitat structure may be more important than the prevailing physico-chemical conditions. However, their study was limited to a single sampling season and did not assess

temporal variability in the fish community in the Port. This study is particularly informative in this respect, in that it covers two seasonal cycles.



Figure 7.1: Fish sampling - deploying seine net (top), Malabar rockcod - *Epinephelus malabaricus* (bottom left) and yellow-banded goatfish – *Upeneus vittatus* (bottom right).

7.2 Sampling Methodology

Experimental seine netting was conducted using a beach-seine net, 30 m long, 2 m deep, with a stretched mesh size of 12 mm at 24 sites along the margins of the main sand bank areas in

the Port (Figure 7.2). The net was deployed from a small rowing dinghy 30-50 m from the shore during daylight hours. Samples at all 24 sites were collected on four occasions during the year (autumn, winter, spring, summer). All fish collected in the net at each site were identified, enumerated, weighed and measured, and if possible, returned to the sea alive.



Figure 7.2: Location of Fish Sampling Sites (Google Earth 2015).

Both univariate and multivariate statistical analyses were used to investigate spatial patterns in fish community structure between the five apriori defined sampling areas (Island View: SN24, Centre Bank: SN 1-10, Northern Bank: SN 19-23, Little Lagoon: SN 11-14 and Mangroves: SN 15-18). All univariate analyses were performed using STATISTICA. A factorial Analysis of Variance (ANOVA) was used to test the differences in the number of species, total abundance and biomass between sand bank areas and season. All data were tested for normality and equal variance using the Kolmogorov-Smirnov goodness of fit test and Levene's equal variance test respectively. Data were log transformed if either of these criteria were not met. Multivariate analysis of the fish data was conducted in accordance with the analyses describe in the previous chapter (See Macrofauna, Section 6).

All species caught were also classified using an adaption of Whitfield's (1998) estuarine fish classification system. Four broad categories were used: marine, estuarine dependent, estuarine resident and freshwater species.

7.3 Results and Analysis of Data

7.3.1 Catch Composition

A total of 1 424 869 fish representing 62 species were captured in the 192 hauls made (Table 7.1). Overall, the catch was dominated by bald glassies *Ambassis dussumieri* that contributed 96% numerically and 58% by weight to the total catch. Other very abundant species in samples were thorny anchovy *Stolephorus holodon* (1.46% by number, 2.17% by mass), pony fish *Leiognathus equulus* (0.93% by number, 1.99% by mass), and groovy mullet *Liza dumerilii* (0.20% by number, 5.37% by mass). Several important angling or food fish species contributed significantly to the total mass of fish sampled, these included spotted grunter - *Pomadasys commersonnii* (1.07%), needlescaled queenfish - *Scomberoides tol* (2.22%), freshwater mullet - *Myxus capensis* (1.07%) and pickhandle barracuda - *Sphyraena jello* (13.79%).

Table 7.1: Total catch made in 192 experimental seine hauls conducted in the Port over the period November 2014- August 2016.

Species name	Common name	Number	Mass (g)	% Number	% Mass
<i>Ambassis dussumieri</i>	Bald Glassy	1373345	1318023	96.36	58.05
<i>Stolephorus holodon</i>	Thorny anchovy	20788	49301	1.46	2.17
<i>Leiognathus equulus</i>	Pony-Slimy	13214	45080	0.93	1.99
<i>Liza dumerilii</i>	Groovy mullet	2878	121915	0.20	5.37
<i>Hilsa kelee</i>	Razor belly	2165	5922	0.15	0.26
<i>Sillago sihama</i>	Silver sillago	1616	11118	0.11	0.49
<i>Pomadasys commersonnii</i>	Spotted grunter	1447	24308	0.10	1.07
<i>Sardinella gibbosa</i>	Gold-striped sardine	1069	4926	0.07	0.22
<i>Gerres filamentosus</i>	Threadfin pursemouth	904	13815	0.06	0.61
<i>Scomberoides tol</i>	Needlescaled queenfish	876	50396	0.06	2.22
<i>Crenidens crenidens</i>	White karanteen	821	12624	0.06	0.56
<i>Gerres longirostris</i>	Smallscaled pursemouth	655	10609	0.05	0.47
<i>Argyrosomus japonicus</i>	Dusky kob	621	6143	0.04	0.27
<i>Rhabdosargus sarba</i>	Natal stumpnose	608	8295	0.04	0.37
<i>Myxus capensis</i>	Freshwater mullet	520	24202	0.04	1.07
<i>Yongeichthys nebulosus</i>	Shadow goby	400	4537	0.03	0.20
<i>Thryssa vitrirostris</i>	Orange mouth glass nose	382	1882	0.03	0.08
<i>Pseudorhombus arsius</i>	Large tooth Flounder	248	8603	0.02	0.38
<i>Platycephalus indicus</i>	Bartailed flathead	242	15683	0.02	0.69
<i>Tylosaurus crocodilus</i>	Crocodile needle fish	234	22533	0.02	0.99

Species name	Common name	Number	Mass (g)	% Number	% Mass
<i>Gerres methueni</i>	Evenfin pursemouth	220	10324	0.02	0.45
<i>Pomadasys olivaceum</i>	Piggy grunter	214	363	0.02	0.02
<i>Favonigobius melanobranchus</i>	Black throat goby F	181	83	0.013	0.004
<i>Valamugil robustus</i>	Robust mullet	141	2054	0.010	0.090
<i>Sphyræna jello</i>	Pickhandle Baracuda	126	313162	0.009	13.79
<i>Arothron immaculatus</i>	Black edged Blaasop	122	6086	0.009	0.268
<i>Diplodus capensis</i>	Blacktail	117	2740	0.008	0.121
<i>Terapon jarbua</i>	Thornfish	100	1590	0.007	0.070
<i>Caranx heberi</i>	Blacktipped kingfish	98	8166	0.007	0.360
<i>Acanthopagrus berda</i>	River bream	92	23393	0.006	1.030
<i>Amblyrhynchotes honckenii</i>	Evileye blaasop	69	8200	0.005	0.361
<i>Pomadasys kaakan</i>	Cock grunter	61	2024	0.004	0.089
<i>Epinephelus malabaricus</i>	Malabar rockcod	54	2819	0.004	0.124
<i>Herklotsichthy quadramaculata</i>	Blueline herring	51	51	0.004	0.002
<i>Himantura gerrardi</i>	Sharpnose stingray	28	87005	0.002	3.832
<i>Monodactylus argenteus</i>	Moony	23	73	0.002	0.003
<i>Pomatomus saltatrix</i>	Elf (Shad)	19	1542	0.001	0.068
<i>Himantura uarnak</i>	Honeycomb ray	16	31811	0.001	1.401
<i>Caranx papuensis</i>	Brassy kingfish	11	1	0.001	0.000
<i>Heteromycteris capensis</i>	Cape sole	10	7	0.001	0.000
<i>Liza richardsonii</i>	Southern mullet	9	442	0.001	0.019
<i>Upeneus vittatus</i>	Yellow-banded goatfish	9	0	0.001	0.000
<i>Secutor ruconius</i>	Pugnose soapy	8	533	0.001	0.023
<i>Arothron hispidus</i>	Whitespotted blaasop	7	26	0.000	0.001
<i>Psammogobius knysnaensis</i>	Knysna goby	6	2	0.000	0.000
<i>Favonigobius reichei</i>	Tropical sand goby	5	5	0.000	0.000
<i>Glossogobius callidus</i>	River goby	5	67	0.000	0.003
<i>Liza macrolepis</i>	Large scale mullet	5	445	0.000	0.020
<i>Liza tricuspidens</i>	Stripped mullet	5	1484	0.000	0.065
<i>Lactoria cornuta</i>	Longhorn cowfish	4	92	0.000	0.004
<i>Lutjanus fulviflamma</i>	Dory snapper	4	8	0.000	0.000
<i>Trichiurus lepturus</i>	Largehead hairtail (Walla walla)	3	417	0.000	0.018

Species name	Common name	Number	Mass (g)	% Number	% Mass
<i>Lithognathus mormyrus</i>	Sand steenbras	3	27	0.000	0.001
<i>Elops machnata</i>	Springer	2	3236	0.000	0.143
<i>Lagocephalus inermis</i>	Moontailed blaasop	1	113	0.000	0.005
<i>Leiognathus elongatus</i>	Elongate slimy	1	1	0.000	0.000
<i>Liza luciae</i>	St Lucia mullet	1	4	0.000	0.000
<i>Rhinobaous annulatus</i>	Sandshark	1	356	0.000	0.016
<i>Synodus sp.</i>	Lizard fish	1	1	0.000	0.000
<i>Tetrosomus concatenatus</i>	Triangular boxfish	1	1087	0.000	0.048
<i>Valamugil buechanani</i>	Bluefin Mullet	1	510	0.000	0.022
<i>Scomberoides commersonnianus</i>	Largemouth queenfish	1	174	0.000	0.008
Total		1 424 869	2 270 437	100	100

7.3.2 Estuarine Association

Estuarine dependent species dominated catches throughout the estuary and comprised >99% of the catch in all areas except for Island View (90%). This was largely a result of the very abundant estuarine resident *Ambassis dussumieri* that was caught in large numbers at nearly all sites throughout the estuary (except the marine dominated Island View site). To investigate estuarine association of the remaining species in the ichthyofaunal community, the numerical composition of estuarine dependence categories is graphed in Figure 7.3(after Whitfield, 1998). Estuarine resident and estuarine dependent species still dominated in the upper reaches of the estuary comprising 97% of the catch in the Mangroves and 90% at Little Lagoon. Estuarine dependent and resident species also dominated at the Centre Bank sites (91%) and estuarine dependent species (75%) dominated catches in the Island View terminal. There were no estuarine resident species caught at the latter site. Approximately 60% of the catch in the Northern Bank area was comprised of estuarine dependent or resident species. Estuarine dependent species such as mullet, spotted grunter, pony fish, purse mouths and Natal stumpnose were common in Northern Bank catches, but the reduced proportion of estuarine dependence was due to relatively large catches of marine migrant species at this, such as needlescaled queenfish and gold striped sardine (Figure 7.4).

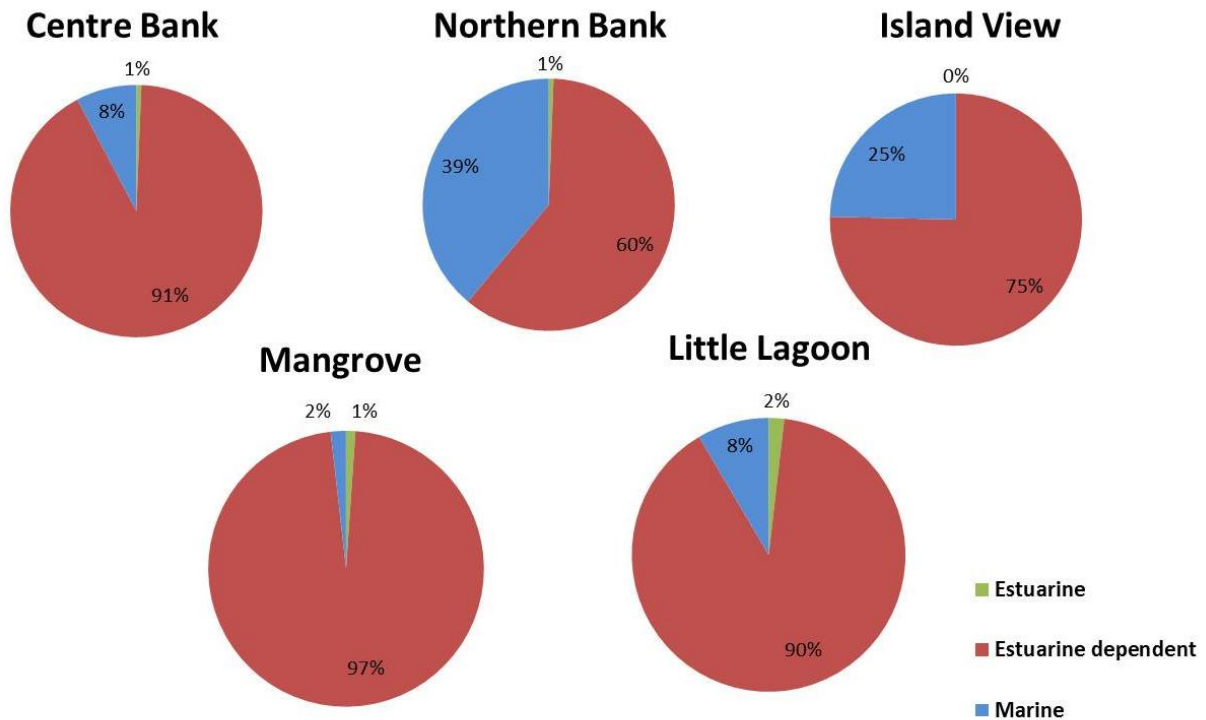


Figure 7.3: Proportion of fish by estuarine dependence category in seine net samples collected within different areas of sand bank in Durban Port (after Whitfield 1998) Note: Excludes *Ambassis dussumieri* an estuarine resident species).

7.3.3 Spatial and Seasonal Patterns

Diversity of fish catches averaged over all surveys showed a clear spatial pattern with the most diverse catches being taken at the Little Lagoon and Mangrove sites (around 20 species on average), slightly fewer species were caught at Centre Bank and Northern Bank sites and the least diverse catches were made at the Island View site (Figure 7.5). Sites with the most diverse catches (≥ 25 species) were in the Little Lagoon (sites 12 and 13) and the most upstream sites 15-18 in the Mangroves.

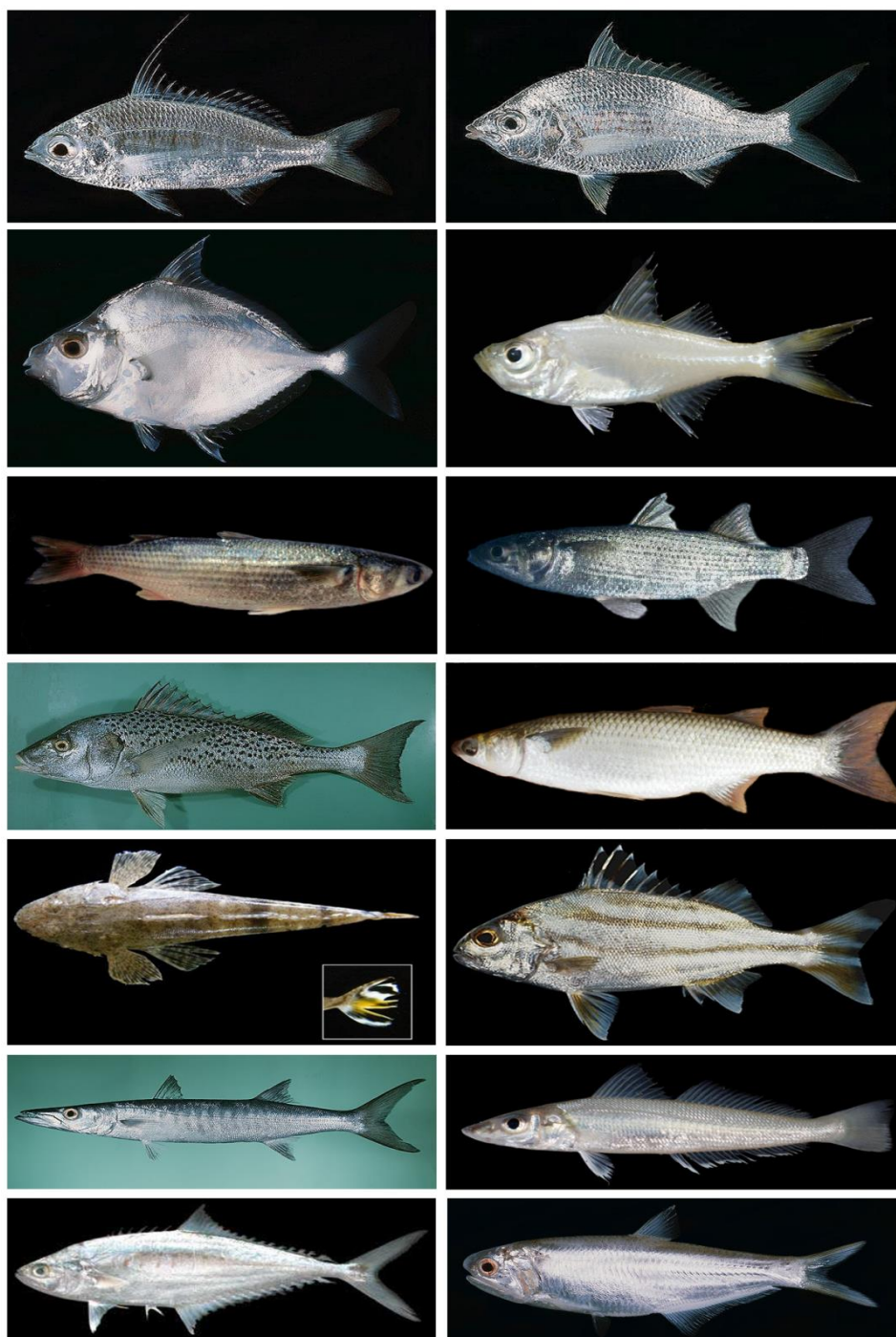


Figure 7.4: The most common fish species found in Durban Harbour during various surveys. From left to right and top to bottom species are as follows: threadfin pursemouth, smallscale pursemouth, slimy ponyfish, bald glassy, flathead mullet, groovy mullet, spotted grunter, freshwater mullet, bartailed flathead, thornfish, pickhandled barracuda, silver sillago, needle-scaled queenfish and orange-mouth glassnose. Photo credits: FishBase, Zip Code Zoo, Bold Systems, Mark Brown, Pay Zania, Fish Asia

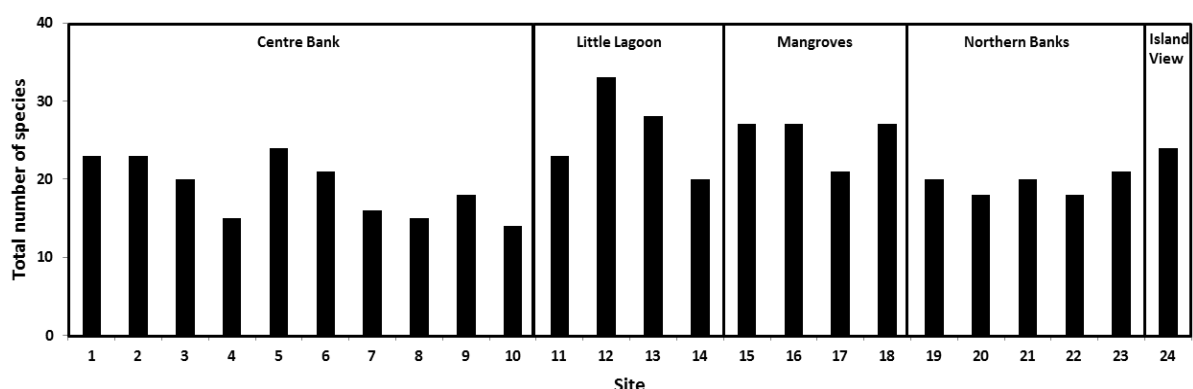


Figure 7.5: Total number of species of fishes recorded at each site on sandbanks in the Port.

Seasonal and spatial patterns are evident in the abundance of some of the more common and more widely distributed species collected (Figure 7.6). The two estuarine dependent species spotted grunter *P. commersonnii* and pony *L. equulus*, were noticeably more abundant at the Little Lagoon and the mangrove areas, particularly during the drier winter months. This probably reflects a contraction of the river–estuary interface during these dry periods and the fact that these species prefer reduced salinities in the upper parts of the estuary. Both these species were rare at the Centre Bank and the Island View sand bank sites. The groovy mullet *L. dumerilii* is also an estuarine dependent species, but was caught in similar quantities across most areas in all seasons, revealing a greater tolerance of the marine dominated lower estuary reaches. The needlescale queenfish (*S. to*) is classified as a marine straggler and was also caught in similar quantities across all areas except for a peak in spring catches at Island View.

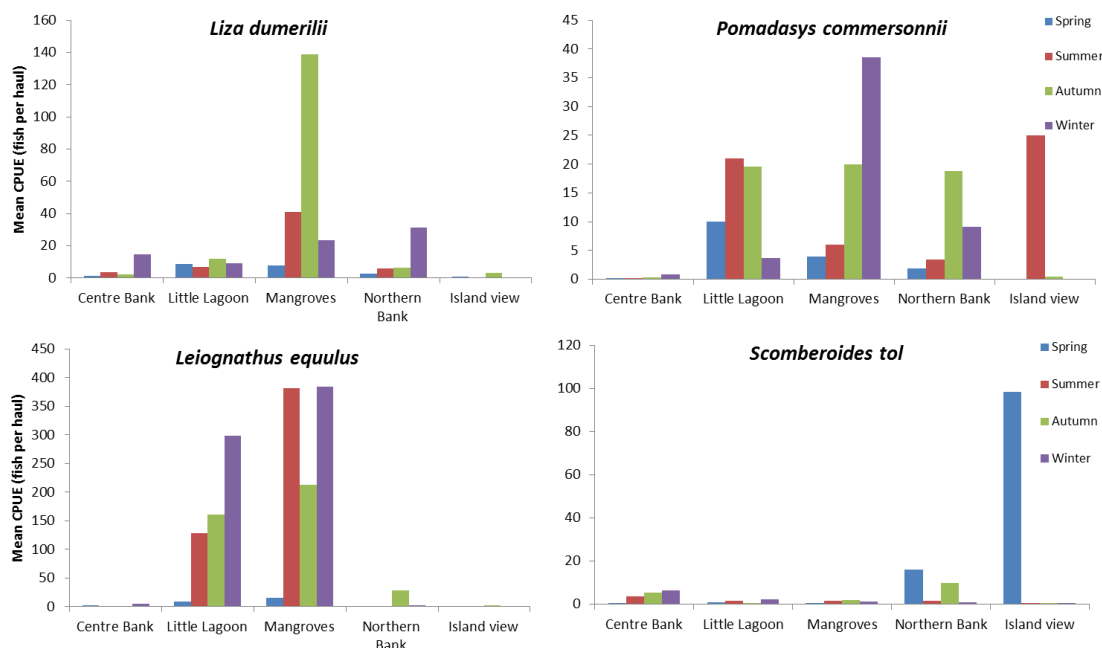


Figure 7.6: Mean CPUE of common fish species at sites within the five sand bank areas during each of the four seasonal surveys conducted over the period November 2014- August 2016 in the Port.

7.3.4 Univariate Analysis of Seasonal and Spatial Patterns in Fish Communities

7.3.4.1 Species richness

Comparison of the number of fish species caught in different areas during the four season surveys using a factorial ANOVA revealed significant “Area” ($F_{4,192} = 12.5$; $P < 0.001$) and “Seasonal” effects ($F_{3,192} = 2.8$, $P < 0.05$), and an insignificant interactive between Area x Season ($F_{12,192} = 0.8$, $P > 0.05$). Average species richness was highest at Little Lagoon and was most pronounced during the summer season (% confidence intervals of the mean, non-overlapping error bars indicate significant differences). The number of species recorded at Centre Bank and Little Lagoon in winter was significantly less than in summer. Species count across all other seasons within each site did not differ significantly. There were, however, differences in species counts between areas during different seasons e.g. average species richness at Little Lagoon and Mangrove sites during summer, autumn and spring was not significantly greater than that recorded at Centre Bank sites during the same seasons, but was greater than that recorded at the Centre Bank during the winter sampling. An alternative approach is to combine the seasonal data and investigate spatial patterns using a one way ANOVA. This analysis revealed a significant area effect ($F_{4,192} = 11.6$; $P < 0.001$) with Little Lagoon and Mangrove sites having a significantly greater average species richness than other areas that were not significantly different from each other (% confidence intervals of the mean, non-overlapping error bars indicate significant differences).

7.3.4.2 Abundance

The factorial ANOVA results of average fish abundance at the five areas during all seasons showed significant “Area” ($F_{4, 192} = 16.8$, $P < 0.001$), “Season” ($F_{4, 192} = 10.4$, $P < 0.001$) and interactive effects ($F_{12, 192} = 2.2$, $P < 0.001$). With a significant interactive effect, the individual area and season effects (although also significant) are not consistent and normally do not warrant interpretation (e.g. the area differences are variable depending on the season). What is clear from the plot of mean abundance values and associated confidence intervals, is that the autumn and winter fish abundance estimates at the Little Lagoon, Mangroves and Northern Bank sites (and in the case of the Little Lagoon, also summer) were in most cases significantly greater than that recorded at the Centre Bank or Island View sites (that were not significantly different from each other) (Figure 7.8). There was a significant difference between the Mangroves and Centre Bank, while all other areas showed similar patterns in abundance.

Averaging fish abundance estimates across all seasons does reveal significant spatial differences ($F_{4, 192} = 10.6$, $P < 0.001$), with the highest estimates found at the Little Lagoon and Mangrove sites being slightly greater (but not statistically different) from that recorded for the Northern Bank sites (Figure 7.8). The Mangroves and Little Lagoon abundance estimates were significantly greater than Centre Bank and Island View. Northern Bank estimates, however, was also significantly greater than Centre Bank.

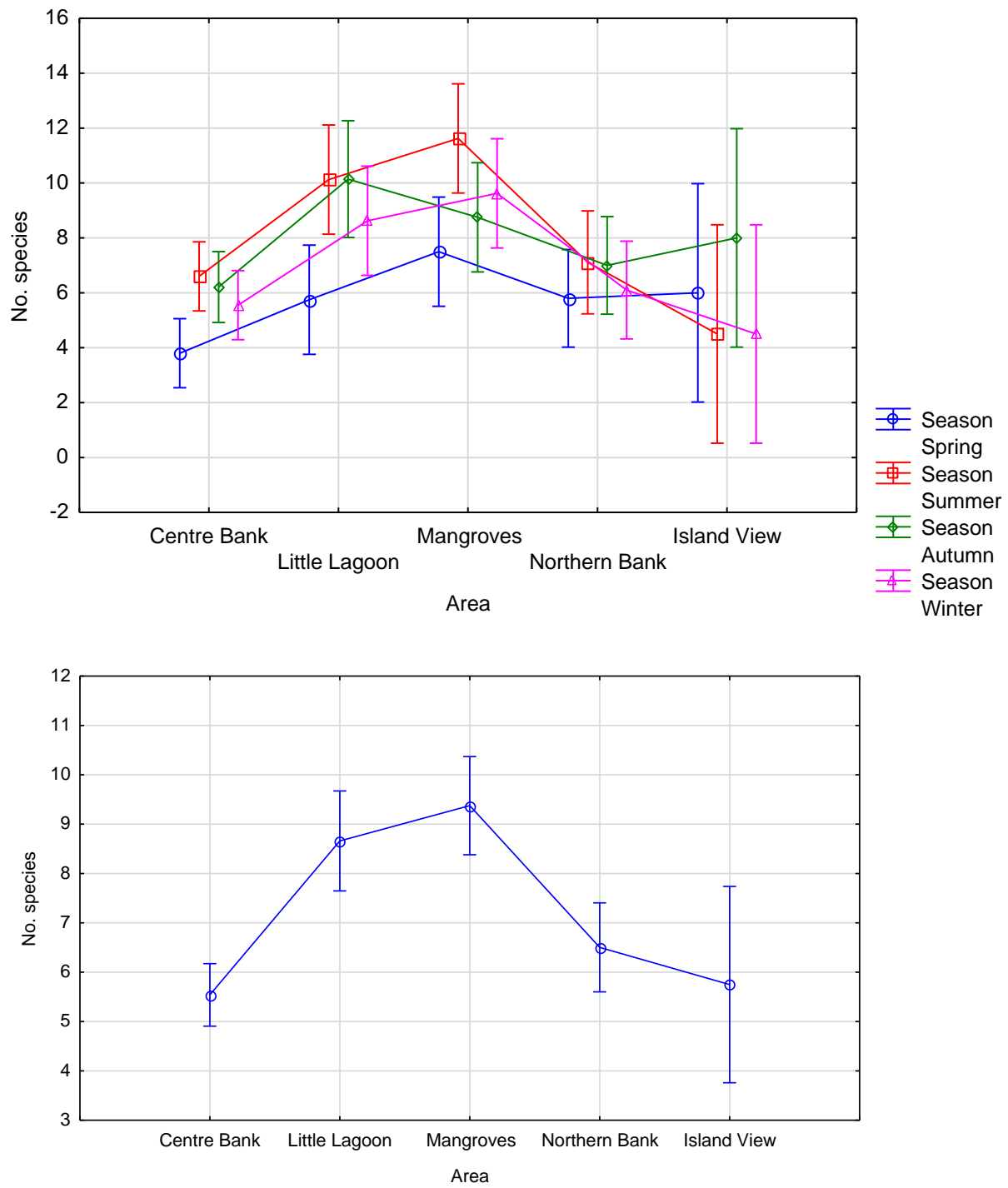


Figure 7.7: Comparison of the average number of species caught in hauls at the five apriori defined sandbank areas within the Port for each season surveys (top) and with the seasonal data combined (bottom). (Error bars show 95% confidence intervals of the mean, non-overlapping error bars indicate significant differences).

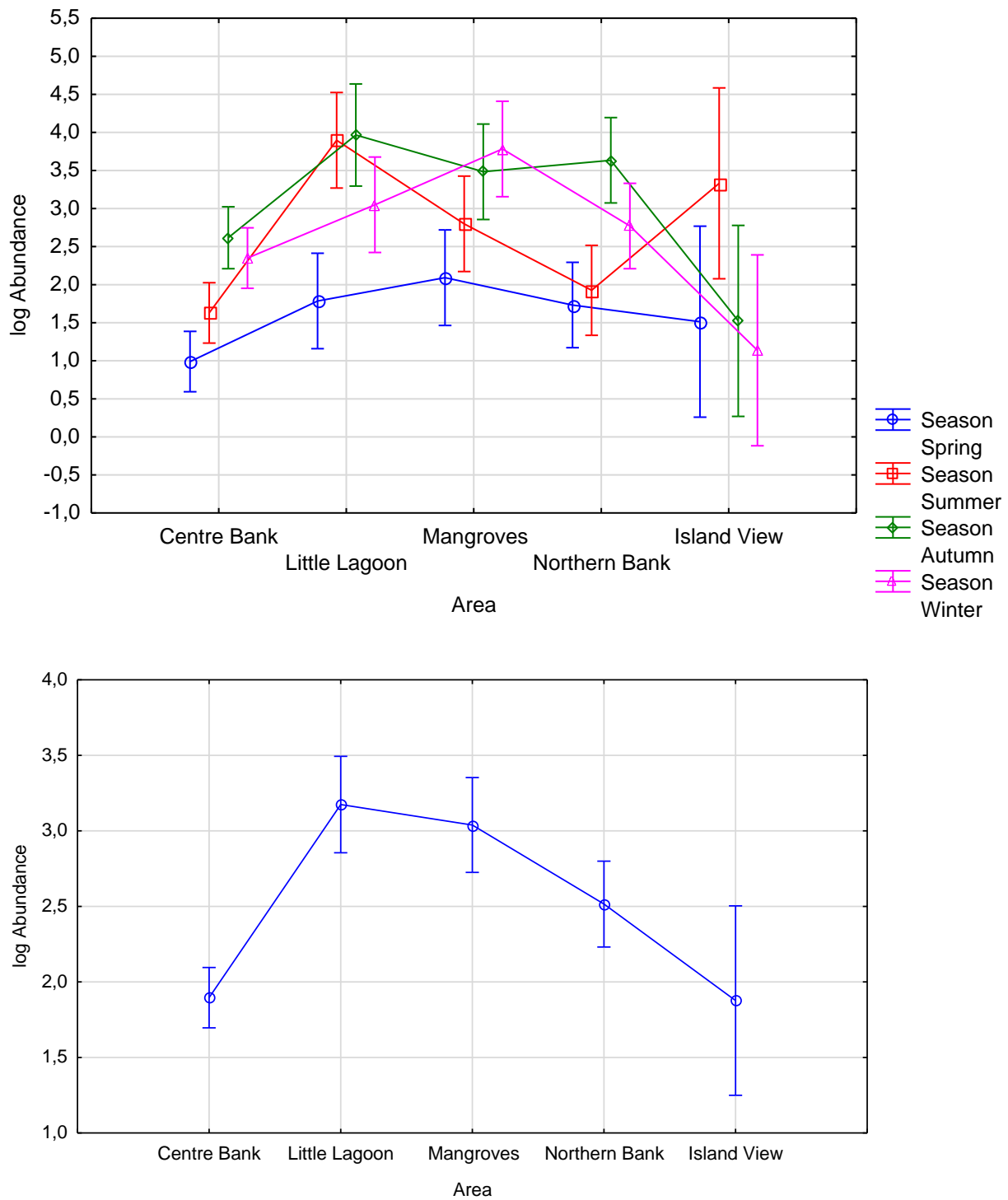


Figure 7.8: Comparison of the average fish abundance at the five a priori defined sandbank areas within the Port for each season (top) and with the seasonal data combined (bottom). (Error bars show 95% confidence intervals of the mean, non-overlapping error bars indicate significant differences)

7.3.4.3 Biomass

The seasonal and spatial pattern of fish biomass at the different sand banks followed a similar trend to that seen for abundance, with the exception of Island View where the catches of a few large individuals elevated average biomass estimates (Figure 7.9). A factorial ANOVA detected a significant “Area” ($F_{4,192} = 12.1$; $P < 0.001$) and “Seasonal” ($F_{3,192} = 3.3$; $P < 0.001$) effect but an insignificant interactive between Area x Season ($F_{12,192} = 1.3$; $P > 0.05$). The insignificant interactive describes limited variation in biomass estimates between seasons within each site. Significant seasonal differences were however, found between sites. The average Centre Bank autumn and summer biomass estimates were significantly lower than The Mangroves Little Lagoon. Biomass estimates were also significantly greater at the Northern Banks in autumn than Centre Bank. Combining across seasons show clearer and significant ($F_{4,192} = 10.9$; $P < 0.001$), spatial differences in average fish biomass with Little Lagoon, Mangrove and Northern Bank areas having significantly higher average fish biomass than the Centre Bank (Figure 7.9).

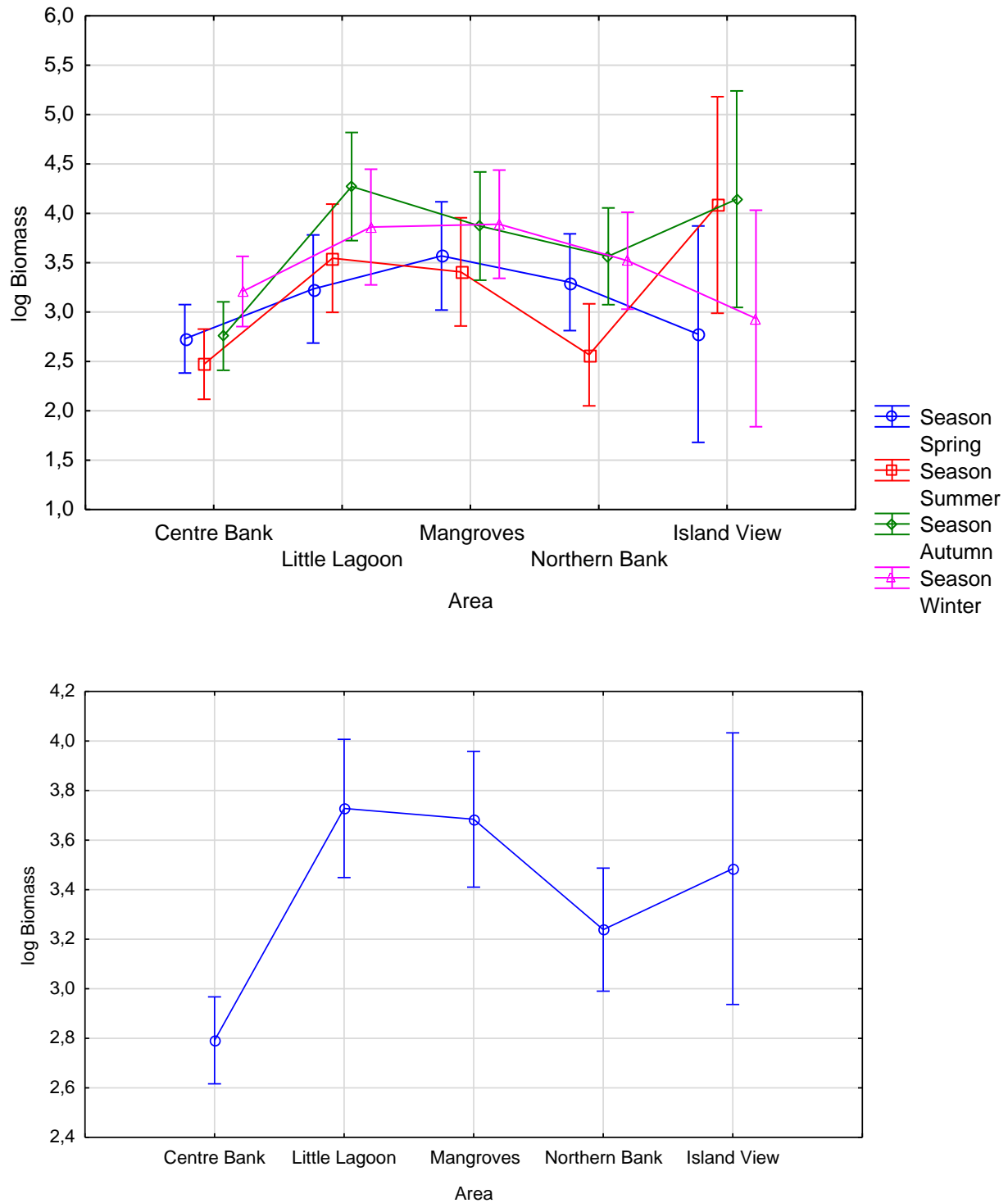


Figure 7.9: Comparison of the average fish biomass at the five a priori defined sandbank areas within the Port for each season (top) and with the seasonal data combined (bottom). (Error bars show 95% confidence intervals of the mean, non-overlapping error bars indicate significant differences)

7.3.4.4 Multivariate Analysis of Spatial Patterns

Cluster analysis identified four significant groupings of sites, which did not correspond exactly with the a priori defined areas within the Port. One significant grouping included the majority of the Centre Bank sites and a single Northern Bank site (site 23, entrance to Point Yacht Club), whilst the most upstream sites located at Little Lagoon and Mangrove formed another significant grouping. The remaining Northern Bank sites grouped together with Centre Bank Site 1, located in the sand bank removal area, and the marine dominated Island View site. The Northern Bank Site 21 and Mangrove site 17 formed a separate grouping. The spatial pattern is more easily interpreted in the MDS plot where a clear transition is evident from the marine dominated Island View site near the Port entrance through the Northern Bank and Centre Bank sites, to the more freshwater influenced Little Lagoon and Mangrove sites on the upper left of the plot (Figure 7.10).

A one way ANOSIM test indicated significant differences between sites (Global $R = 0.579$, $P < 0.01$), with pair wise testing indicating significant differences in the fish communities sampled at the Centre Bank sites and the Little Lagoon sites (Global $R = 0.613$, $P < 0.05$) and the Mangrove sites (Global $R = 0.858$, $P < 0.05$). No significant differences in fish communities were detected between other sites, although in the case of the Island View site this was due insufficient sample size for sufficient permutations used in the ANOSIM procedure (only 1 site, a constraint of the very limited sand bank area). The principal species contributing to the dissimilarities were lower abundances of estuarine dependent and resident species such as, *Ambassis dussumieri*, *Leiognathus equulus*, *Thryssa vitrirostris*, *Rhabdosargus sarba*, *Myxus capensis*, *Acanthopagrus berda* and *Pomadasys commersonnii* at the Centre Bank sites compared to the Little Lagoon and Mangrove sites (Table 7.2 and Table 7.3). Pony fish, *Leiognathus equulus* and spotted grunter *Pomadasys commersonnii*, contributed most to the dissimilarity between Centre Bank and Little Lagoon having relatively high dissimilarity: Standard Deviation Ratios. The principal fish species contributing most towards the dissimilarity between Centre Bank and Mangrove samples was the river bream *Acanthopagrus berda*. Overall, Pony fish, *Leiognathus equulus* appears to be a good indicator species for the upper regions of the Port having relatively high dissimilarity: Standard Deviation Ratio in both cases.

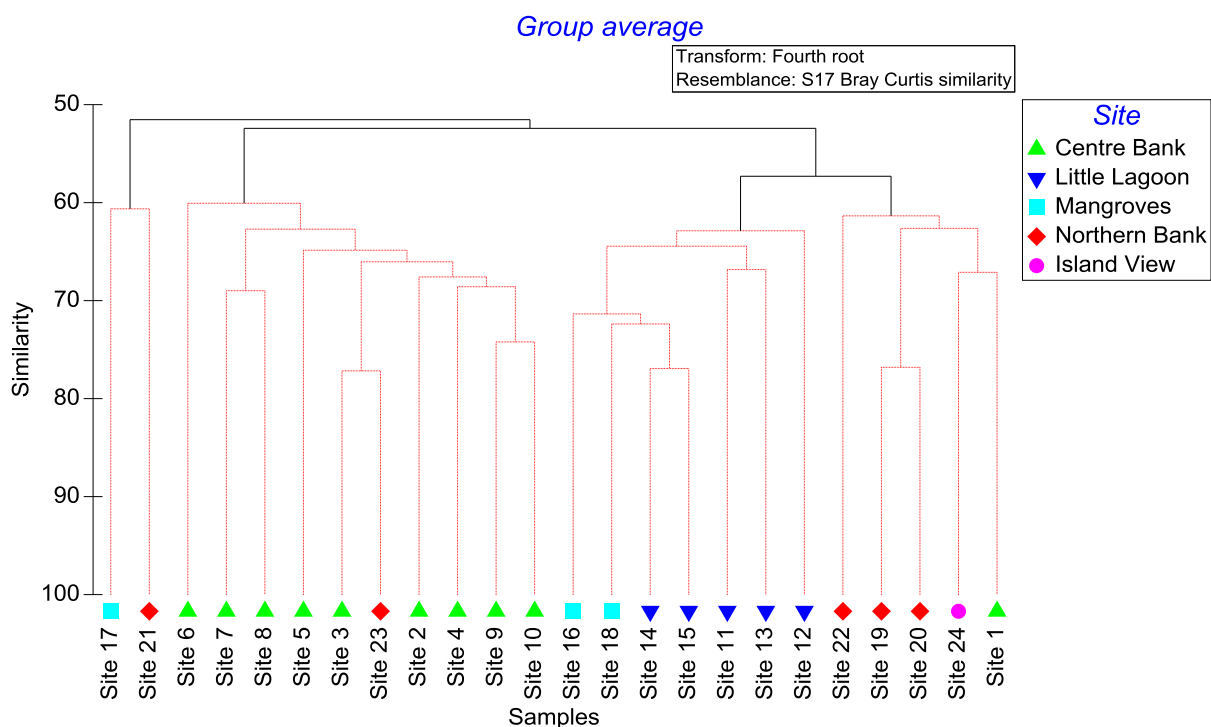
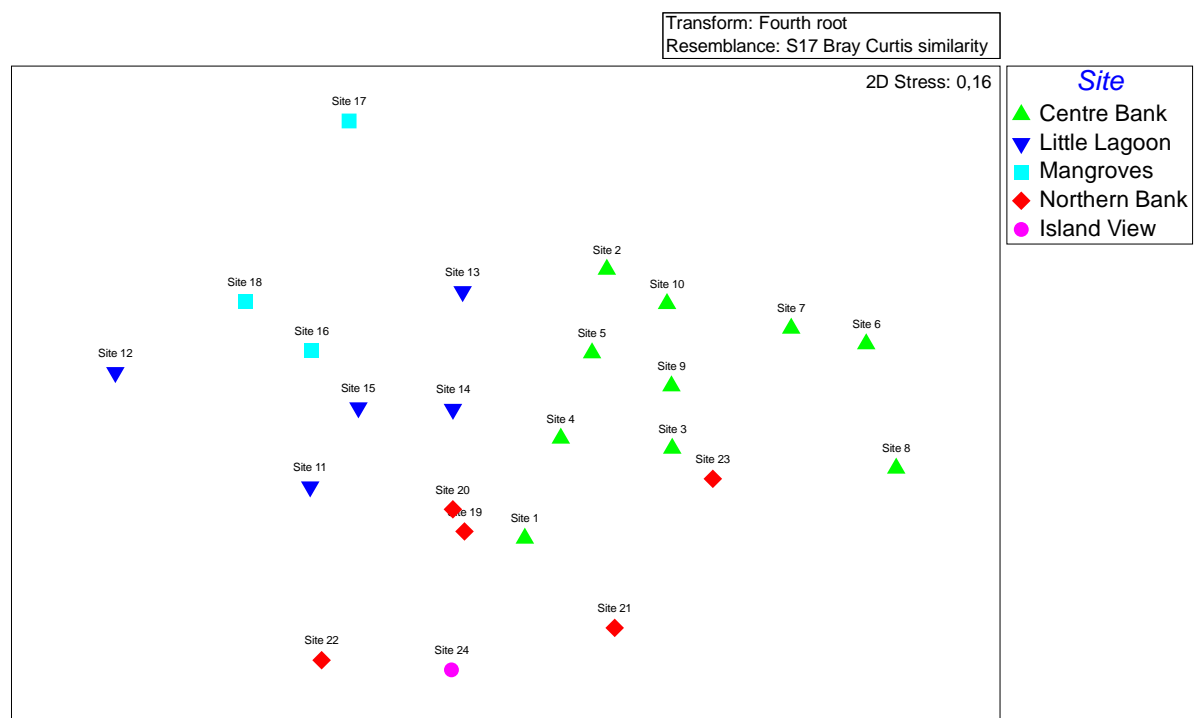


Figure 7.10: Multi dimensional Scaling plot and dendrogram showing similarities in fish communities between different sandbank areas. The average catch per species per sampling site was fourth root transformed prior to construction of the Bray-Curtis similarity matrix

Table 7.2: Principal fish species contributing towards the dissimilarity between Centre Bank and Little Lagoon samples

Species	Av. Abund Centre Bank	Av. Abund Little Lagoon	Av. Diss	Diss/SD	Contrib %	Cum. %
<i>Ambassis dussumieri</i>	5.21	9.98	7.12	1.58	15.34	15.34
<i>Leiognathus equulus</i>	0.88	3.23	3.33	2.26	7.18	22.52
<i>Stolephorus holodon</i>	1.89	3.01	2.1	1.8	4.53	27.06
<i>Pomadasys commersonnii</i>	0.57	1.9	1.92	2.43	4.14	31.2
<i>Hilsa kelee</i>	0.21	1.34	1.63	1.08	3.51	34.71
<i>Rhabdosargus sarba</i>	0.51	1.49	1.52	1.63	3.27	37.99
<i>Thryssa vitirostris</i>	0	1.13	1.49	1.67	3.22	41.21
<i>Yongeichthys nebulosus</i>	0.06	1.1	1.47	1.83	3.16	44.36

Table 7.3: Principal fish species contributing towards the dissimilarity between Centre Bank and Mangrove samples.

Species	Av. abund Centre Bank	Av. abund Mangroves	Av. Diss	Diss/SD	Contrib%	Cum. %
<i>Ambassis dussumieri</i>	5.21	8.26	5.21	1.5	9.98	9.98
<i>Stolephorus holodon</i>	1.89	3.44	4.09	2.2	7.82	17.79
<i>Leiognathus equulus</i>	0.88	3.42	3.62	1.87	6.93	24.73
<i>Yongeichthys nebulosus</i>	0.06	1.73	2.56	2.66	4.89	29.62
<i>Valamugil robustus</i>	0	1.33	2.08	1.89	3.97	33.59
<i>Myxus capensis</i>	0.39	1.57	1.96	1.31	3.74	37.33
<i>Liza dumerilii</i>	1.43	2.72	1.95	2.12	3.73	41.06
<i>Acanthopagrus berda</i>	0	1.14	1.7	4.82	3.26	44.32
<i>Pomadasys commersonnii</i>	0.57	1.73	1.68	1.73	3.21	47.52

7.4 Comparison with Data from Previous Studies

The dominant species in our surveys were very similar to those recorded in earlier surveys e.g. Day & Morgan (1956), Cyrus & Forbes (1996), Forbes et al. (1996), Forbes & Demetriades (2003), Angel & Clark (2008) and CSIR (2008). The total species count is about 25% of the total of 246 species recorded in all previous surveys as reported in the inventory compiled by Beck et al. (2001). However, only about half the species recorded in this inventory are typical of KZN estuarine systems, with the remainder been marine vagrants Beck et al. (2001). These authors remarked that the relatively large area and diversity of habitat found within Durban harbour contributed to the relatively high diversity. The most common species in terms of abundance in recent studies have been the Ambassidae. This group of fish seems to have increased in abundance in the Port over the last 20 years, given that it only contributed 2% of the total catch in 1993/1994 (Graham 1994), increased substantially to 86% in 2001/2002 and 83% in 2007 (CSIR, 2008) and now 96% in this study. Other notable species highlighted in this study and previously, based on their contribution to fish abundance, included *Leiognathus equulus*, *Thryssa vitirostris*, *Gerres filamentosus*, *Liza dumerili*, *Sillago sihama* and *Pomadasys commersonnii*. The majority of these species are estuary dependent and have been found utilizing the sandbank habitats in the Port (Day & Morgan, 1956; Cyrus & Forbes, 1996; Forbes et al. 1996; Newman et al. 2008). CSIR (2008) reported that the level of estuarine dependence in the catch composition was greatest in the regions closest to freshwater input (80-95 %) which corresponds with the main finding of this study. Their study did, however, identify lower proportion of marine species at the Northern Banks (5-10%), compared to that recorded in the present study (39%). Notable differences in the proportions of marine species are most likely due to the limitations of their study which included only two sampling sites and a single sampling session. Consequently, the study could not accurately account for the temporal variability in the fish distributions in the Port. Although the study by CSIR (2008) was restricted to a single sampling session, their data did indicate spatial distributions of fish species and abundance between the different sand bank habitats in the Port. Their findings showed that Little Lagoon (20 species), the Mangrove areas (14 species) and Northern Banks (13 species) supported higher abundances and number of species than Centre Bank. High species richness at Little Lagoon was also highlighted by Graham (1994) and Forbes & Demetriades (2003); however, both studies focused on Little Lagoon only, and did not sample other sand bank habitats in the Port.

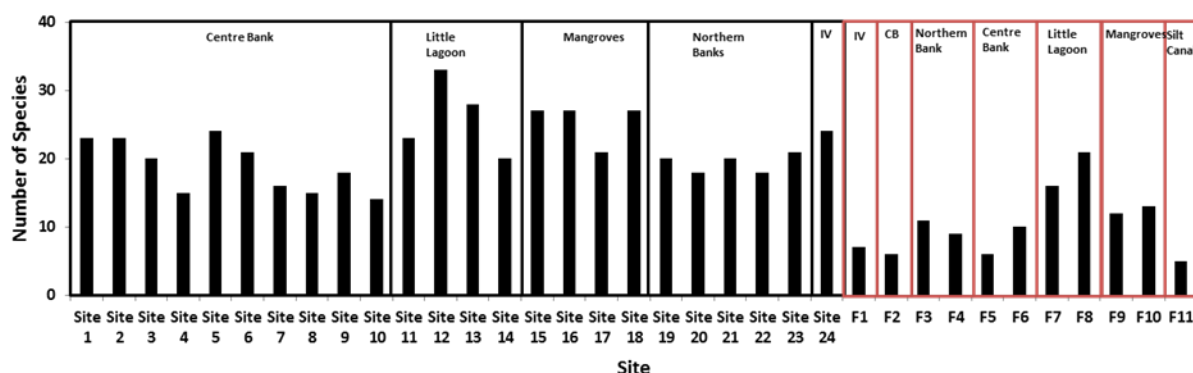


Figure 7.11 Total number of species of fishes recorded at each site on sandbanks in the Port 2014-2016 (this study) and 2007 (CSIR, 2008) indicated in red.

Despite the limited number of studies investigating the spatial and seasonal trends of fish assemblages in the Port, comparisons of the dominant species (*Liza dumerilii*, *Gerres* spp. and *Leiognathus equulus*) offers some insight into the differences between Little Lagoon and Centre Bank. Although limited to a single year, Graham (1994) conducted seasonal survey at Centre Bank and Little Lagoon, while CSIR (2008) sampled both areas in spring 2007. Despite the differences in sampling gear - Graham (1994) and (CSIR, 2008) both used a larger (70 m) seine net than the one used in this study - preliminary seasonal and spatial comparisons can be made (Figure 7.11). All studies reported lower abundances for all species at Centre Bank compared to Little Lagoon, except for *Liza dumerilii* which were abundant in both areas. Graham (1994) recorded exceptionally high abundances of *Leiognathus equulus* in Little Lagoon, corresponding with the findings of this study. There were indications of seasonal variation, with lower abundances in spring; however, limited seasonal sampling in the previous studies makes it difficult to draw an accurate assessment.

7.5 Conclusion – Fish

In summary, univariate and multivariate statistics have shown significant differences between the Centre Bank fish communities and those found at Little Lagoon, Mangroves and Northern Banks where freshwater inputs take place. These spatial patterns are related to the salinity gradient in the system, with the river - estuary interface (REI) that represents the area of freshwater and marine water mixing providing the most important habitat for the largely estuarine dependent ichthyofauna. The elevated water temperature and organic input in these areas facilitate more rapid growth of juvenile fishes, whilst the high turbidity and muddy sediments provide shelter from predators and rich feeding grounds. The more exposed Centre Bank and Island View sand banks also comprise important estuarine habitat and feeding areas, particularly for larger individuals (e.g. spotted grunter) or marine species that enter the estuary to feed (e.g. pick handle barracuda), that are more mobile and may be better able to avoid the sampling gear (seine net) in the typically clearer water found at these sites. Despite these larger individuals possibly being underrepresented in catches, the intensive sampling

conducted does indicate that the most important fish habitat in the Port is found in the upper reaches and areas of freshwater inflow.

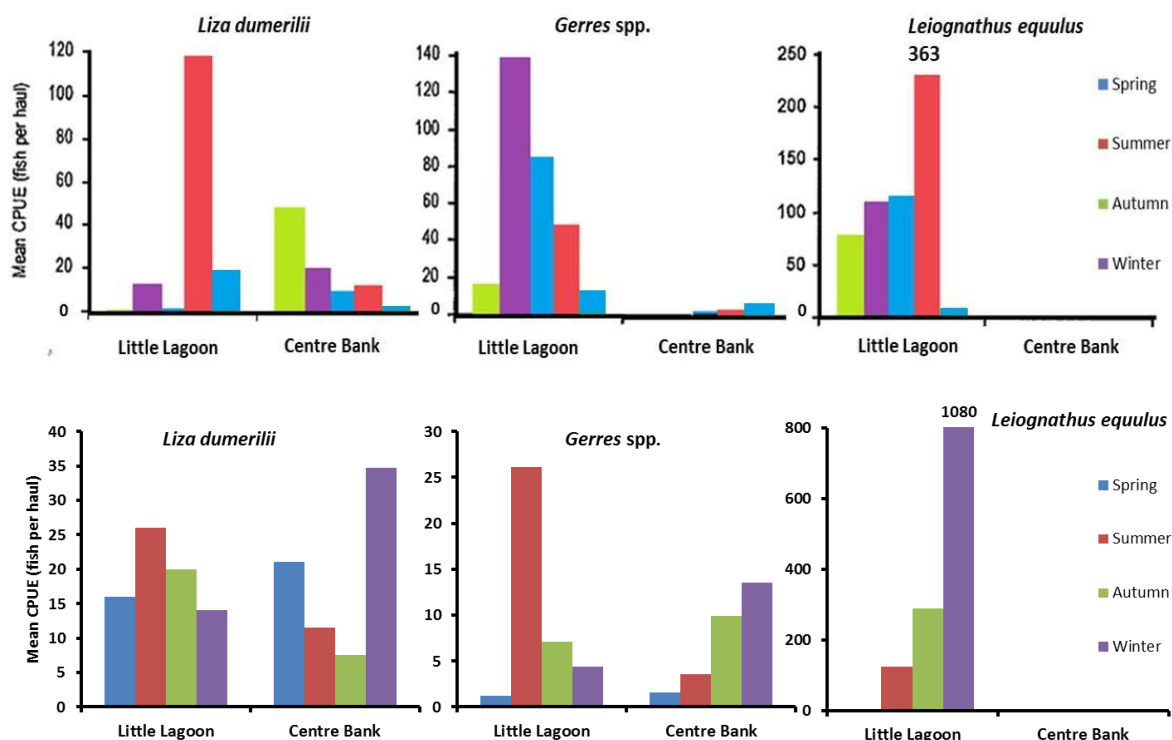


Figure 7.12: Mean CPUE of fish species *Liza dumerillii*, *Gerres spp.* and *Leiognathus equulus* on Little Lagoon and Centre Bank. Top graphs: Previous studies Graham (1994) (spring, summer, autumn, winter) and Newman (2008) (spring); amended from CSIR (2008). Bottom graphs: Seasonal surveys conducted over the period November 2014- August 2016 in the Port

The new sandbank as an extension of the existing Centre Bank would create additional shallow intertidal and subtidal habitats that could potentially benefit estuarine dependent ichthyofauna in the Port. As these habitats function as feeding and nursery areas, the sandbank extension would increase these areas at Centre Bank benefitting fish communities. The utilisation of the sandbank extension, however, will depend on the successful establishment of benthic infaunal assemblages that resemble those at the other sandbank sites. Benthic macrofauna including polychaetes, decapod crustaceans, copepods and mysids, comprise the dominant food source for most of the fish species in the Port. Full recovery of the fish fauna will thus only take place once a benthic invertebrate community has become fully established.

8 BIRDS

8.1 Introduction

Much of the intertidal habitat in Durban Bay has been replaced by harbour development, leaving only 14% of the original tidal flats and 30% of bird abundance relative to that recorded in 1965 (Allan et al. 1999). Mangrove forests have also been extensively reduced. Durban Bay had an extensive mangrove forest of 200 ha, but 78% of this was physically removed in 1979 when construction of the harbour began (Ward & Steinke, 1982). Approximately 16 ha of mangrove forest, 8 ha submerged macrophytes, 2 ha reeds and sedges and 149 ha of intertidal flats remains at present (eThekweni Municipality, 2008; Van Niekerk & Turpie, 2012). These habitats have been replaced with open water areas and concrete berths to allow for the safe passage and mooring of large ships. These new artificial habitats do not support the same numbers or bird diversity as did the original habitat. In the National Biodiversity Assessment conducted in 2011, the birdlife health condition of the Port was rated poor due to substantial loss of habitat and generally poor prey abundance and diversity (Van Niekerk & Turpie, 2012). So far, five bird species have also been declared locally extinct (Allan et al. 1999).

Five broad level habitat types specific to birds are found in the Port (McInnes et al. 2005):

- Intertidal sand and mud flats
- Mangrove forest
- A small semi-natural island at Sporting Bodies-Pelican Island
- A semi-natural shore line associated mostly with Sporting Bodies
- Open harbour waters

The aim of the avifaunal monitoring programme is to establish the spatial and seasonal variability in community structure prior to construction, and later assess the impacts and effectiveness of the mitigation measures implemented during the construction and operational phase. The monitoring programme was designed to align with the long-term monitoring already being conducted by the Durban Natural Science Museum (Allan et al. 1999; McInnes et al. 2005; Allan, 2012) and the proposed avian monitoring suggested in the Bay of Natal Estuarine Management Plan (ERM/MER, 2012 & 2015). The Bay of Natal Estuarine Management Plan (ERM/MER, 2012 & 2015) proposed monthly surveys of birds utilising the intertidal, shallow subtidal and mangrove habitats of the Bay.

8.2 Sampling Methodology

Monitoring of the avian fauna in the Port has been ongoing since the 1960s. These data have been published in a number of works (see Allan et al. 1999; McInnes et al. 2005; Allan, 2012). Based on the previous studies mentioned above, five natural and semi-natural habitats were identified from 20 sampling sites in Durban Bay (Figure 8.1):

- Centre Bank and little lagoon (Bayhead North, MW West, MW East, CT West, CT East, FW North, FW South and Centre Bank Roost)
- Northern Sand Banks (Yacht Basin, Fish Wharf East and Fish Wharf West)
- Muddy/mangrove habitat (Sporting Bodies, Pelican Island, Bayhead West, Bayhead Central)
- Island View Sandbank
- Open Water (Harbour East, West, North and Harbour Mouth)

Monthly counts for these habitat types were conducted between October 2014 and September 2016. No data was collected in December 2014 due to unavailability of the motorised vessel normally used for these surveys. The surveys were carried out based on methods of Allan et al. (1999), McInnes et al. (2005) and Allan (2012). The inner periphery of the Port was circumnavigated with a small motorised vessel during spring low tide between 08h30 and 12h30. At least two observers counted all birds observed overhead and to the right-hand side of the vessel.



Figure 8.1: Aerial view of Durban Bay (Port) showing the 20 sampling areas

Historical monthly data provided by David Allan (published in part in Allan et al. 1999; McInnes et al. 2005; Allan, 2012) together with data collected as part of this monitoring programme were used to characterise overall taxonomic composition, community structure, abundance, species richness (i.e. number of species) and diversity, as well as, seasonal and spatial variations in these parameters.

Understanding changes in avian diversity is important because increasing levels of environmental stress generally decreases diversity. Two different aspects of community structure contribute to community diversity, namely species richness and equability (evenness). Species richness refers to the total number of species present while equability or evenness expresses how evenly the individuals are distributed among different species. For this reason, it is important to consider physical parameters, as well as, other biotic indices when drawing a conclusion from a diversity index. The Shannon-Wiener diversity index (H') and the Pielou's evenness (J') were calculated for each habitat type using PRIMER V 6.

Both univariate and multivariate statistical analyses were used to investigate patterns in avian community structure. All univariate analyses were performed using STATISTICA v13. Overall, seasonal differences in species abundance and richness were determined using the statistical t-test. Season was categorised according to the time that migratory waders spend in Port each year. Migratory waders start arriving in September and depart by the end of April, therefore, summer constituted September to April and winter May to August. A non-parametric Kruskal-Wallis test was used to investigate the differences in bird abundance and species richness between habitats.

The multivariate analysis was conducted using PRIMER v.6 (Plymouth Routines in Multivariate Ecological Research) (Clarke & Warwick, 2001). Multivariate analysis of the bird data was conducted in accordance with the analyses describe in the previous chapters (See Macrofauna Section 6).

8.3 Results and Analysis of Data

8.3.1 Community Composition

A total of 16789 birds were recorded during monthly counts between October 2014 and September 2016 (Annexure 4), of which the largest proportion was counted at Centre Bank and Little Lagoon (8287 birds). A total of 71 species were recorded over the two-year period. Waders and wading birds comprised approximately half of the total number of species recorded, comprising 15 species (31%) and 11 species (21%), respectively (Figure 8.2).

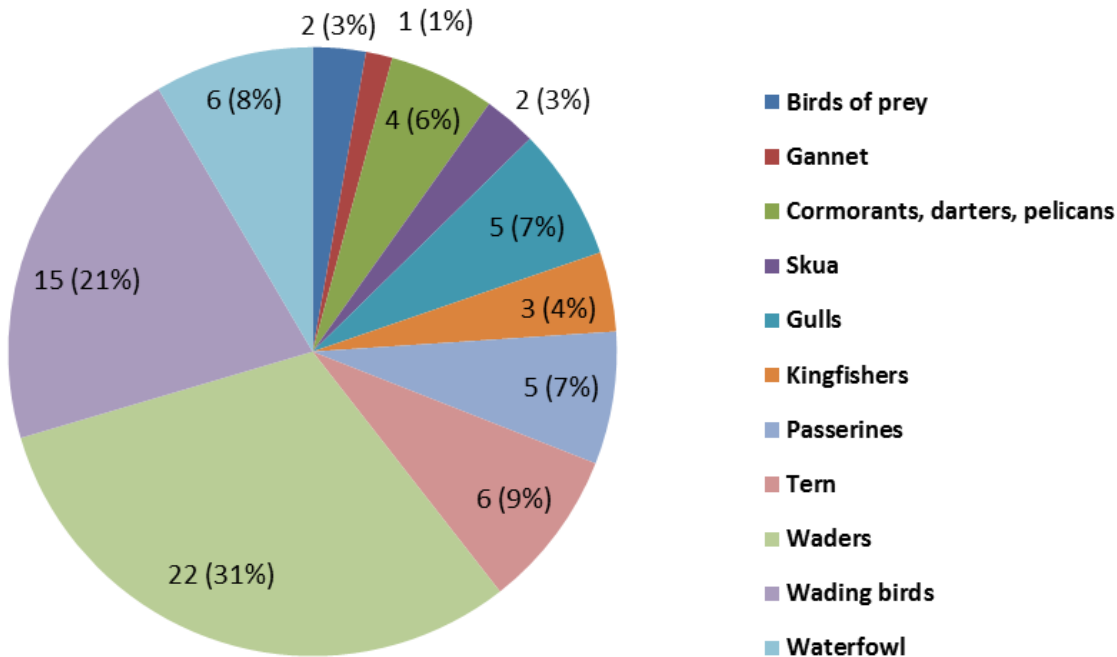


Figure 8.2: Number of species (number, percentage) per taxonomic group found during monthly counts between October 2014 and September 2016. Note that no data was collected in December 2014.

Overall, piscivores and invertebrate feeders make up the largest proportion of the average numbers of birds observed, contributing 43 and 39%, respectively (Figure 8.3). Omnivores comprise 10% and include species, such as Kelp gull, African pied wagtail, and Water thick-knee. Herbivores are poorly represented (7%) and include various geese and duck species.

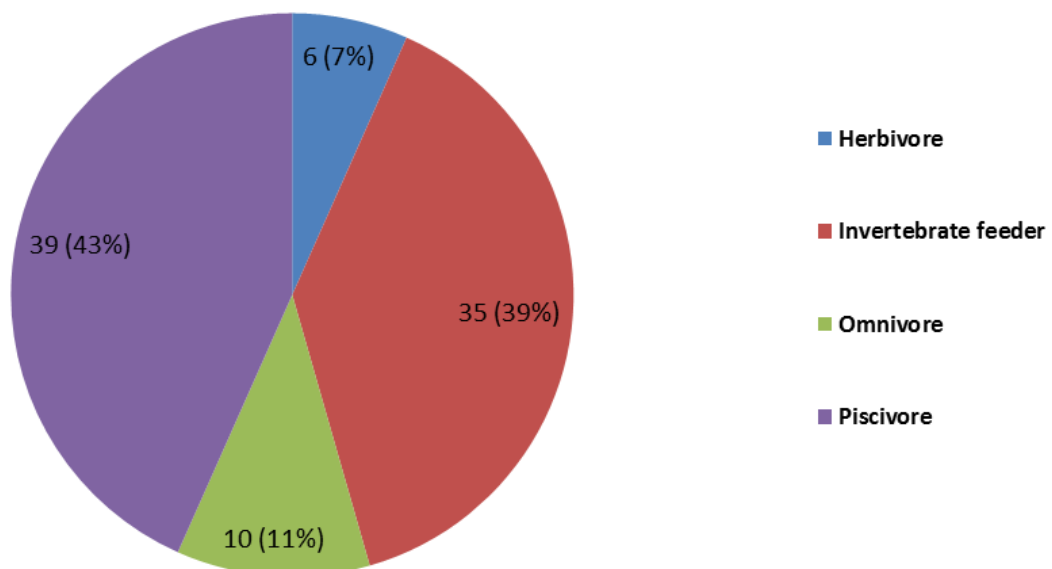


Figure 8.3: Average numerical composition of avian feeding guilds in the Port in the period 1999 to 2016.

Over 110 water associated bird species excluding rare vagrants (Annexure 4) have been recorded in the Port. This includes 17 Red Data species (Barnes, 2000) of which three, the Pink-backed Pelican, Woolly-necked Stork and Caspian Tern are permanent residents in the Port. Sixty-two species are listed in the annex of the Agreement on the Conservation of African-Eurasian Migratory Waterbirds of the Bonn Convention. The birds of greatest potential importance in terms of the possible impacts of the proposed development are likely to be (i) estuary-dependent species – particularly Pink-backed pelican, Greater sand plover, Lesser sand plover, Grey plover, Terek sandpiper, Red knot, Bar-tailed godwit, Eurasian curlew, Caspian tern, Little tern (ii) palearctic migrants, (iii) species with specific requirements and selectivity for intertidal-sand-flat habitat (Ruddy turnstone, Marsh sandpiper, Common whimbrel, Lesser-crested tern, Sandwich tern, Osprey, Sanderling, and (iv) species that utilise the Central Bank and Little Lagoon for roosting – Kelp gull, Swift tern. The level of southern African endemism is not high in the Port with only four endemics, the Cape cormorant, Cape gannet, Cape shoveller and Hartlaub's gull which are all recorded at frequencies of far less than 25% (McInnes et al. 2005).

The waterbirds of the Port can be divided into six different taxonomic orders (Figure 8.2), each of which is described in more detail below. The most species-rich group of birds that occur are the Charadriiformes, which includes waders, gulls and terns.

Table 8.1: Taxonomic composition of common water associated birds in the Port, excluding rare vagrant species. Birds considered as representative (i.e. common) were found in more than 10% of the total number of samples collected between 1999 and 2016. (Data source: David Allan, partially published data. See Allan et al. 1999; McInnes et al. 2005 & Allan 2012).

Common groupings	Order	No. of SA resident species	No. of migrant species
Waterfowl	Anseriformes (Ducks, geese)	2	
Cormorants, darters, pelicans	Pelecaniformes (Cormorants, darters, pelicans)	4	
Wading birds	Ciconiiformes (Heron, egrets, ibises, spoonbill, etc.)	9	1
Birds of prey	Falconiformes (Birds of prey)	1	11
Waders	Charadriiformes	4	14
Gulls	Charadriiformes	2	
Terns	Charadriiformes	2	3
Kingfishers	Coracliformes	3	
Water associated passerines	Passeriformes (Swallows, martins and wagtails)	3	1
Total		26	20

Waders are the most important group of birds in terms of numbers. The influx of waders into the area during spring and summer accounts for most of the seasonal change in community composition. Most of the Palaearctic migrants depart quite synchronously around early April, but some immature birds of many of these species remain behind and do not have the breeding plumage of the rest of the flock. Resident species take advantage of relief in competition for resources and use this period to breed.

Waders feed on invertebrates that mainly live in intertidal areas, at low tide, both by day and night (Turpie & Hockey, 1993). They feed on a whole range of crustaceans, polychaete worms and gastropods, adapting their foraging techniques to suit the type of prey available. Among the waders, plovers stand apart from the rest in that they have insensitive, robust bills and rely on their large eyes for locating prey visually. Oystercatchers have similar characteristics, using their strong bills to prise open shellfish. Most other waders have soft, highly sensitive bills and can locate prey by touch as well as visually. Those feeding by sight tend to defend feeding territories, whereas tactile foragers often forage in dense flocks. Waders require undisturbed sandflats in order to feed at low tide and undisturbed roosting sites at high tide.

Gulls and terns are common throughout the area. Although their diversity is relatively low, they make up for this in overall biomass, and form an important group. Both kelp gulls and grey-headed gulls commonly occur in Durban Bay and rely on open water habitat for feeding and on sand banks for roosting. Except for the kelp gull, which is considered an omnivore, gulls and terns are largely piscivorous.

Cormorants, darters and pelicans are common as a group, and Durban Bay is an important habitat for the pink-backed pelican. African Darters *Anhinga rufa* are very rare, and are more typical of lower salinities and habitats with emergent vegetation which is relatively uncommon in the study area.

Waterfowl occur in low numbers in Durban Bay as they prefer brackish or freshwater over saline water (Turpie & Clark, 2007).

Other birds that commonly occur in Durban Bay include birds of prey such as African Fish-Eagle - *Haliaeetus vocifer* and Osprey - *Pandion haliaetus*, and species such as Pied Kingfisher - *Ceryle rudis* and Cape Wagtail - *Motacilla capensi*.

8.3.2 Seasonal Trends in Avian Communities

A review of numbers of birds recorded during the sampling period revealed greater abundances in the warmer summer months (September–April), corresponding with the period when migratory waders visit the Port (Figure 8.4). Long term trends (1999–2016) were similar to that found in this study, with highest abundances in summer months and lowest in winter (Figure 8.5).

Due to the prevalence of migratory birds in summer, bird numbers in the Port varied substantially between seasons (Figure 8.5). Waders accounted for 40% of bird numbers during summer (September–April), nearly all of these being migratory. In winter, the proportion of resident waders almost doubles from 8 to 14%. Resident gulls (Kelp gulls and Grey-headed gulls) dominate in both summer (33%) and winter (33%), while wading birds increased considerably from summer (4%) to winter (16%).

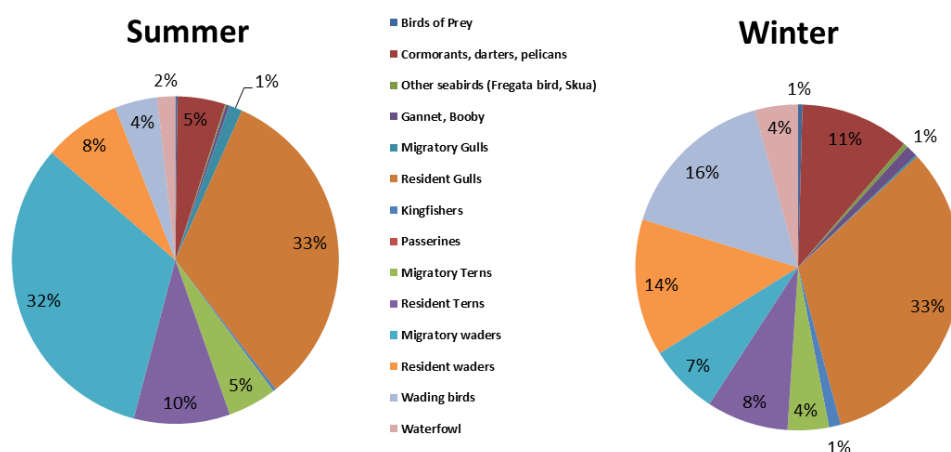


Figure 8.4: Average numerical composition of the birds in the Port, during summer (September–April) and winter (May–August) in the period 1999 to 2016 (Data source: David Allan, partially published data. See Allan et al. 1999; McInnes et al. 2005 & Allan et al. 1999; McInnes et al. 2005 & Allan 2012).

Changes in the bird communities are also reflected in significant differences in bird abundance between seasons for the study period ($t_{98} = 3.18$; $p < 0.001$) (Figure 8.5). Bird abundance was significantly higher in summer than in winter, averaging 206 and 92 individuals, respectively. Congruently, in previous studies key species that were found to contribute to seasonal differences in abundance included the Palearctic migrants, in particular various sandpipers and plovers (McInnes et al. 2005).

Interestingly, no significant differences in species richness were found between seasons for the study period ($t_{113} = 0.76$; $p > 0.05$). The average number of bird species recorded in summer (11 species) was marginally greater than that of winter (10 species) (Figure 8.6). In contrast, significant seasonal differences have been recorded in previous studies with more species generally present in summer than in winter (McInnes et al. 2005; Allan, 2012).

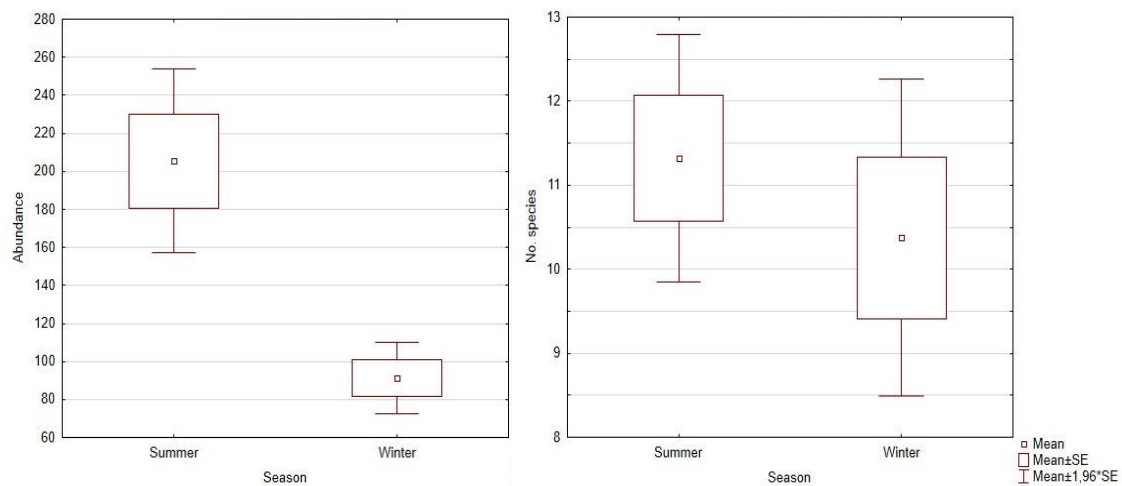


Figure 8.5: Mean bird abundance and number of species in summer (September-April) and winter (May-August) in the Port in the period October 2014 to September 2016

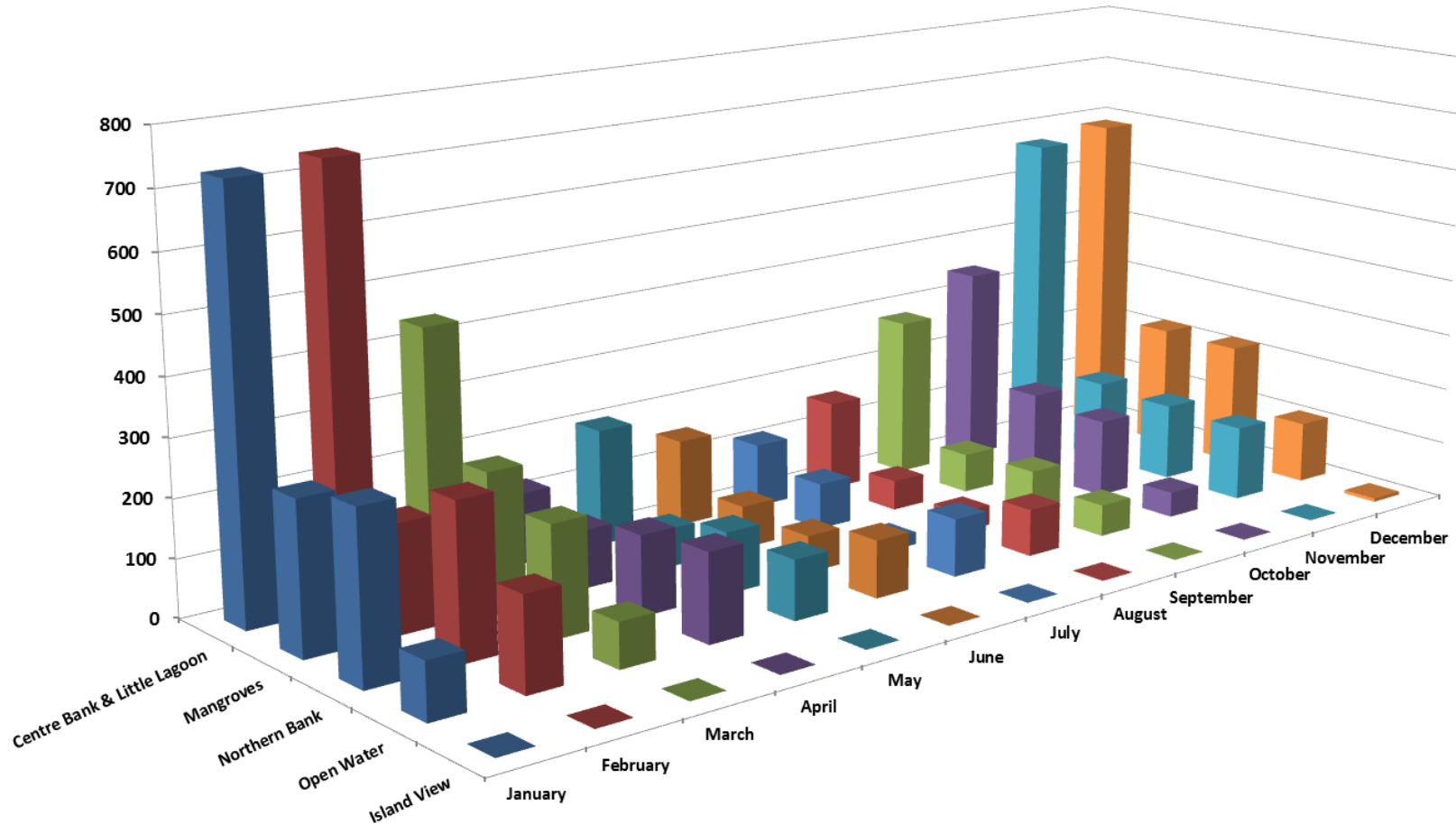


Figure 8.6: Average bird abundance for all habitat types (Centre Bank and Little Lagoon, Northern Bank, Mangroves, Island View and Open water) across monthly counts between October 2014 and September 2016. Note that no data was collected in December 2014.

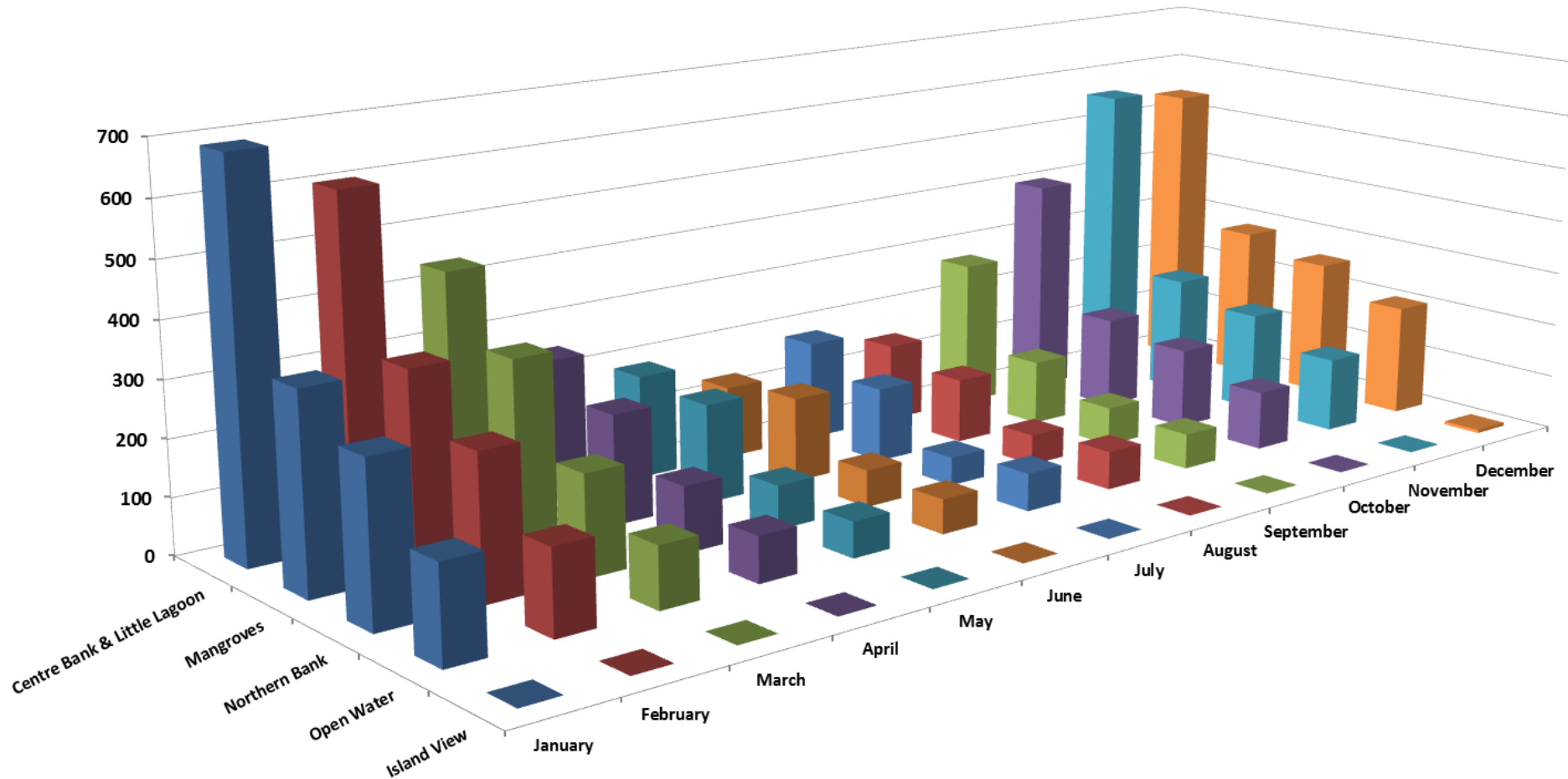


Figure 8.7: Average bird abundance for all habitat types (Centre Bank and Little Lagoon, Northern Bank, Mangroves, Island View and Open water) across monthly counts between October 1999 and September 2016

8.3.3 Spatial Trends in Avian Communities

Spatial variability in avian community structure in the Port was clearly evident. Overall, the five habitats (Centre Bank and Little Lagoon, Northern Bank, Mangroves, Island View and Open Water) were significantly different in terms of total number of birds counted (Kruskal-Wallis test: $H_{4, 100} = 44.58$, $p < 0.001$). Although not statistically different, Centre Bank and Little Lagoon habitat had the highest average number of bird (360 birds) compared to the Mangrove, Northern Bank and the Open Water (Figure 8.7). Island View had significantly lower bird abundance than all other sites. Similar results were found by McInnes et al. (2005), where low abundances of birds were recorded in open water habitat (14.3%) and highest numbers of waterbirds were recorded from the Centre Bank intertidal flats (40.6% of all waterbirds counted). The Centre Bank serves as an important roosting area for both terns and gulls and may be more attractive to birds due to its relatively isolated position compared with other intertidal flats in the Port.

Overall, the five habitats were significantly different from each other in terms of total number of bird species between October 2014 and September 2016 (Kruskal-Wallis test: $H_{4, 115} = 85.58$, $p < 0.001$). Although not statistically different from the Mangroves and Open Water habitats, Centre Bank had the highest average of approximately 16 species (Figure 8.8). The number of species at Northern Bank was significantly lower than that of Centre Bank, Mangroves and the Open Water, averaging only 9 species. The Open Water habitat had the third highest average number of species with 14 species. Centre Bank and Little Lagoon, Mangroves and the Open Water habitat were also found to have the highest number of species by McInnes et al. (2005). Here, the highest number of species recorded over a four-year period was found in the Mangroves with 58 species, followed by the Centre Bank with 45 and the Open Water with 41 species (note that McInnes et al. 2005; used total number of species to rank the habitat types).

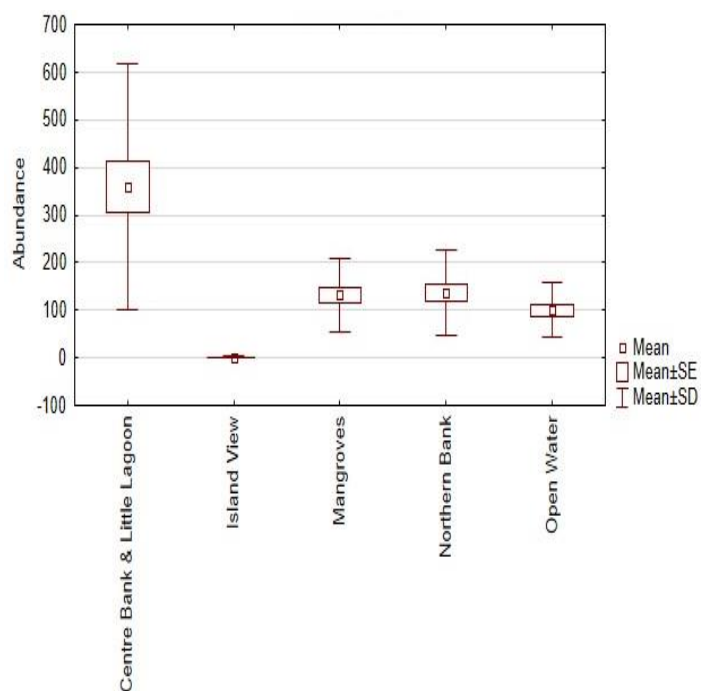


Figure 8.8: Mean bird abundance at five different habitat types in the Port in the period October 2014 to September 2016.

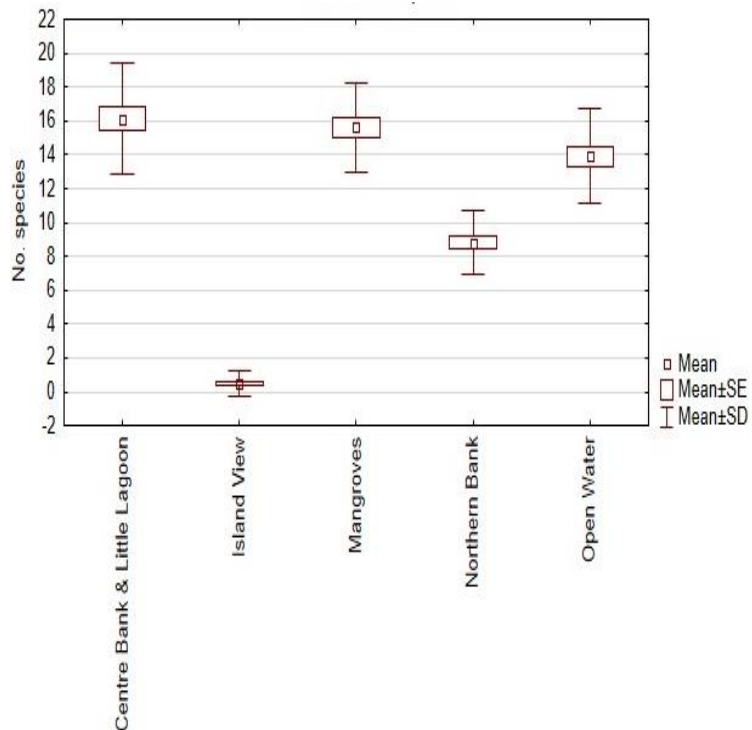


Figure 8.9: Mean number of species at five different habitat types in the Port in the period October 2014 to September 2016.

The MDS ordination plots prepared from bird abundance data is presented in Figure 8.10. ANOSIM analysis comparing different sand bank habitats indicated significant differences between habitats ($p < 0.001$) and a reasonable degree of dissimilarity between communities (Global $R = 0.491$). Pair wise analysis between habitats indicated significant differences between all habitats. However, habitats with the greatest dissimilarity, as indicated by R values greater than 0.5, were Centre Bank and the Mangroves ($R = 0.581$, $p < 0.001$) and the Mangroves and Northern Bank ($R = 0.509$, $p < 0.001$). The MDS ordination supported the ANOSIM results with clear groupings in community structure found for each habitat. Although the community structures at the different sites were statistically different, some overlap was evident. The sand bank habitats of the harbour consist of varying proportions of coarse sand and fine mud with mud content ranging up to 14%. The intertidal flats of Central Bank, Fish Wharf and Yacht Basin (Figure 4.3) are largely dominated by sand (80-90%), which is likely to be the reason why those two bird communities were fairly similar.

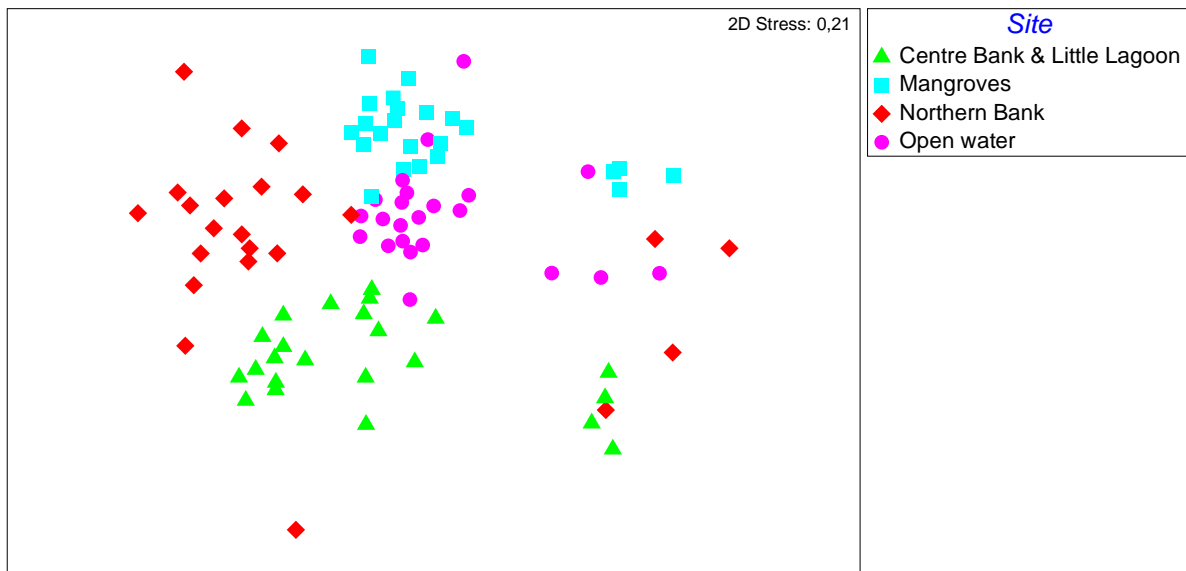


Figure 8.10: Multidimensional Scaling (MDS) Plot showing differences in community structure amongst avian fauna assemblages in Durban Bay (Port) in the period October 2014 to September 2016.

8.3.4 Indicator and Discriminating Species

The SIMPER analysis was performed to identify indicator and discriminatory species in the bird communities of each habitat. Kelp gulls, Swift terns and White-breasted cormorants dominated bird numbers at Centre Bank and Little Lagoon sites. Having highest contributions to the similarity in assemblages (31%) they were identified as the best indicator species for that habitat. The resident Swift tern contributed most to the dissimilarity between the Centre Bank and Little Lagoon and the other habitats by having both high average dissimilarity and Diss/SD values, ranging from 3.1-6.2% and 1.4-2.1 respectively. The Centre Bank serves as an extremely important roosting area for gulls and terns (Allan et al. 1999), especially the Kelp gull, and supports regionally and potentially globally important numbers (McInnes et al. 2005).

The occurrence of resident and migratory waders other than Common greenshank and Blacksmith lapwing (including Common whimbrel, Curlew sandpiper, Grey plover and Common ringed plover) clearly distinguished Centre Bank and Little Lagoon from the other habitats and demonstrates the importance to wader communities in the Port. Migratory wader species, although contributing to dissimilarity, were not identified as good discriminating species ($Diss/SD < 1.3$) due to seasonal variation in their abundance. Being the largest of the sand bank habitats and its isolated position, Centre Bank is the most favourable intertidal sand flat habitat for waders to feed undisturbed.

In the Open Water habitat, Egyptian geese and White-breasted cormorants were the most abundant and good indicators species representing 17.1% (Sim/SD; 5.9) and 11.7% (Sim/SD: 2.4) respectively. Abundant species that rely on the Open Water habitat as feeding grounds include the White-breasted cormorant and Kelp gull.

8.3.5 Species Richness and Diversity

Species diversity represented by the Shannon Wiener Index (H') for the bird communities in the Port. Highest diversity was found at the Open Water habitat (2.04), followed by Mangroves (2.06) and Centre Bank and Little Lagoon (1.92). It was rather unexpected to find high bird diversity in the Open Water habitat due to the constant disturbance by a range of Port activities including shipping, dredging, pollution etc. A high evenness index of 0.76 (represented by the Pielou's Index J') combined with a moderate number of species and low abundances are the likely reason for the high diversity value. Mangrove was expected to have high diversity being the only protected area in the Port (McInnes et al. 2005). The heterogeneous nature of this area, concomitant with reduced human disturbance, is likely to be an important determining factor for the higher avian diversity. The Centre Bank and Little Lagoon habitat had much higher species diversity compared to the similar Northern Bank. This can be attributed to the occurrence of wader species other than Common greenshank and Blacksmith lapwing. Centre Bank and Little Lagoon is certainly a preferred habitat for feeding and roosting due to its isolated position in the Port. The Northern Bank had a substantially lower diversity index value (1.23) that is most likely attributable to the higher levels of human disturbance (mainly angling and bait collection).

Long-term historic data reveals a steep downward trend in migratory wader abundance since 2000 (Figure 8.11). Bird numbers have decreased from 3 400 in 1999-2000 to 1 953 in 2014-2015, representing a 50% decline within this period. Similarly, the number of migratory species visiting the Port each year has also decreased over this period, from 16 to 13 species (Figure 8.12).

The reasons for these declines in migratory wader abundance and species richness is mainly due to the loss and degradation on their breeding and over-wintering grounds during their non-breeding period (Dias et al. 2006). The downward trend in migrant wader numbers echo global trends in wader populations. Ryan (2012) reports on similar declines in migrant waders throughout the Western Cape over the last three decades, irrespective of the protection status of the areas where counts were undertaken. This suggested that factors outside of the

Western Cape were partially responsible for the observed trends and probably reflected global population declines (Ryan, 2012).

Resident wader abundance in the Port is generally much lower than that of migratory waders and has remained relatively stable with an annual average count of 883 ± 191 birds since 1999-2000. Long term trends have indicated a slight increase in abundance in the last ten years (Figure 8.11). Although resident wader abundance appears to be stable, the number of species has decreased slightly within this period.

The construction of the Port and associated habitat loss would have initially been the reason for the rapid loss of wader abundance and richness. The continued incremental loss of intertidal habitat, as well as, siltation of the system and human disturbance, has been the main cause of the continued decline. Human disturbance in particular has been shown to have a dramatic impact on bird numbers in other estuaries (Turpie & Love, 2000).

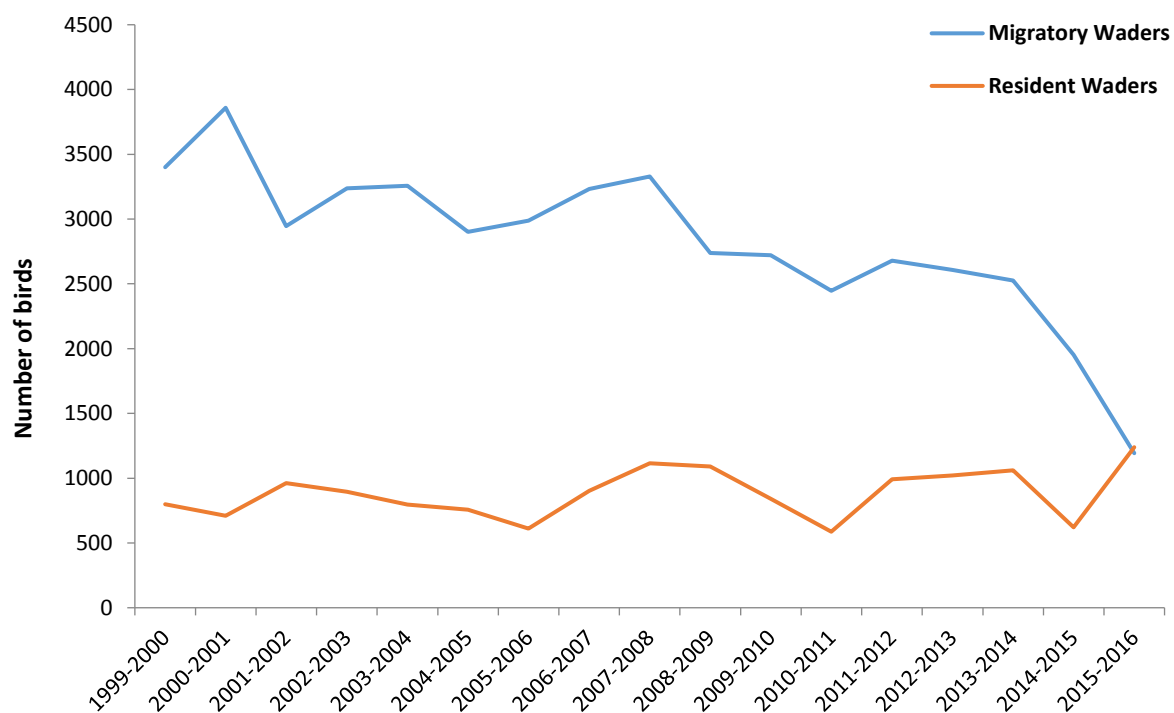


Figure 8.11: Long term trends in the numbers of resident and migratory waders in the Port. Year periods are grouped from October – September. (Data source: David Allan, partially published data. See Allan et al. 1999; McInnes et al. 2005 & Allan 2012).

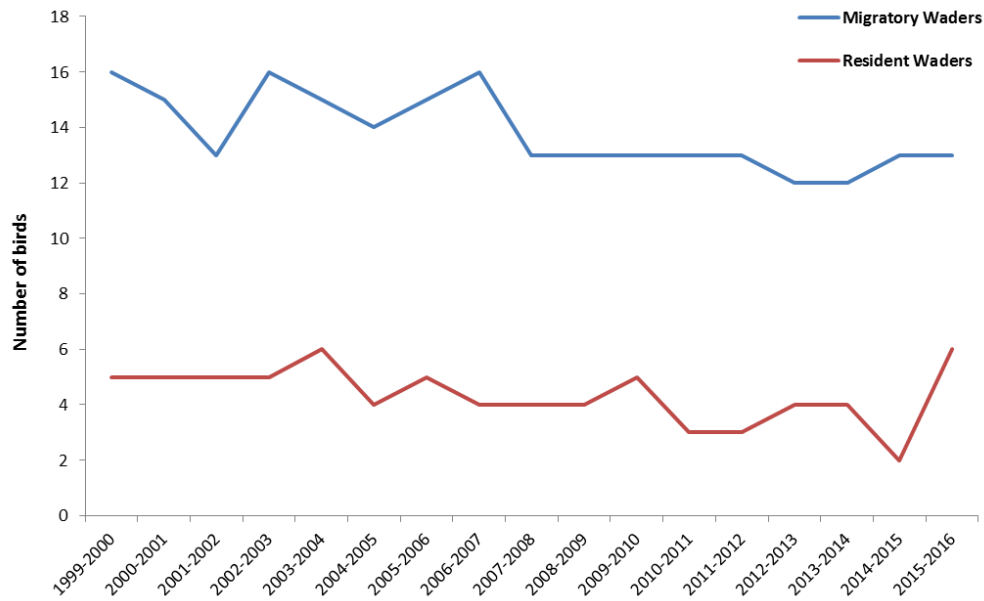


Figure 8.12: Long term trends in the numbers of resident and migratory waders species in the Port. Year periods are grouped from October – September. (Data source: David Allan, partially published data. See Allan et al. 1999; McInnes et al. 2005 & Allan

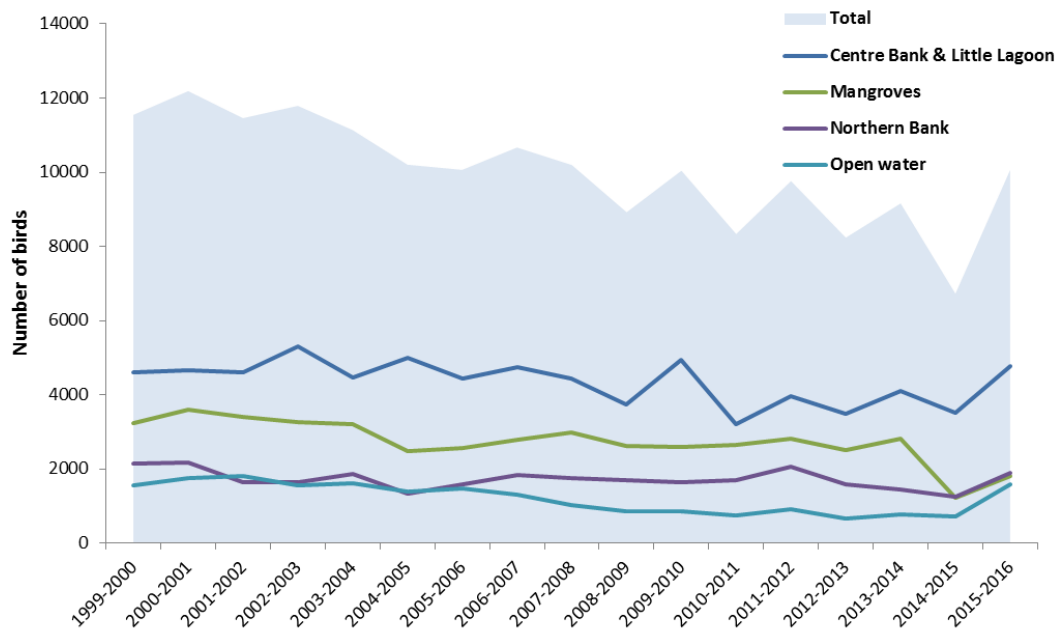


Figure 8.13 Long term trends in the numbers of birds in the Port. Year periods are grouped from October – September. (Data source: David Allan, partially published data. See Allan et al. 1999; McInnes et al. 2005 & Allan 2012).

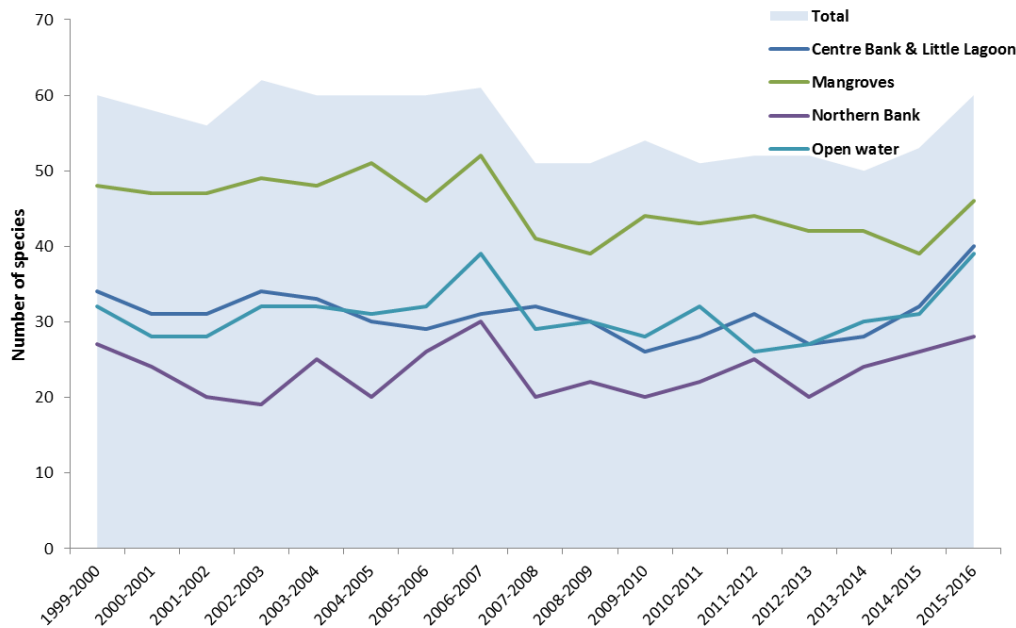


Figure 8.14: Long term trends in the numbers of bird species in the Port. Year periods are grouped from October – September. (Data source: David Allan, partially published data. See Allan et al. 1999; McInnes et al. 2005 & Allan 2012).

8.4 Conclusion - Birds

Due to the prevalence of migratory birds, bird numbers in the Port differed significantly between seasons. Spatial variability in avian community structure in the Port was also clearly evident. A larger proportion of birds were counted at Centre Bank and Little Lagoon, more than double the numbers observed at the Mangroves and Northern Bank. Centre Bank is a crucial avian habitat in the Port, which supports high bird abundances and a unique set of species. Estuarine-dependent species such as migratory waders rely on the Centre Bank for feeding and roosting and any disturbance has a high probability of significantly impacting community structure. This study also demonstrated that the Northern Bank is not an equitable intertidal habitat when compared to the Centre Bank.

The new sandbank extension at Centre Bank is likely to benefit avian communities in the Port. The extension will not only create additional roosting areas, but through the successful establishment of macrofauna and fish communities, will also provide a valuable food resources for many bird species. There is, however, likely to be significant disturbance during the construction phase on Centre Bank that will negatively affect bird communities. Mitigation measures proposed in the avian specialist study, undertaken as part of the EIA for the redevelopment of Berth 203-205, must be followed to ensure that the impacts on wader species in the Port are minimised and to prevent further local extinction of sensitive bird species.

9 MINIMUM ENVIRONMENTAL MONITORING REQUIREMENTS

Environmental monitoring entails checking, at pre-determined frequencies, whether thresholds and baseline values for certain environmental parameters are being exceeded. The parameters and sampling localities used during the baseline monitoring will form the basis of the environmental monitoring programme.

The following requirements need to be incorporated into the programme:

- Monitoring during normal operations, abnormal situations and emergency situations (e.g. unexpected spillage of hazardous substance);
- Measuring equipment must be accurately calibrated;
- Adequate quality control of the sampling must be ensured;
- Analysis is to be undertaken at a SANS 17025 certified laboratory;
- Certified methods of testing must be employed;
- Where legal specifications exist for testing and sampling methods, these must be taken into account;
- The Independent Environmental Control Officer must be supported by a competent Marine Ecologist to interpret the data and recommend appropriate mitigation measures if the warning levels are exceeded. The team must establish a process for identifying and implementing corrective measures; and
- Data from monitoring activities that is not available in real time (i.e. all except the turbidity monitoring) must be made available to Transnet within 45 days of samples being collected.

In addition to monitoring against the baseline, the ECO will verify compliance against the conditions specific to the Central Sandbank in the Environmental Authorisation and the Appeals Decision.

9.1 Water Quality Monitoring

Water quality measurements must be taken at 20 stations distributed in the navigation channels surrounding the main intertidal and shallow subtidal sand bank areas in the Port (Figure 9.1) using a Conductivity-Temperature-Depth (CTD) meter. This includes the Central Sand Bank, Little Lagoon, Wilsons Wharf, Victoria Embankment and the Island View Basin.

Water quality profiles must be measured at each station once every three months (each quarter - autumn, winter, spring, summer) during the construction of the Sandbank Extension and must include an assessment of the following parameters:

- Salinity;
- Temperature;
- Dissolved oxygen; and
- Turbidity.

Once the Sandbank Extension is completed, these same variables must be measured at each station, once every six months during the construction of the Berth 203 to 205 Expansion Project.



Figure 9.1: Locations of the 20 water quality monitoring stations in the Port.

In addition, continuous monitoring should be undertaken of turbidity and dissolved oxygen levels using a suite of CTDs moored at -5 m amsl at five monitoring stations (3 impact and 2 control stations) on the north-western margin of the sandbank opposite stations WQ3, WQ4 and WQ5 (impact monitoring stations) and WQ2 and WQ7 (control stations) immediately adjacent to the Central Sand Bank, (hereinafter referred to as “the designated monitoring stations”), during the dredge operations and sandbank construction.

Data from such monitoring work should be available in real time to the person coordinating dredging activities.

A Total Suspended Solids (TSS) threshold has been developed for the dredging Works at the Port to ensure that the environmental impact of dredging is limited. The TSS threshold limit is set as the greater of:

- The 80th percentile of the baseline monitoring data (Appendix 1), which for stations WQ3, WQ4 and WQ5 corresponds to a TSS of 43 mg/l.
- Ten percent (10%) greater than the natural background Port turbidity. For the purposes of this project, the natural background Port turbidity is deemed to be the greater of the real-time readings at control stations WQ2 and WQ7.

If the TSS approaches the threshold limit set above at any of the surveillance monitoring stations (WQ3, WQ4 or WQ5), mitigation measures are to be put in place to prevent any further increase in suspended solid concentration (e.g. reduce rate of dredging, relocate dredger). If mean turbidity levels (average of measured values in any one and a half hour period) exceed the threshold, dredging is to be suspended until measured levels drop below the threshold.

Table 9.1. Coordinates (decimal degrees) for the water quality monitoring stations.

Site	Latitude	Longitude
DHWQ1	29.893020	31.006565
DHWQ2	29.885520	31.005315
DHWQ3	29.878985	31.006924
DHWQ4	29.872453	31.011815
DHWQ5	29.869453	31.018265
DHWQ6	29.868826	31.023321
DHWQ7	29.866587	31.027448
DHWQ8	29.864486	31.030336
DHWQ9	29.867571	31.031369
DHWQ10	29.869719	31.028739
DHWQ11	29.873433	31.029824
DHWQ12	29.876920	31.036947
DHWQ13	29.878260	31.041954
DHWQ14	29.877855	31.047938
DHWQ15	29.888239	31.029933
DHWQ16	29.874550	31.033488
DHWQ17	29.875805	31.025852
DHWQ18	29.876344	31.020905
DHWQ19	29.877731	31.015897
DHWQ20	29.880861	31.025545

Threshold levels to be adopted for dissolved oxygen during the construction phase are as follows:

- The 20th percentile of the baseline monitoring data (Appendix 1), which for stations WQ3, WQ4 and WQ5 corresponds to a level of 5.33 mg/l.

- Ten percent (10%) lower than natural background dissolved oxygen levels. For the purposes of this project, the natural background oxygen level is deemed to be the lower of the real-time readings at control stations WQ2 and WQ7.

If levels exceed limits specified above, negative impacts on biota such as invertebrates, fish and birds in the Port can be expected.

Temperature, salinity and pH in the water column are not expected to be affected by project related activities. It is essential, however, that these parameters be monitored during the construction and post-construction periods as they will provide an indication of the occurrence of any external (i.e. non-project related) natural or anthropogenic perturbations in the Port.

9.2 Sediment Monitoring - Sediment granulometry, Organic content and Chemical Analysis

Sediment samples must be collected every three months (each quarter - autumn, winter, spring, summer) during the construction of the Sandbank and thereafter at six month intervals throughout the Berth 203 to 205 Expansion.

Samples must be collected from 21 intertidal impact-monitoring stations, 10 intertidal control stations, 18 subtidal impact-monitoring stations, and 7 subtidal control stations during the construction of the extension of the Central Sandbank and throughout the Berth 203 to 205 Expansion Project (Table 9.3, Table 9.4). A further 20 samples must be taken at the intertidal impact-monitoring stations on and immediately adjacent to the newly created sandbank during the Berth 203 to 205 Expansion (Figure 9.2 and Figure 9.3).

Intertidal samples must be collected with a hand corer (10 cm diameter).

Subtidal samples must be collected with a Van Veen grab.

Samples must then be placed in sampling jars on ice immediately after collection and submitted to an SANAS accredited analytical laboratory for determination of grain size distribution, organic and trace metal (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg) content.

Threshold (warning) levels to be adopted for grain size (% sand and % mud) and Total Organic Content (%TOC) in sediment samples from the impact monitoring stations during the construction phase are as follows:

- The 10th and 90th percentiles of the baseline monitoring data (Appendix 1), which corresponds to values listed in Table 9.2. Median values to be used in all cases.
- Twenty percent (20%) above or below background levels as measured at the control stations. Values to be compared are median values for all control and impact stations, respectively.

Threshold (warning) levels to be adopted for levels of trace metals in sediment samples from the impact monitoring stations during the construction phase are as follows:

- The 90th percentiles of the baseline monitoring data (Appendix 1), which corresponds to values listed in Table 9.2. Median values to be used in all cases.

- Twenty percent (20%) above background levels as measured at the control stations. Values to be compared are median values for all control and impact stations, respectively.

If levels exceed limits specified above, negative impacts on biota such as invertebrates, fish and birds in the Port can be expected, and additional mitigation may be indicated. The marine/estuarine specialist supporting the ECO must recommend appropriate correct actions. Monitoring frequency for biota (invertebrates, fish and birds) may need to be increased to once per month to establish the extent of the impact.



Figure 9.2: Locations of the 21 intertidal impact-monitoring stations on the existing sandbank (yellow pins – Int 10-31), 10 intertidal control stations (yellow pins, Int 40-49), and 20 intertidal impact-monitoring stations on (red pins, Int 53-63) and immediately adjacent to (black pins, Int 2-9) the newly established sand bank at which sediment samples are collected for analysis of grain size composition, organic carbon content, trace metals (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg), benthic microalgae (microphytobenthos) and benthic macrofauna.

Table 9.2. Threshold (warning) levels to be adopted for sediment parameters (%Sand, %Mud, Total Organic Content) for intertidal and subtidal sediment samples from impact monitoring stations.

	10 th percentile	90 th percentile
Intertidal samples		
%Sand	99.6%	100.0%
%Mud	0.0%	0.4%
Total Organic Content (%TOC)	1.0%	2.0%
As (ppm)	1.7834	4.58
Cd (ppm)	N/A	0.58
Co (ppm)	N/A	3.93
Cr (ppm)	N/A	29.93
Cu (ppm)	N/A	16.13
Fe (%)	N/A	1.14
Mn (ppm)	N/A	214.44
Ni (ppm)	N/A	7.38
Pb (ppm)	N/A	10.94
Zn (ppm)	N/A	25.67
Hg (ppb)	N/A	0.10
Subtidal samples		
%Sand	97.4%	99.9%
%Mud	0.1%	2.6%
Total Organic Carbon	1.4%	6.0%
As (ppm)	N/A	7.73
Cd (ppm)	N/A	1.38
Co (ppm)	N/A	7.09
Cr (ppm)	N/A	54.59
Cu (ppm)	N/A	58.88
Fe (%)	N/A	2.19
Mn (ppm)	N/A	202.83
Ni (ppm)	N/A	15.63
Pb (ppm)	N/A	46.70
Zn (ppm)	N/A	127.26
Hg (ppb)	N/A	0.18



Figure 9.3: Locations of 18 subtidal impact-monitoring stations (Subt13-33) and 7 subtidal control stations (Subt40-48) at which sediment samples are collected for analysis of grain size composition, organic carbon content, trace metals (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg), benthic microalgae (microphytobenthos) and benthic macrofaunal.

Table 9.3: Coordinates (decimal degrees) for the intertidal sediment monitoring stations.

Site	Latitude	Longitude
DHInt2	29.876912	31.013431
DHInt3	29.875489	31.013809
DHInt4	29.874354	31.016157
DHInt5	29.873823	31.018956
DHInt6	29.873261	31.021608
DHInt7	29.872728	31.023875
DHInt8	29.872163	31.025723
DHInt9	29.871070	31.025920
DHInt10	29.871407	31.023956
DHInt11	29.871873	31.021765
DHInt12	29.872513	31.019040
DHInt13	29.872902	31.017428

DHInt14	29.873529	31.015402
DHInt15	29.874744	31.013040
DHInt16	29.876205	31.011606
DHInt17	29.877751	31.010955
DHInt18	29.877453	31.009245
DHInt19	29.875533	31.010362
DHInt20	29.873869	31.012193
DHInt21	29.872890	31.014977
DHInt22	29.871624	31.016558
DHInt23	29.870854	31.018789
DHInt24	29.870465	31.021548
DHInt25	29.870128	31.024291
DHInt26	29.878888	31.009470
DHInt27	29.879999	31.010721
DHInt28	29.881586	31.010957
DHInt29	29.883129	31.010279
DHInt31	29.883003	31.008177
DHInt40	29.868081	31.016248
DHInt41	29.867470	31.018651
DHInt42	29.865703	31.018230
DHInt43	29.867229	31.021142
DHInt44	29.865701	31.020260
DHInt45	29.864211	31.020024
DHInt46	29.866466	31.024278
DHInt47	29.864977	31.022059
DHInt48	29.864574	31.027788
DHInt49	29.863404	31.026495
DHInt53	29.876145	31.014800
DHInt54	29.875678	31.015907
DHInt55	29.875333	31.017191
DHInt56	29.875053	31.018251
DHInt57	29.874853	31.019447
DHInt58	29.874513	31.020705
DHInt59	29.874190	31.022051
DHInt60	29.873860	31.023512
DHInt61	29.873586	31.024759
DHInt62	29.873347	31.025929
DHInt63	29.872768	31.026828
DHInt64	29.871462	31.027384

Table 9.4. Coordinates (decimal degrees) for the subtidal sediment monitoring stations.

Site	Latitude	Longitude
DHSubt13	29.870034	31.026675
DHSubt14	29.869489	31.025192
DHSubt16	29.869681	31.022168
DHSubt18	29.870106	31.018677
DHSubt20	29.871129	31.015855
DHSubt21	29.872388	31.014853
DHSubt22	29.873210	31.013461
DHSubt23	29.873461	31.010982
DHSubt24	29.875293	31.009470
DHSubt25	29.876807	31.008710
DHSubt26	29.878234	31.008068
DHSubt27	29.879865	31.007363
DHSubt28	29.880190	31.008386
DHSubt29	29.880598	31.010154
DHSubt30	29.882237	31.009943
DHSubt31	29.881590	31.009444
DHSubt32	29.881133	31.007002
DHSubt33	29.881376	31.008147
DHSubt40	29.868547	31.015944
DHSubt41	29.868490	31.018605
DHSubt42	29.868124	31.021201
DHSubt43	29.867644	31.023992
DHSubt44	29.866572	31.026187
DHSubt45	29.863282	31.025808
DHSubt46	29.864464	31.026522
DHSubt47	29.865308	31.027626
DHSubt48	29.865138	31.029313

9.3 Biomonitoring For Trace Metals

Samples of the bivalve *Perna perna* (brown mussel) must be collected from 16 channel marker buoys lying adjacent to the sandbanks (Table 9.5, Figure 9.4). Samples must be collected once every three months (each quarter - autumn, winter, spring, summer) during the Sandbank Extension construction and thereafter once every six months throughout the remainder of Berth 203 to 205 construction period.

The samples must be placed in sampling jars on ice immediately after collection and submitted to a SANAS accredited analytical laboratory for determination of trace metal (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg) content.



Figure 9.4: Location of biomonitoring sites in the Port. Bivalves (brown mussels *Perna perna*) are collected from channel marker buoys at these sites and analysed for trace metal content. Sites 11, 12, 14, 16, 18-21 are impact monitoring stations and the rest are control stations.

Table 9.5. Coordinates (decimal degrees) for the biomonitoring stations.

Site	Latitude	Longitude
DHBM8	29.866292	31.029771
DHBM9	29.86638	31.029700
DHBM10	29.867147	31.027148
DHBM11	29.869191	31.025851
DHBM12	29.869481	31.022376
DHBM13	29.868104	31.022593
DHBM14	29.869900	31.019528
DHBM15	29.868688	31.019523
DHBM16	29.870287	31.016618
DHBM17	29.869071	31.015696
DHBM18	29.872181	31.014326
DHBM19	29.872851	31.012034
DHBM20	29.874184	31.009802
DHBM21	29.877669	31.007923
DHBM22	29.883680	31.007090
DHBM23	29.885677	31.007605

Threshold (warning) levels to be adopted for levels of trace metals in mussel samples from the impact monitoring stations during the construction phase are as follows:

- The 90th percentiles of the baseline monitoring data (Appendix 1), which corresponds to values listed in Table 9.6. Median values to be used in all cases.
- Twenty percent (20%) above background levels as measured at the control stations. Median values to be used in all cases.

If levels exceed limits specified above, risks to health of people consuming shellfish and fish from the Port are likely to be elevated and negative impacts on biota such as invertebrates, fish and birds in the Port can be expected. The marine/estuarine specialist supporting the ECO must recommend appropriate corrective actions such as increasing the sampling frequency to once per month to establish the extent of the impact.

Table 9.6. Threshold (warning) levels to be adopted for sediment parameters (%and, %Mud, Total Organic Content) for intertidal and subtidal sediment samples from impact monitoring stations.

Metal	90 th percentile	Metal	90 th percentile
As (ppm)	3.61	Hg (ppb)	293.06
Cd (ppm)	1.08	Mn (ppm)	134.75
Co (ppm)	0.95	Ni (ppm)	5.60
Cr (ppm)	8.44	Pb (ppm)	8.95
Cu (ppm)	23.18	Zn (ppm)	223.88
Fe (ppm)	800.11		

9.4 **Benthic Microalgae (Microphytobenthos)**

Samples for assessment of benthic microalgae biomass must be collected from the same sampling stations as for the sediment monitoring activities (see section 2.2.2.) and analysed in accordance with methods prescribed by Pinckney & Zingmark (1993). Samples must be collected once every three months (each quarter - autumn, winter, spring, summer) during the Sandbank Extension construction and thereafter once every six months throughout the remainder of Berth 203 to 205 construction period.

This entails slowly inserting a plastic pipe of known diameter (20 mm), either directly into the sediment (in the case of the intertidal samples) or into the contents of the grab (in the case of the subtidal samples) down to a depth of 40 mm. The top of the pipe must then be plugged with a bung and a spatula inserted under the bottom of the tube, before it is slowly withdrawn from the sediment. Samples must then be placed in sampling jars on ice, protected from light, and submitted to an analytical laboratory for further analysis.

In the laboratory, the biomass of the microalgae must be estimated as total chlorophyll (Chl a) according to the methods of Whitney & Darley (1979), Dandonneau & Neveux (2002) and Seuront & Leterme (2006).

For total chlorophyll, sediment samples are extracted in 8-10 mL of 90% acetone in centrifuge tubes. These samples must then be centrifuged for approximately 5 minutes and the

supernatant containing the chlorophyll pipetted into microfuge tubes. The extracts in the microfuge tubes must be analysed spectrophotometrically using standard methods of chlorophyll concentration determination and employing the equation given by Lorenzen (1967), which yields results of chlorophyll per m⁻², thus giving an indication of microalgal biomass at each site. The spectrophotometric method employs partitioning of a 90%~ acetone pigment extract with hexane to eliminate interference from degraded pigments that are common in sediment samples (Cahoon & Cooke 1992).

Threshold (warning) levels to be adopted for benthic microalgae biomass at the intertidal and subtidal impact monitoring stations during the construction phase are as follows:

- Biomass should not drop below the 20th percentile or rise above 80th percentile of the median baseline monitoring level (Appendix 1), as indicated in Table 9.7; and
- Biomass should not drop below 20th percentile or rise above 80th percentile of median levels at the control sites.

Monitoring stations on the newly constructed sandbank area are required to comply with the same criteria as the impact monitoring stations and must remain within the guideline levels for at least two years for recovery to be considered complete.

If levels exceed these limits, recovery of other biota in the affected areas may be delayed and additional mitigation may thus be indicated. The marine/estuarine specialist supporting the ECO must recommend appropriate corrective action.

Table 9.7. Threshold (warning) levels to be adopted for benthic microalage samples from impact monitoring stations

	Spring	Summer	Autumn	Winter
Intertidal				
Median	22.6	17.7	12.3	2.5
80%	6.3	7.7	1.4	0.6
120%	47.7	66.4	43.7	21.6
Subtidal				
Median	3.7	11.5	6.5	3.0
80%	1.5	6.6	1.6	1.1
120%	8.2	21.2	26.8	8.3

9.5 Benthic Macrofauna

Benthic macrofauna samples must be collected from the same sampling stations as for sediment and benthic microalgae monitoring activities.

Samples must be collected once every three months (each quarter - autumn, winter, spring, summer) during the Sandbank Extension construction and thereafter once every six months throughout the remainder of Berth 203 to 205 construction period.

Intertidal samples must be collected at spring low tide by inserting a large (18 cm diameter) corer into the sediment to a depth of 30 cm, plugging the open end, extracting the core and transferring the contents to a 0.5 mm mesh bag. Three cores equating to a surface area of 0.3m² are taken and pooled at each sampling station. The mesh bag is agitated until all the fine sediment has been removed and the remaining contents placed in a sample jar together with 5% formalin.

Subtidal samples must be collected at corresponding times (autumn, winter, spring, summer) using a Van Veen grab with a bite of at least 0.143 m² deployed from a small inflatable boat. Two grabs equating to a surface area of 0.286m² are to be taken and pooled at each subtidal sampling station.

In all cases, macrofauna from the samples are extracted from the residual sediment in the lab, identified to species level, counted and weighed (wet weight).

Threshold (warning) levels to be adopted for benthic invertebrate fauna at the impact monitoring stations during the construction phase are as follows:

- Abundance, biomass and species richness should not drop below 80% or rise above 120% of median baseline monitoring levels (Appendix 1), as indicated in Table 9.8; and
- Abundance, biomass and species richness should not drop below 80% or rise above 120% of the median levels at the control sites.

Monitoring stations on the newly constructed sandbank area are required to comply with the same criteria as the impact monitoring stations and must remain within the guideline levels for at least two years for recovery to be considered complete. If levels exceed limits specified above, recovery of invertebrate populations may be delayed and negative impacts on biota such as fish and birds in the port can be expected. Additional mitigation may thus be indicated. The marine/estuarine specialist supporting the ECO must recommend appropriate corrective action.

Table 9.8. Threshold (warning) levels to be adopted for benthic intertidal and subtidal macrofauna abundance (no. ind/m²), biomass (g/m²) and species richness (no. species) for the impact monitoring stations.

	Spring	Summer	Autumn	Winter
Intertidal invertebrates				
Abundance (indiv. m ²)	162.4	209.6	277.6	204.3
Biomass (g. m ²)	5.8	4.7	11.8	15.8
Species richness (no. species)	4.0	5.2	6.4	5.6
Subtidal invertebrates				
Abundance (indiv. m ²)	232.0	256.0	232.0	176.0
Biomass (g. m ²)	5.2	7.4	8.3	3.2
Species richness (no. species)	7.2	8.0	7.2	6.4

9.6 Fish

Fish present at 9 impact monitoring stations and 5 control stations sites along the margins of the main sand bank areas in the Port must be sampled with a 30 m beach seine net with 12 mm stretched mesh (Figure 9.5).

Samples must be collected on four occasions during the year (autumn, winter, spring, summer) during construction of the Sandbank Extension and thereafter once every six months throughout the remainder of Berth 203 to 205 construction period.

All fish collected in the net at each site are identified, enumerated, weighed and measured, and if possible, returned to the sea alive.

Threshold (warning) levels to be adopted for fish at the impact monitoring stations during the construction phase are as follows:

- Abundance, biomass and species richness should not drop below 80% of median baseline monitoring levels (Appendix 1).
- Abundance, biomass and species richness should not drop below 80% of the median levels at the control sites.

Monitoring stations on the newly constructed sandbank area are required to comply with the same criteria as the impact monitoring stations and must remain within the guideline levels for at least two years for recovery to be considered complete. If levels drop below limits specified in Table 9.10, recovery of these faunal components on the Central sandbank may be delayed and further mitigation may be indicated. The marine/estuarine specialist supporting the ECO must recommend appropriate corrective action.



Figure 9.5: Location of fish sampling sites. Sites 6-12 should be regarded as impact monitoring stations and sites 13, 14, and 19-23 as control stations.

Table 9.9. Coordinates (decimal degrees) for the fish monitoring stations.

Site	Latitude	Longitude
DHSeine1	29.876842	31.014607
DHSeine2	29.875963	31.017911
DHSeine3	29.874857	31.021770
DHSeine4	29.873949	31.025545
DHSeine5	29.872494	31.027467
DHSeine6	29.870622	31.023150
DHSeine7	29.871145	31.018931
DHSeine8	29.872665	31.016027
DHSeine9	29.873853	31.011918
DHSeine10	29.876466	31.009507
DHSeine11	29.878918	31.010771
DHSeine12	29.880502	31.011048
DHSeine13	29.882678	31.010872
DHSeine14	29.883448	31.008304
DHSeine19	29.867971	31.015886

DHSeine20	29.865827	31.018275
DHSeine21	29.864400	31.020520
DHSeine22	29.865941	31.025260
DHSeine23	29.863167	31.027476

Table 9.10. Threshold (warning) levels to be adopted for fish abundance (no. ind/haul), biomass (g/haul) and species richness (no. species/haul) for the impact monitoring stations.

	Spring	Summer	Autumn	Winter
Abundance				
Median	19.0	39.5	510.9	319.2
80%	15.2	31.6	408.721	255.3333
Biomass				
Median	219.0	315.0	888.9	2657.6
80%	175.2	252	711.1506	2126.102
Species richness (no. species)				
Median	5.0	5.5	6.5	6.0
80%	4	4.4	5.2	4.8

9.7 Birds

Bird counts on all sandbank habitats in the Port are currently undertaken by an avifauna specialist (David Allan, Durban Natural Science Museum) once per month at spring-low tide. These counts should be continued through the Sandbank Extension period as well as the Berth 203 to 205 Expansion construction.

Numbers of birds of each species must be recorded within a series of counting sections (Figure 9.6).

Counts must be conducted at low tide in the morning with the aid of binoculars and telescope within a six-hour period.

Threshold (warning) levels to be adopted for birds at the impact monitoring stations during the construction phase are as follows:

- Monthly counts of numbers of water birds and water bird species on Centre Bank and Little Lagoon (counting areas: Bayhead North, MW West, CT West, MW East, CT East, FW North, FW South, Centre Bank Roost, SB Ext 1, SB Ext 2, SB Ext 3) should not drop below 80% of median baseline monitoring levels for the avifauna assemblage as a whole and for key groups (Waterfowl; Cormorants, darters, pelicans; Wading birds; Birds of prey; Waders; Gulls; Terns), as indicated in Table 9.11 (median values from the last 10 years – 2007-2016).

Monitoring stations on the newly constructed sandbank area are required to comply with the same criteria as the impact monitoring stations and must remain within the guideline levels for at least two years for recovery to be considered complete. If levels drop below limits specified in Table 9.11, recovery of bird populations on the Central sandbank and in Durban Bay as a whole may be delayed and additional mitigation may be indicated. The avifauna specialist supporting the ECO must recommend appropriate corrective action.



Figure 9.6: Avifauna counting sections in the Port. Counting sections on the newly created sandbanks have white shading while the rest have yellow shading.

Table 9.11. Threshold (warning) levels to be adopted for bird numbers and species richness (no. species) for Centre Bank and Little Lagoon. Values correspond with 80% of the median from the last 10 years – 2007-2016.

	J	F	M	A	M	J	J	A	S	O	N	D	Total
Thresholds for all species													
Total number of species	24	24	24	23	20	19	20	20	23	23	24	24	42
Total number of individuals	1019	1000	755	510	389	324	336	317	386	591	808	884	7568
Thresholds for major groups													

Waterfowl													
No. species	1	1	1	1	1	1	1	1	1	1	1	1	2
No. individuals	17	22	16	15	17	12	13	13	12	10	15	14	199
Cormorants, darters, pelicans													
No. species	2	2	2	2	2	2	3	3	3	2	2	2	4
No. individuals	33	32	26	22	34	29	40	59	56	49	47	41	485
Wading birds													
No. species	4	4	5	5	5	4	4	5	4	4	4	3	9
No. individuals	28	31	44	58	60	57	49	41	36	24	26	18	505
Waders													
No. species	8	8	8	6	3	2	3	4	8	8	9	9	13
No. individuals	435	433	361	136	78	68	66	80	174	289	336	369	2886
Gulls													
No. species	2	2	2	2	2	2	2	2	2	2	2	2	2
No. individuals	384	323	219	179	175	121	77	48	48	108	155	288	2287
Terns													
No. species	4	4	3	3	3	2	2	2	2	2	2	3	4
No. individuals	112	108	52	56	21	12	23	37	30	72	127	119	816

Once the construction of the Sandbank Extension is completed, the following conditions are applicable:

- Undertake all dredging within the 100m of the Centre Bank intertidal and sand flats during winter when bird abundances are lower and palearctic migrants are not present.
- When dredging within 100m of the Centre Bank intertidal-sand flats, do not dredge at multiple sites concurrently, but only at one area at a time with a single dredger.
- No dredging operations should be conducted between sunset and sunrise within 100m of Centre Bank intertidal-sands flats.

10 CONCLUSION

In spite of the transformation in the Port, the Port of Durban is still considered to be an estuary with high national conservation importance (Turpie & Clark, 2007). It is ranked as the 10th most important estuary in South Africa (Turpie & Clark, 2007). The extension of the Central Sandbank will assist in securing the benefits provided by this system in terms of ecosystem goods and services.

The CSMP describes the environmental baseline conditions of Sandbank habitats in the Port. The information presented in the study serves as a benchmark against which the impacts of any disturbance associated with the Berth 203 to 205 Expansion Project can be assessed. Furthermore, it acts as an end-reference point at which the proposed new Central Sandbank Extension can be considered equivalent to the habitat lost as a result of the development. Implementation of the established thresholds for various variables and EQTs during the construction and operational phases of the development will contribute to effective mitigation of potential impacts associated with the proposed development.

Hence, it is imperative that the entire construction phase of the Berth 203 to 205 Expansion Project is closely monitored against the thresholds identified in the CSMP. In addition to monitoring against the baseline, the ECO will verify compliance against the conditions specific to the Central Sandbank in the Environmental Authorisation and the Appeals Decision.

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ANNEXURE 1:

Water Quality Baseline Monitoring Data

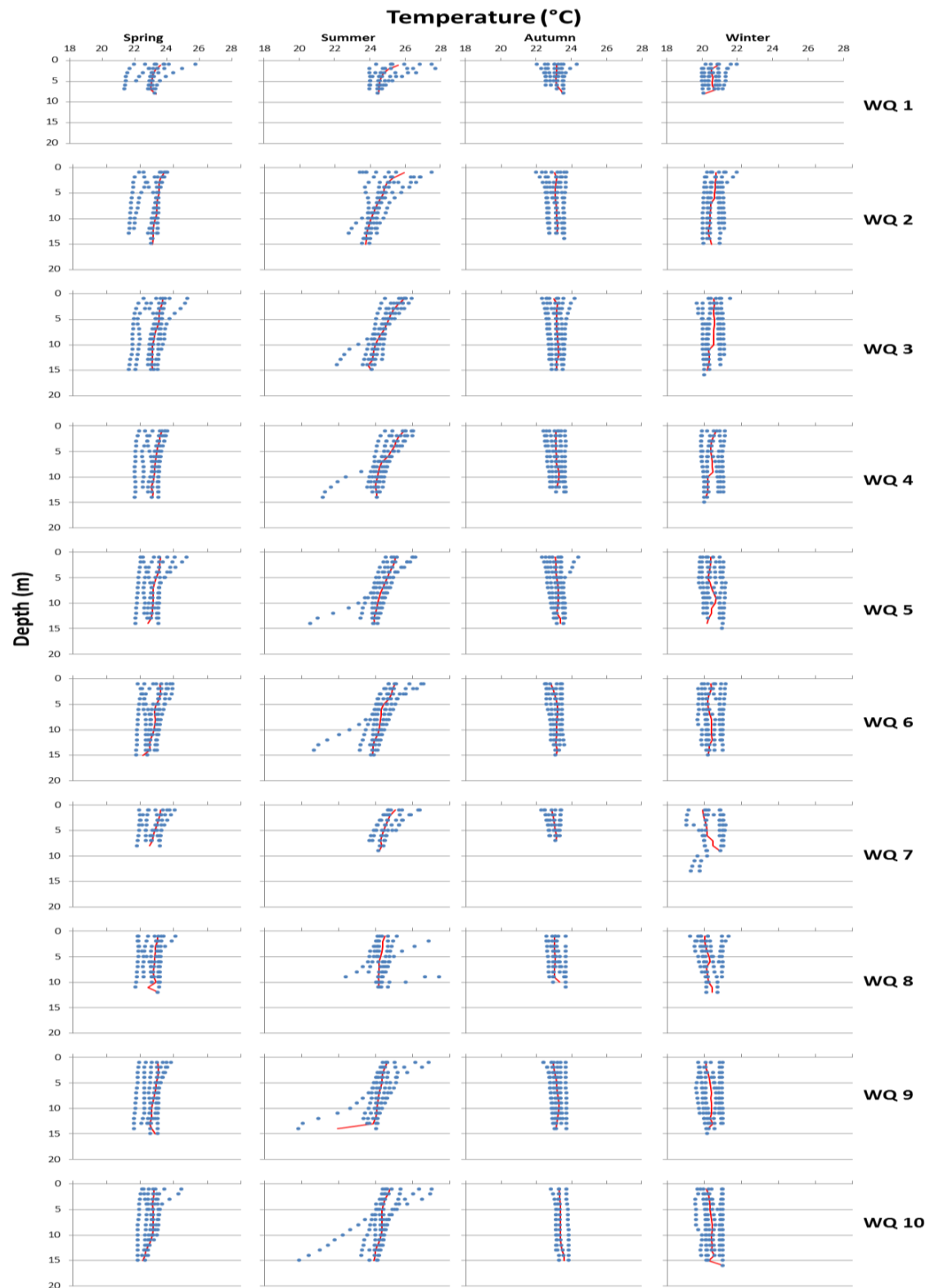


Figure 1A: Depth profile data of the temperature at each water quality monitoring stations for each season over the entire survey period. Median trends are shown in red.

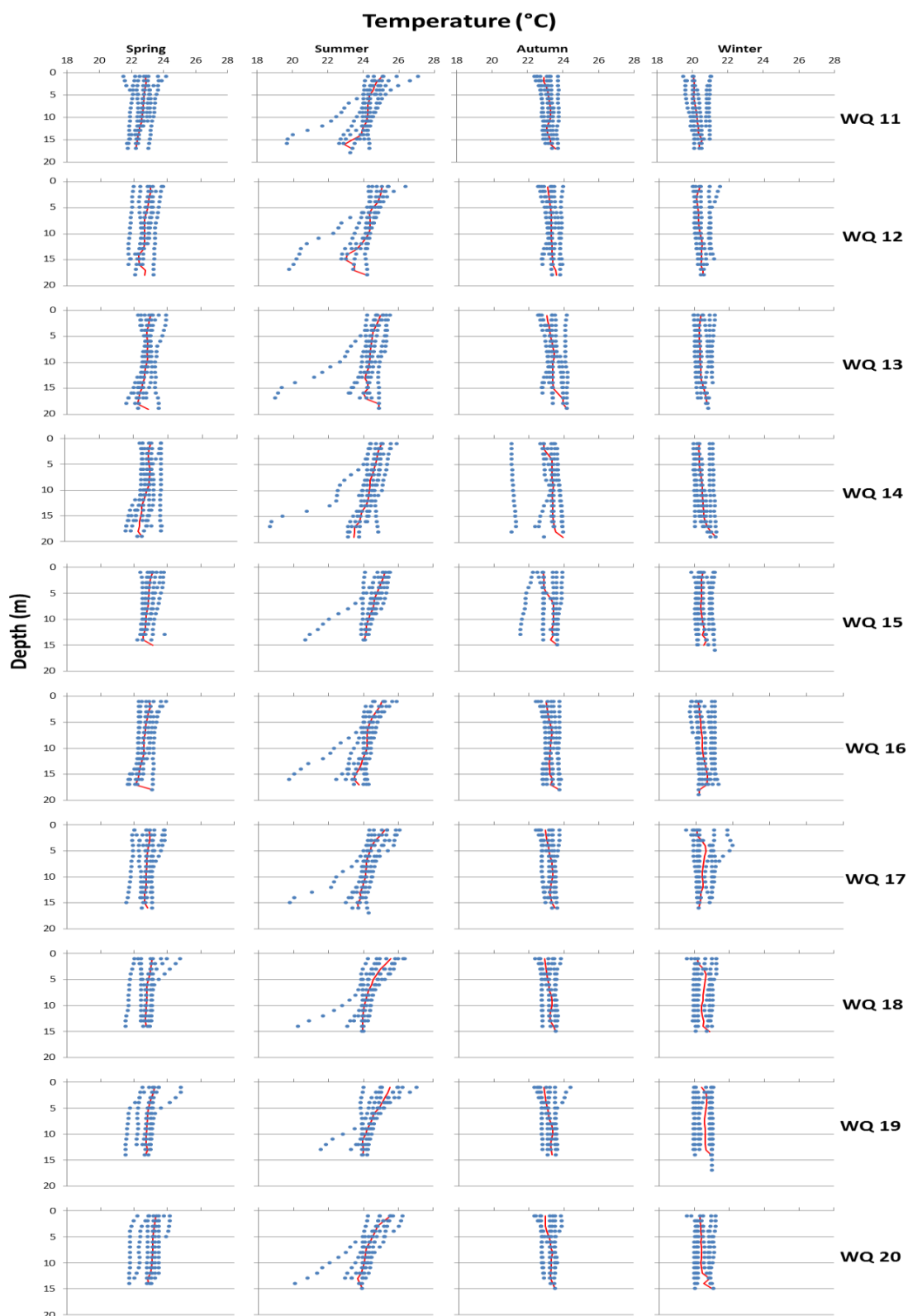


Figure 1B: Depth profile data of the temperature at each water quality monitoring stations for each season over the entire survey period. Median trends are shown in red.

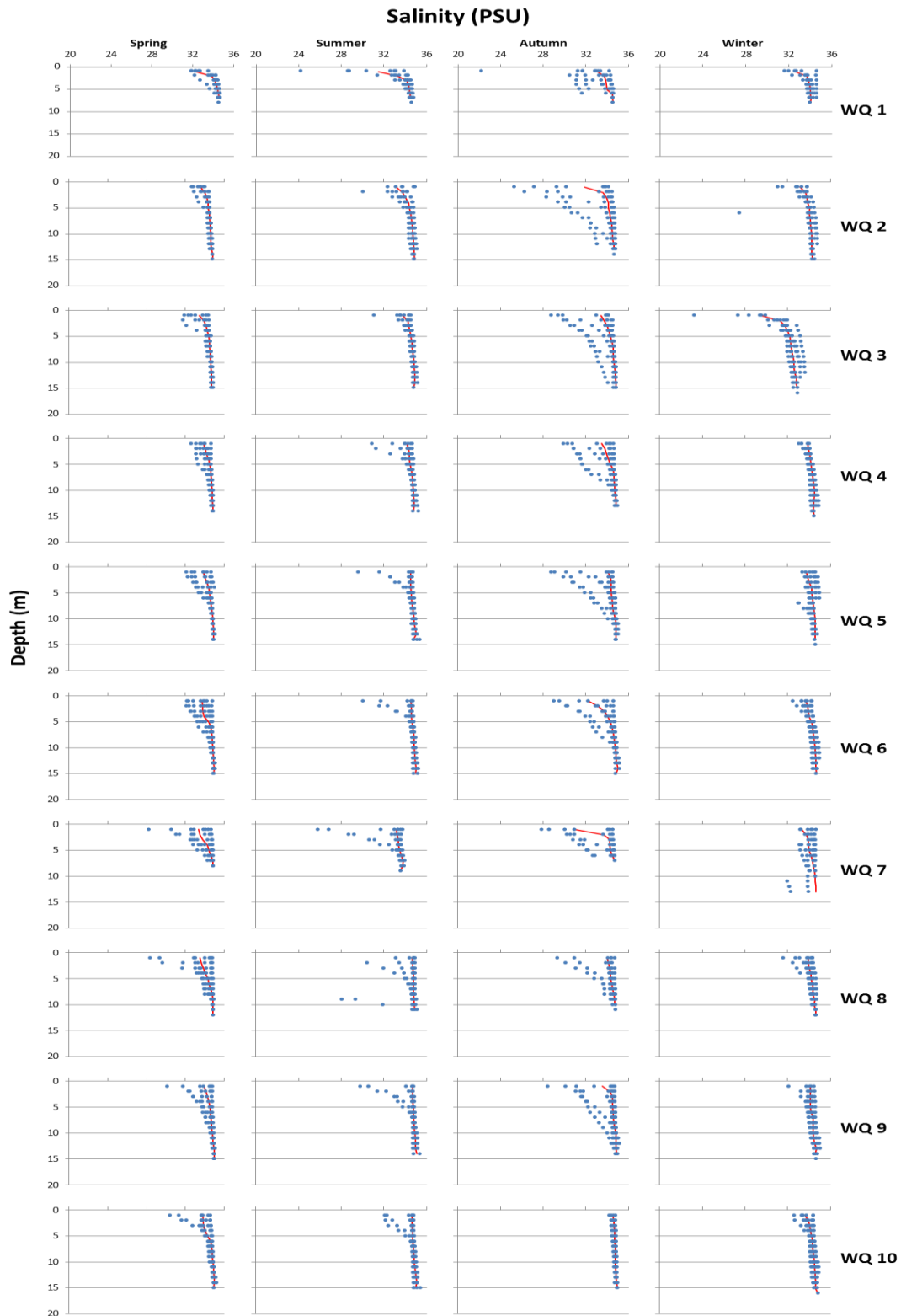


Figure 1C: Depth profile data of the salinity at each water quality monitoring stations for each season over the entire survey period. Median trends are shown in red.

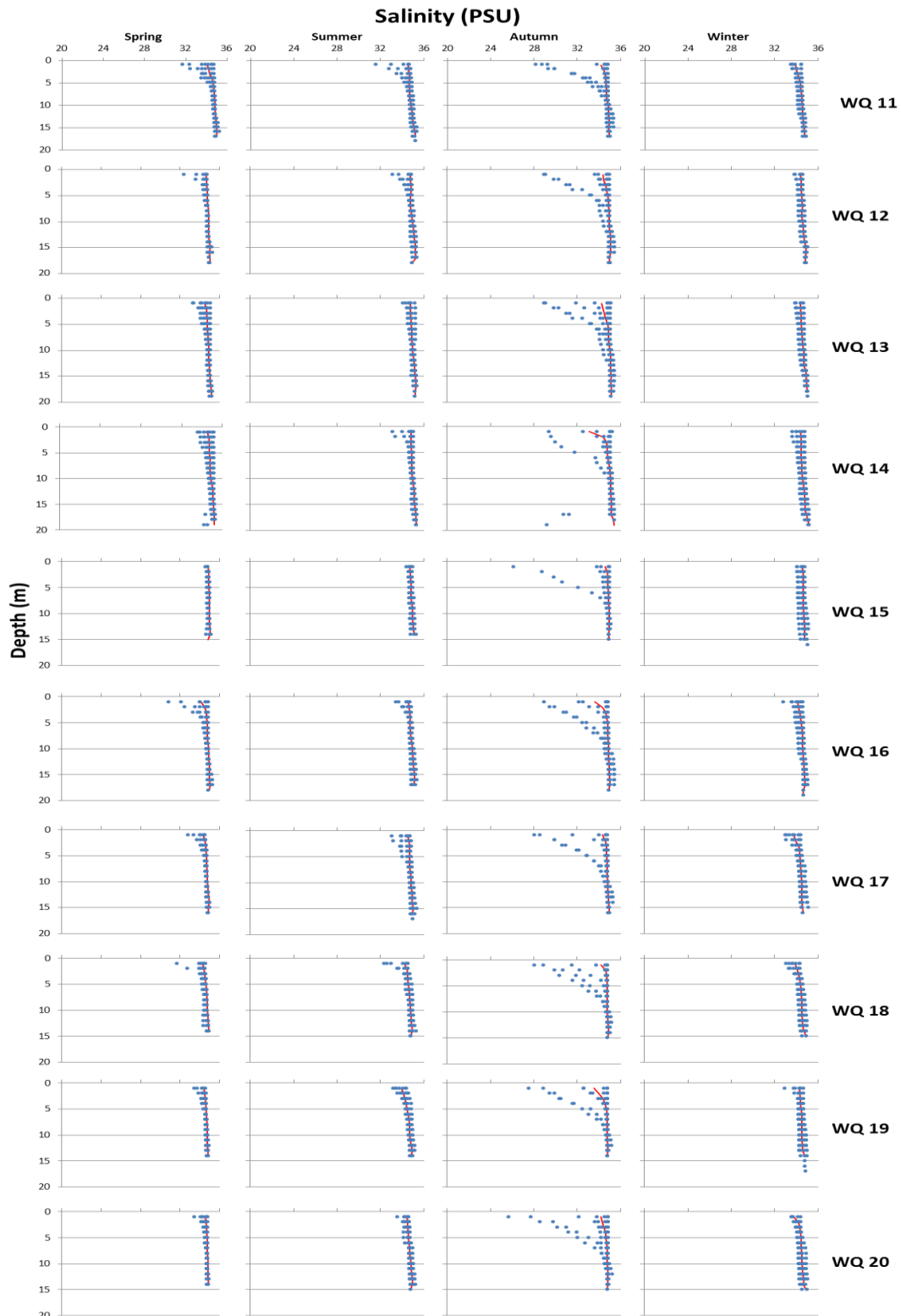


Figure 1D: Depth profile data of the salinity at each water quality monitoring stations for each season over the entire survey period. Median trends are shown in red.

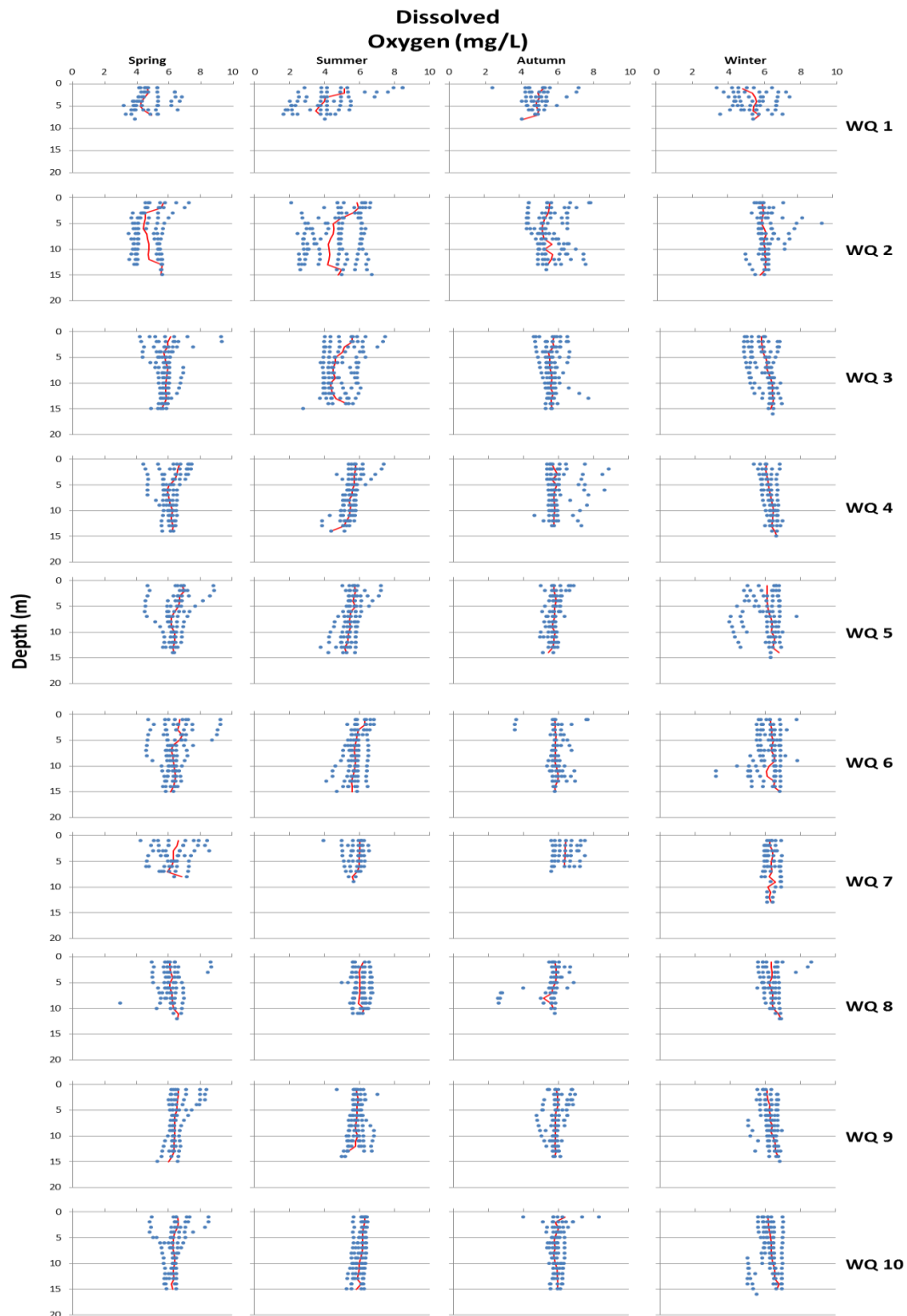


Figure 1E: Depth profile data of the dissolved oxygen at each water quality monitoring stations for each season over the entire survey period. Median trends are shown in red.

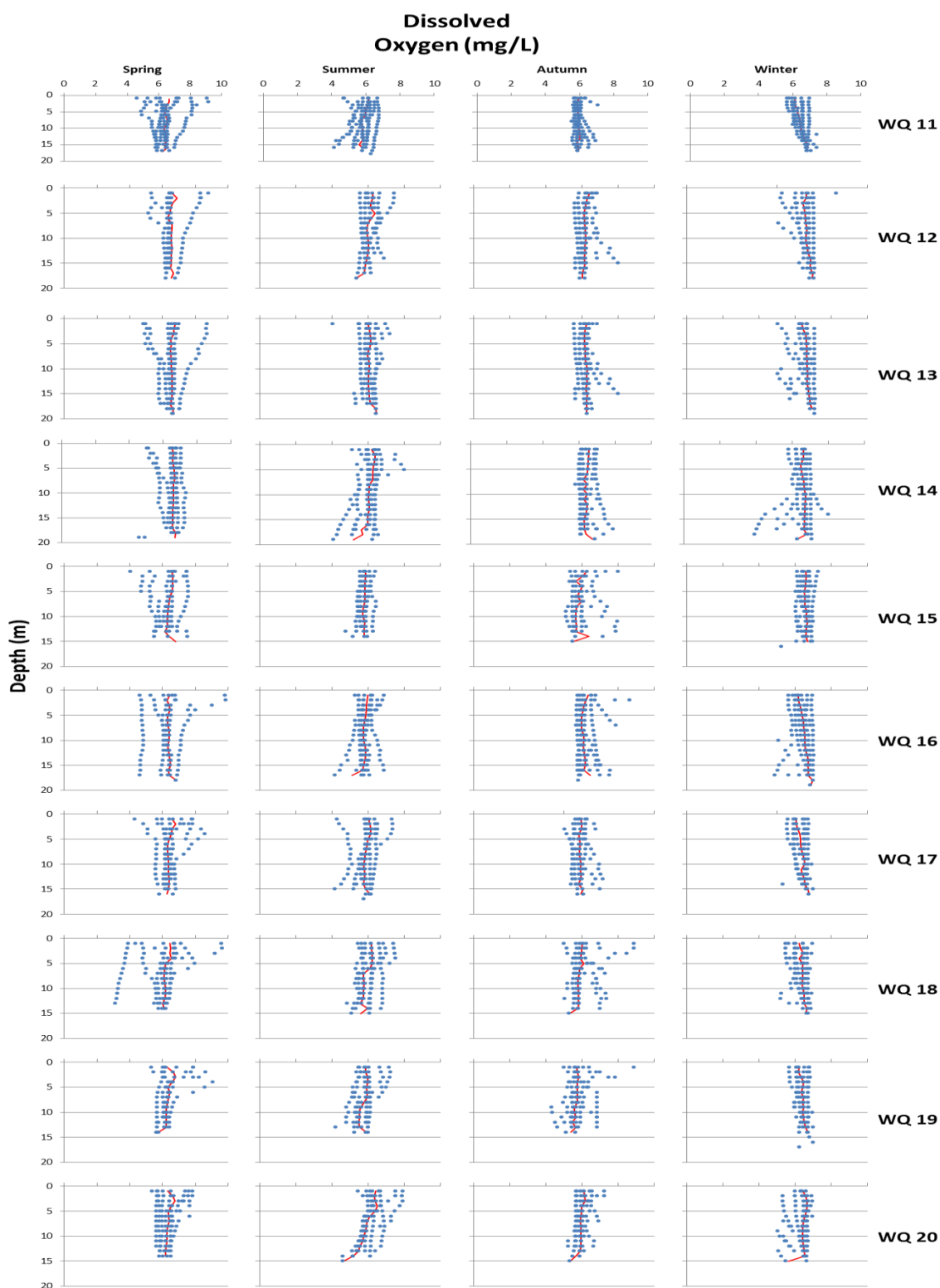


Figure 1F: Depth profile data of the dissolved oxygen at each water quality monitoring stations for each season over the entire survey period. Median trends are shown in red.

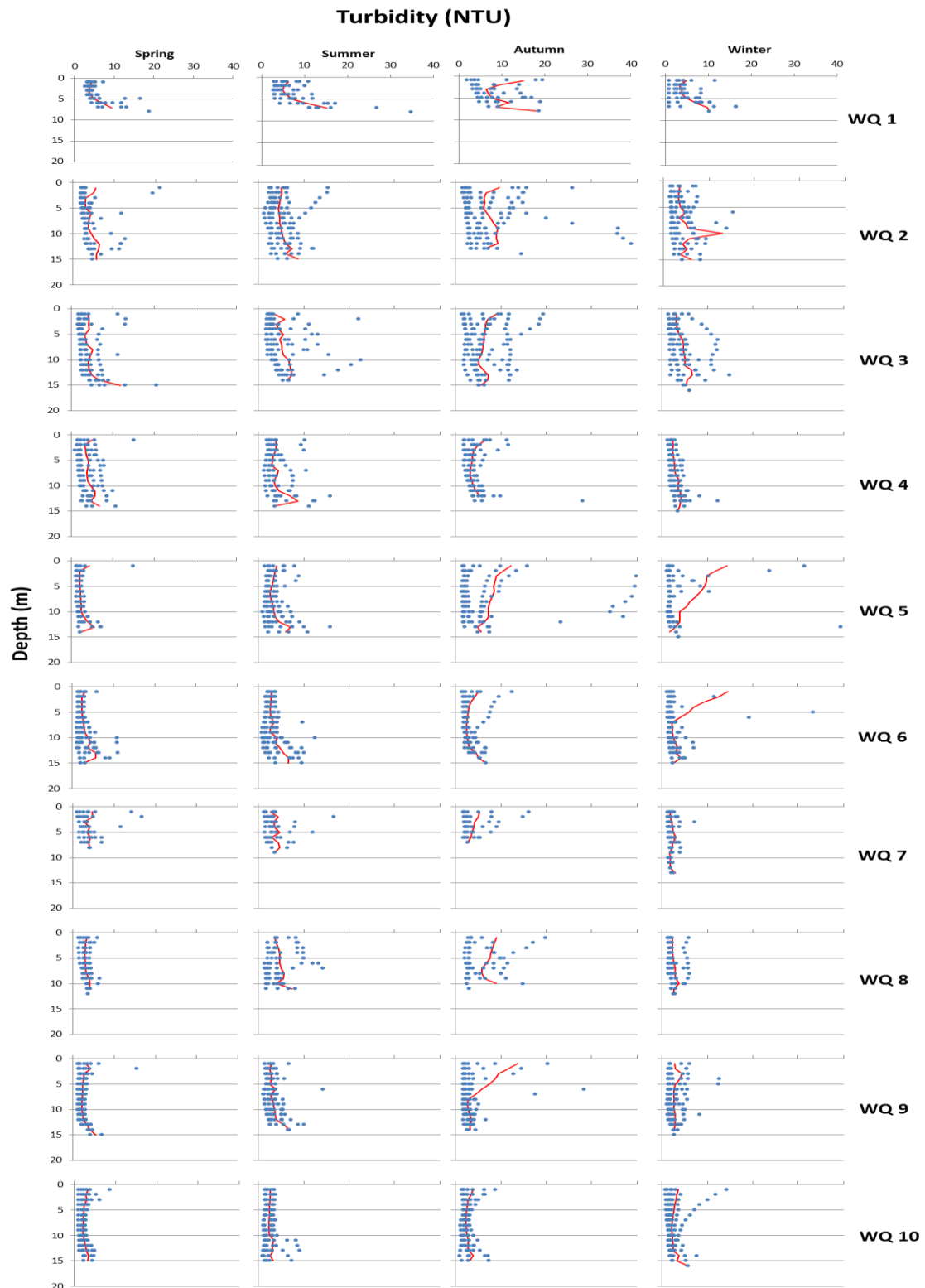


Figure 1G: Depth profile data of the turbidity at each water quality monitoring stations for each season over the entire survey period. Median trends are shown in red.

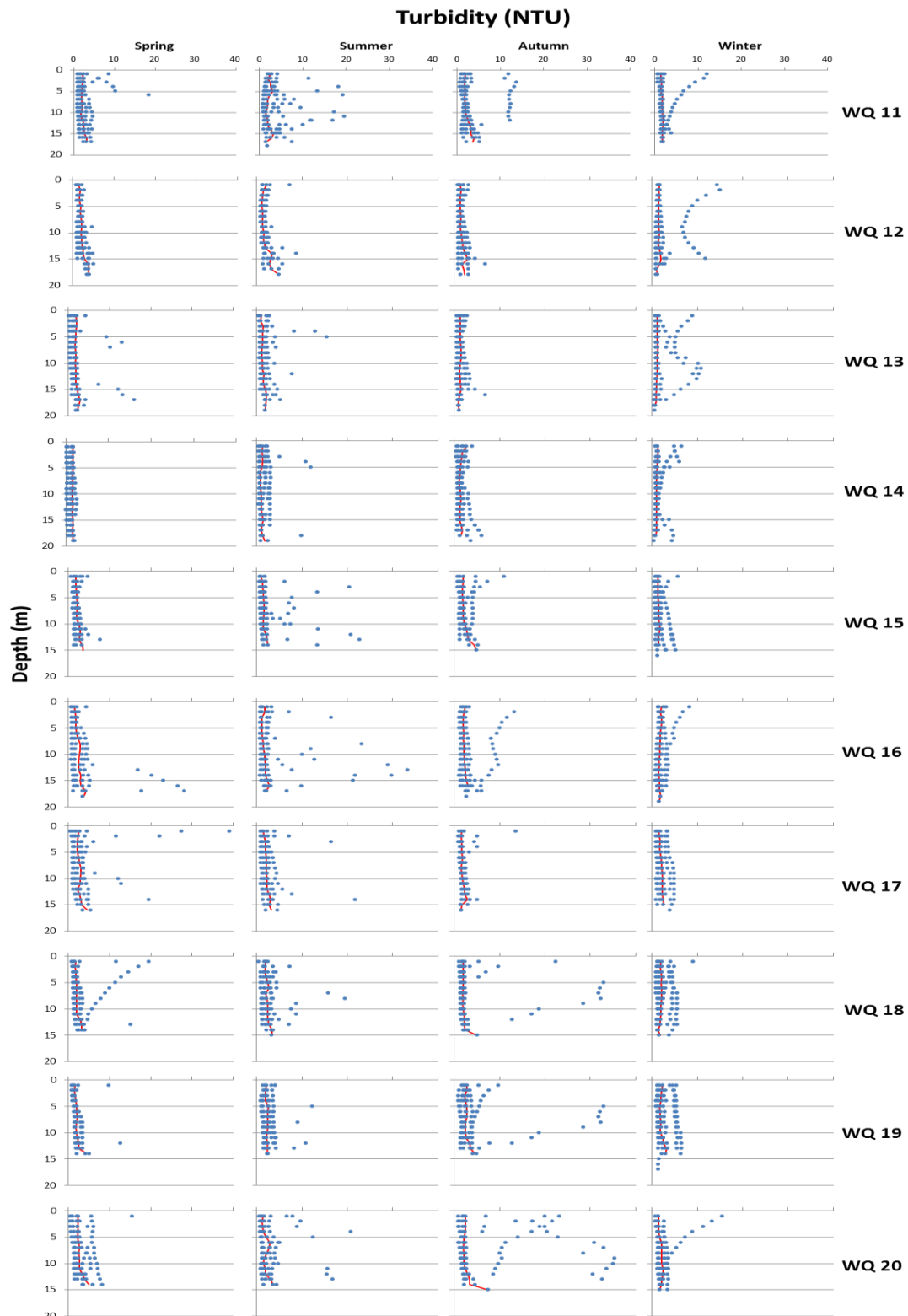


Figure 1H: Depth profile data of the turbidity at each water quality monitoring stations for each season over the entire survey period. Median trends are shown in red.

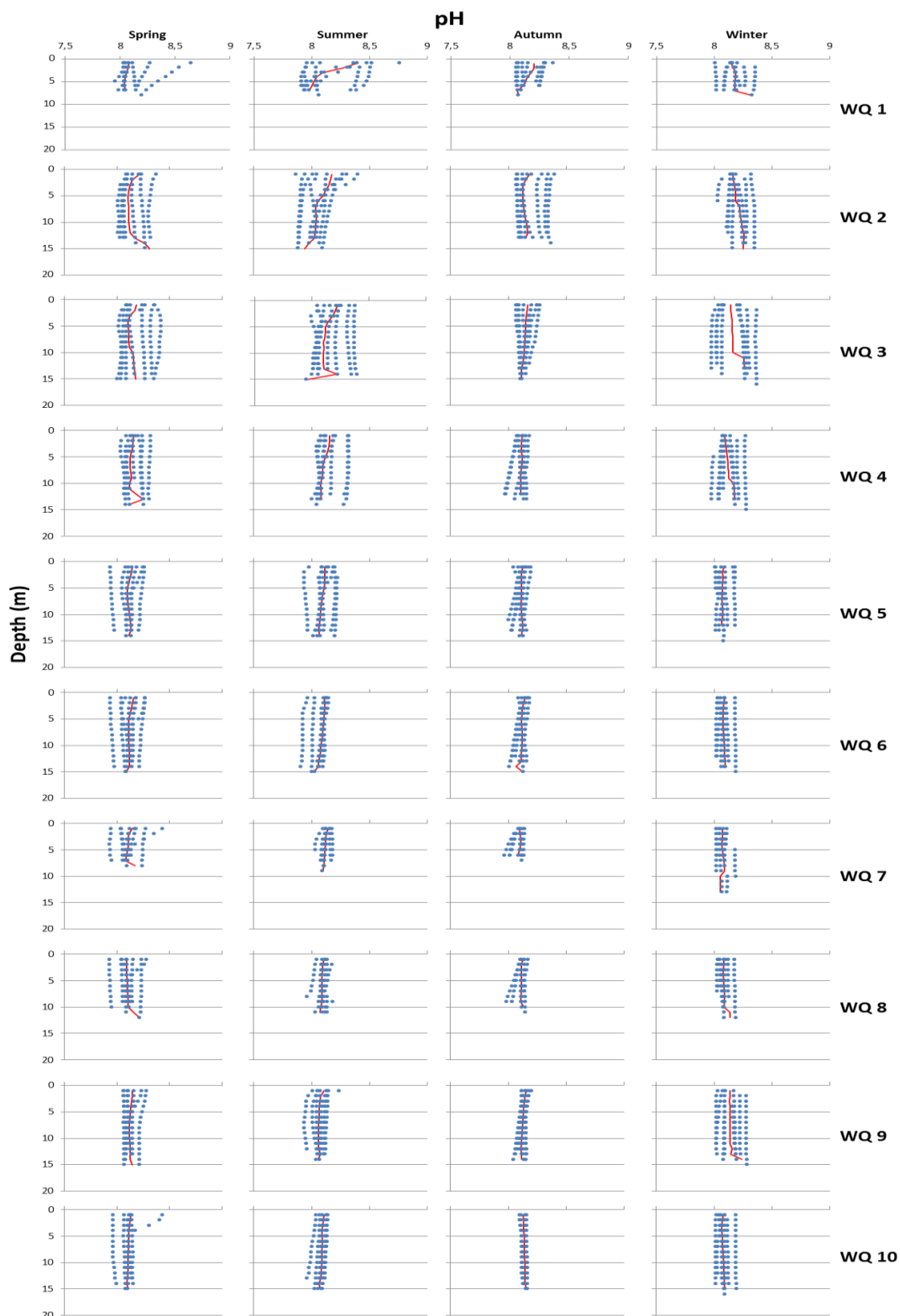


Table 11: *Depth profile data of the pH at each water quality monitoring stations for each season over the entire survey period. Median trends are shown in red.*

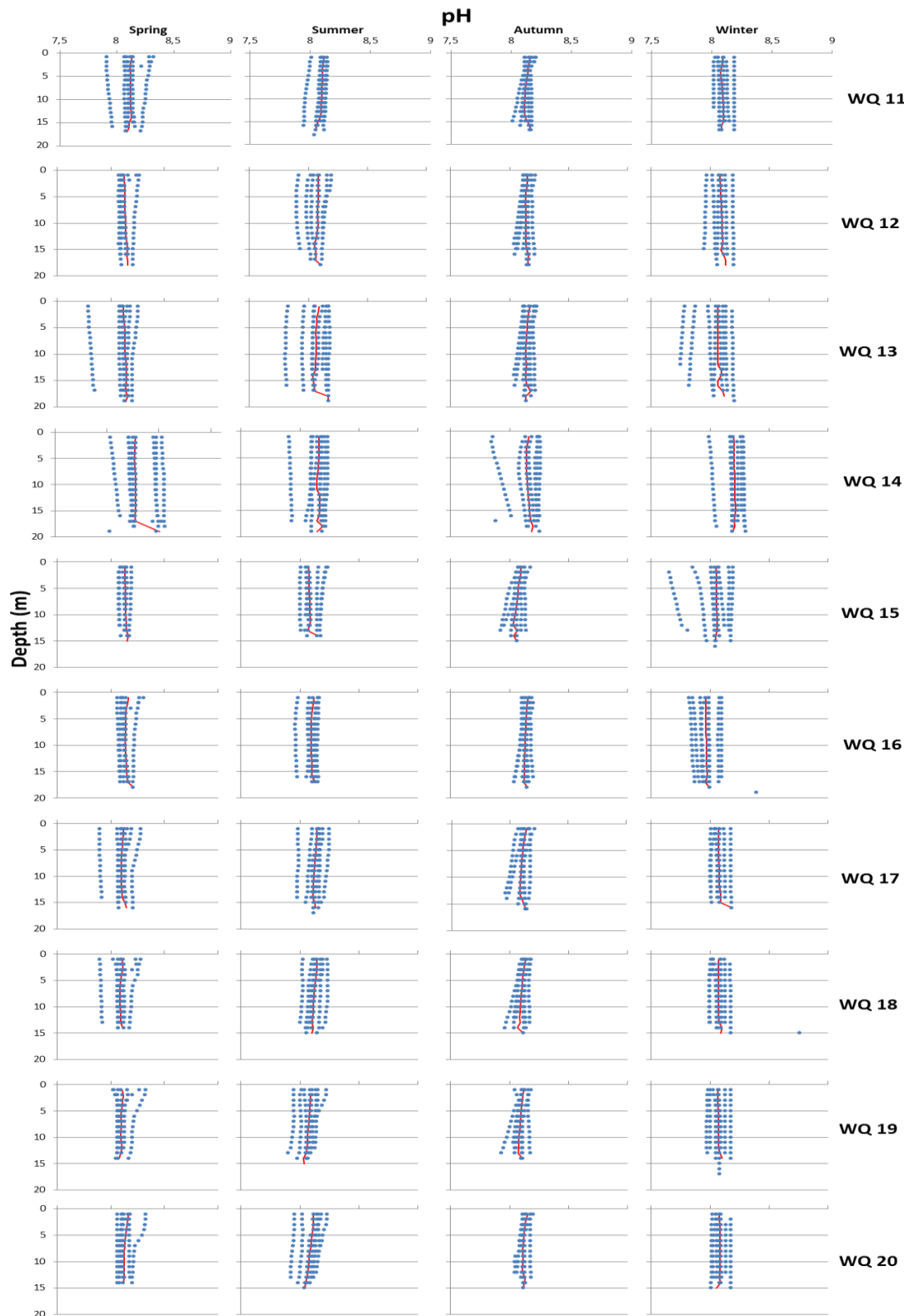


Figure 1J: Depth profile data of the pH at each water quality monitoring stations for each season over the entire survey period. Median trends are shown in red.

ANNEXURE 2:

Sediment Quality Baseline Monitoring Data

Table 2A: Grain size composition and total organic carbon (TOC) of intertidal sediment for November 2015.

Sample #	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHInt1	0.12	1.47	0.85	1.72	3.85	3.98	16.59	32.66	32.24	6.50	0.02	1.98
DHInt2	0.02	0.74	0.46	0.51	1.67	1.26	8.97	29.43	47.17	9.74	0.04	2.97
DHInt3	0.12	0.76	0.42	0.88	1.74	1.89	9.65	29.71	43.33	11.48	0.03	1.90
DHInt4	0.07	0.55	0.33	0.70	1.39	1.65	9.15	31.22	45.26	9.64	0.03	2.00
DHInt5	0.16	0.60	0.35	0.53	2.25	1.85	11.35	28.26	45.52	9.14	0.00	1.98
DHInt6	0.06	0.70	0.50	1.69	2.86	3.12	13.43	30.93	39.58	7.13	0.00	1.90
DHInt7	0.07	0.74	0.79	1.37	5.65	4.52	24.19	30.39	27.44	4.85	0.00	0.99
DHInt8	0.02	0.69	0.56	1.30	2.89	3.18	14.68	27.69	38.88	10.11	0.00	1.94
DHInt9	0.11	0.76	0.72	1.02	4.38	3.53	22.39	32.43	29.40	5.27	0.00	1.94
DHInt10	1.53	0.30	0.00	0.01	0.73	1.39	8.03	23.84	48.90	15.05	0.22	1.56
DHInt11	0.08	0.26	0.27	0.42	1.63	1.31	9.57	25.70	48.85	11.76	0.17	1.00
DHInt12	0.05	0.66	0.42	0.86	1.62	1.78	9.46	28.84	45.15	11.04	0.11	1.98
DHInt13	0.05	0.69	0.47	0.63	2.31	1.84	14.13	33.25	38.13	8.47	0.04	1.94
DHInt14	0.05	1.24	0.65	1.24	2.30	2.41	11.65	31.86	40.46	8.13	0.01	1.96
DHInt15	0.00	0.38	0.25	0.37	1.16	0.96	6.81	25.28	51.11	13.58	0.10	0.83
DHInt16	0.08	0.90	0.47	0.83	1.66	1.69	8.62	28.20	45.24	12.31	0.01	1.98
DHInt17	0.07	0.86	0.59	0.75	2.60	2.11	13.90	31.41	38.99	8.66	0.06	1.96
DHInt18	0.11	2.19	1.25	2.53	4.59	5.03	26.64	26.87	26.82	3.94	0.02	0.91
DHInt19	0.04	1.24	0.73	0.82	2.87	2.05	13.73	33.02	35.69	9.78	0.04	0.99
DHInt20	0.03	0.43	0.30	0.60	1.29	1.54	10.08	38.53	39.14	8.03	0.03	0.98
DHInt21	0.01	0.56	0.42	0.55	1.70	1.27	8.14	32.71	47.44	7.18	0.02	0.98
DHInt22	0.22	1.72	0.68	1.29	2.40	2.35	11.18	31.64	41.96	6.54	0.02	0.99

Sample #	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHInt23	0.06	0.61	0.28	0.35	1.38	1.22	8.42	30.43	48.77	8.47	0.00	0.99
DHInt24	0.04	0.52	0.32	0.64	1.32	1.49	7.34	21.27	53.52	13.51	0.02	1.00
DHInt25	0.03	0.28	0.22	0.40	1.58	1.38	9.74	25.00	45.68	15.32	0.38	1.98
DHInt26	0.11	1.12	0.64	1.28	2.64	3.07	14.02	33.22	37.07	6.80	0.03	0.91
DHInt27	0.00	0.62	0.47	0.67	2.34	1.94	13.23	33.73	38.44	7.96	0.61	1.98
DHInt28	0.19	1.15	0.64	1.57	3.83	4.27	17.53	30.53	31.81	7.43	1.04	1.98
DHInt29	0.06	0.44	0.30	0.48	2.43	2.35	15.52	33.79	35.43	8.65	0.57	1.00
DHInt30	0.04	0.63	0.43	0.92	2.23	2.52	12.08	29.68	43.08	8.32	0.07	1.98
DHInt31	0.00	0.16	0.18	0.30	1.59	1.55	11.20	33.98	43.60	7.43	0.01	1.92
DHInt32	0.12	1.13	0.74	1.66	3.19	2.62	8.53	19.55	49.42	12.96	0.07	1.00
DHInt33	0.12	0.80	0.77	1.38	6.09	5.10	24.13	33.91	23.15	4.53	0.02	1.00
DHInt34	0.06	0.74	0.59	1.44	3.23	3.47	15.92	31.67	34.41	8.36	0.11	1.64
DHInt35	0.22	0.50	0.55	1.01	4.07	3.31	14.87	33.32	35.73	6.42	0.02	1.00
DHInt36	0.19	0.61	0.50	1.47	3.51	3.95	18.31	31.22	31.64	8.50	0.12	1.98
DHInt37	0.94	0.56	0.34	0.66	2.92	2.46	16.68	29.68	36.86	8.80	0.09	0.99
DHInt38	1.35	0.58	0.21	0.29	1.34	1.29	11.23	20.70	27.86	30.47	4.69	2.50
DHInt39	0.09	0.87	0.58	1.00	4.74	4.13	29.05	35.48	20.33	3.62	0.12	2.00
DHInt40	44.40	2.16	0.37	0.52	2.29	1.89	10.29	16.55	18.34	3.13	0.07	1.00
DHInt41	0.04	0.39	0.22	0.31	1.40	1.14	9.00	27.91	50.51	9.07	0.02	1.98
DHInt42	0.58	0.61	0.32	0.51	2.06	1.45	9.46	27.11	44.36	13.31	0.24	2.00
DHInt43	0.01	0.33	0.19	0.43	1.05	1.06	5.44	22.26	53.55	15.66	0.02	0.99
DHInt44	0.16	0.76	0.34	0.40	1.56	1.20	9.21	25.76	46.68	13.80	0.12	0.96
DHInt45	1.22	2.54	1.08	1.10	2.86	1.56	9.09	25.47	43.99	10.95	0.14	1.98

Sample #	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHInt46	0.17	0.99	0.55	1.01	2.10	2.06	9.56	25.55	47.42	10.59	0.00	1.96
DHInt47	0.05	0.60	0.43	0.59	2.40	1.76	12.84	29.41	44.06	7.79	0.06	1.98
DHInt48	0.02	73.77	0.06	0.09	0.31	0.20	1.27	4.09	14.50	5.68	0.01	1.98
DHInt49	0.47	0.29	0.38	0.60	2.66	2.12	14.46	27.44	41.35	10.21	0.01	2.00
DHInt50	0.07	0.47	0.27	0.38	1.53	2.49	13.53	38.58	33.79	8.77	0.12	0.93
DHInt51	0.00	0.08	0.09	0.27	1.07	1.56	25.13	52.35	17.88	1.55	0.03	2.00
DHInt52	0.03	0.60	0.55	1.30	3.66	4.77	23.03	32.28	26.29	7.46	0.03	0.98
DHInt53	4.29	2.52	1.01	1.45	6.01	4.18	25.54	33.13	19.16	2.69	0.03	0.99

Table 2B: Grain size composition and total organic carbon (TOC) of subtidal sediment for November 2015.

Sample #	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHSubt1	0.00	0.25	0.23	0.77	2.24	2.59	8.94	19.73	37.99	21.69	5.56	5.80
DHSubt2	0.09	0.89	0.54	0.57	1.75	1.38	10.36	29.59	45.99	8.66	0.19	1.96
DHSubt3	0.01	0.30	0.33	0.77	1.52	1.84	8.75	25.10	45.48	14.96	0.95	2.27
DHSubt4	0.00	0.12	0.15	0.21	0.75	0.56	4.66	30.67	54.28	8.44	0.17	1.37
DHSubt5	0.05	0.50	0.28	0.60	1.38	1.47	6.76	22.63	49.11	16.51	0.72	2.20
DHSubt6	0.09	0.70	0.55	0.74	2.66	2.02	10.69	24.37	44.04	12.06	2.08	2.48
DHSubt7	0.01	0.49	0.32	0.68	1.50	1.69	8.73	21.29	50.41	14.14	0.74	2.48
DHSubt8	0.00	0.43	0.37	0.47	1.94	1.63	11.56	32.55	37.67	10.93	2.44	2.11
DHSubt9	0.00	0.33	0.28	0.53	1.04	1.27	8.28	24.87	48.30	14.28	0.81	2.54
DHSubt10	0.01	0.50	0.36	0.47	1.50	1.19	7.85	25.65	45.38	14.40	2.68	3.19
DHSubt11	0.01	0.29	0.19	0.41	0.82	1.01	6.21	21.28	53.23	15.07	1.47	2.44
DHSubt12	0.00	0.30	0.25	0.30	1.15	0.86	6.99	29.48	51.87	8.22	0.57	1.98
DHSubt13	0.01	0.57	0.45	1.12	1.88	3.78	16.43	28.21	36.59	10.47	0.49	1.69
DHSubt14	0.03	0.39	0.26	0.30	1.13	1.00	9.73	28.75	45.92	12.02	0.47	1.98
DHSubt15	0.05	0.49	0.31	0.76	1.90	2.21	11.31	28.40	42.17	12.26	0.13	1.98
DHSubt16	0.00	0.27	0.24	0.35	1.41	1.24	11.87	33.49	41.31	9.80	0.02	1.98
DHSubt17	0.00	0.29	0.17	0.41	1.13	1.44	8.65	27.29	48.48	11.89	0.25	2.22
DHSubt18	0.02	0.32	0.27	0.34	1.47	1.23	9.84	29.82	43.23	12.89	0.57	2.13
DHSubt19	0.00	0.26	0.19	0.45	0.92	1.10	6.66	27.37	49.53	12.98	0.54	2.56

Sample #	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHSubt20	0.01	0.36	0.42	0.63	3.43	3.52	26.69	43.22	19.48	2.25	0.00	0.89
DHSubt21	0.00	0.29	0.24	0.43	2.17	2.48	17.32	37.10	34.00	5.85	0.15	1.90
DHSubt22	0.11	1.20	0.71	1.61	3.49	3.43	12.97	28.00	33.99	12.49	2.00	3.96
DHSubt23	0.03	0.67	0.46	0.54	2.13	1.82	12.20	34.66	39.95	7.49	0.05	1.83
DHSubt24	0.03	0.41	0.30	0.68	1.80	8.19	5.97	16.38	50.57	13.70	1.97	2.35
DHSubt25	0.01	0.65	0.48	0.58	2.58	2.71	26.06	35.47	23.74	7.45	0.28	1.08
DHSubt26	0.12	0.88	0.72	1.60	3.99	3.64	9.62	15.27	33.73	25.31	5.11	8.33
DHSubt27	0.00	1.24	0.98	1.39	5.43	3.67	18.28	29.75	27.11	9.73	2.42	3.96
DHSubt28	0.01	0.77	0.52	1.08	2.44	3.15	19.30	37.00	29.02	6.63	0.07	1.74
DHSubt29	0.64	1.17	1.17	1.37	4.85	3.25	14.23	21.69	21.02	19.88	10.73	6.54
DHSubt30	0.53	0.99	0.32	0.70	1.68	2.10	12.23	27.69	31.76	18.30	3.70	3.00
DHSubt31	0.48	1.27	0.57	0.79	3.70	2.90	16.00	27.03	26.94	16.35	3.96	4.39
DHSubt32	0.07	0.97	0.71	1.38	2.67	2.51	11.79	35.41	38.47	5.77	0.25	0.99
DHSubt33	0.08	0.54	0.41	0.66	2.85	2.37	13.77	35.09	38.04	5.81	0.38	1.80
DHSubt34	0.12	1.06	0.70	1.51	3.40	3.67	16.89	33.19	25.83	11.12	2.52	2.75
DHSubt35	0.06	0.70	0.66	0.98	4.47	3.17	14.98	22.64	26.52	18.33	7.50	4.62
DHSubt36	0.32	1.15	0.79	1.53	3.53	3.32	12.10	21.77	26.30	21.03	8.15	3.88
DHSubt37	1.30	2.12	0.72	0.83	3.07	2.28	13.97	30.37	26.05	17.18	2.12	3.60
DHSubt38	0.81	1.78	0.84	1.51	3.21	3.13	12.26	23.15	24.80	20.11	8.41	4.95
DHSubt39	0.21	5.10	3.01	2.90	6.68	2.85	9.26	12.07	14.47	22.43	21.01	8.14

Sample #	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHSubt40	0.06	0.42	0.35	0.96	3.44	4.45	18.91	33.54	32.86	4.95	0.05	0.00
DHSubt41	0.00	0.29	0.26	0.41	1.48	1.26	8.60	34.81	47.51	5.36	0.02	0.95
DHSubt42	0.02	0.47	0.33	0.58	1.08	0.96	4.85	18.65	56.15	16.88	0.04	1.92
DHSubt43	0.01	0.27	0.25	0.38	1.67	1.39	10.75	29.63	45.98	9.61	0.07	0.99
DHSubt44	0.06	0.77	0.61	1.39	3.26	3.55	17.61	37.61	27.84	7.22	0.08	0.00
DHSubt45	0.37	2.77	1.76	1.99	5.62	3.37	13.37	25.06	30.73	11.91	3.04	5.00
DHSubt46	0.00	0.10	0.08	0.22	0.55	0.57	3.12	12.59	60.83	21.87	0.07	3.19
DHSubt47	0.08	0.61	0.51	0.73	3.78	2.98	13.74	25.89	27.89	18.03	5.75	5.06
DHSubt48	0.15	5.86	3.21	5.77	9.76	6.46	11.96	10.29	12.08	19.71	14.75	13.95
DHSubt49	0.02	0.36	0.37	0.59	3.33	3.71	27.82	37.11	22.83	3.86	0.00	1.82
DHSubt50	0.02	0.04	0.39	1.23	3.60	4.55	17.69	28.38	35.35	8.58	0.15	1.98
DHSubt51	0.00	0.23	0.23	0.31	1.30	1.27	12.13	38.28	41.21	4.94	0.11	0.97

Table 2C: Trace metal concentrations of intertidal sediment for November 2015.

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHInt1	0.17	2.2	0.2	1.4	11.7	1.9	0.43	100.5	2.9	5.4	10.8	75.7
DHInt2	0.25	2.1	0.3	1.6	14.9	2.2	0.53	130.8	3.5	4.6	13.4	32.4
DHInt3	0.23	2.2	0.3	1.8	14.5	1.4	0.55	150.2	3.5	2.3	18.6	64.9
DHInt4	0.23	2.0	0.2	1.4	12.9	1.2	0.55	107.4	3.0	3.6	10.3	118.9
DHInt5	0.20	2.3	0.3	1.3	12.2	1.4	0.49	85.1	3.0	2.4	13.0	10.8
DHInt6	0.22	3.1	0.2	1.4	14.2	1.8	0.53	112.0	3.4	3.6	10.6	ND
DHInt7	0.23	3.4	0.2	1.2	13.8	1.2	0.48	118.7	3.1	0.2	9.6	ND
DHInt8	0.27	3.2	0.3	1.3	14.5	1.1	0.46	134.0	3.2	3.9	12.3	21.6
DHInt9	0.22	2.9	0.2	1.2	14.7	0.1	0.50	122.8	2.9	3.4	11.7	ND
DHInt10	0.34	2.9	0.5	1.3	21.0	2.4	0.67	95.2	3.2	4.3	14.8	259.5
DHInt11	0.27	3.5	0.3	1.2	17.5	2.4	0.51	75.7	2.7	4.7	13.4	140.5
DHInt12	0.27	1.2	0.3	1.3	19.8	2.2	0.72	87.9	2.8	1.1	12.0	97.3
DHInt13	0.28	2.6	0.3	1.4	21.0	1.3	0.76	131.8	3.0	4.9	11.1	50.0
DHInt14	0.25	1.4	0.3	1.1	19.8	1.4	0.72	133.8	2.8	2.2	10.5	7.2
DHInt15	0.24	0.7	0.1	1.5	14.9	2.5	0.51	63.5	3.2	4.6	13.4	14.3
DHInt16	0.26	2.6	0.2	1.7	15.7	2.8	0.53	156.3	4.2	3.7	15.1	14.3
DHInt17	0.27	2.8	0.3	1.7	15.2	3.1	0.50	162.2	4.1	5.6	16.3	ND
DHInt18	0.24	1.8	0.1	1.9	14.5	11.0	0.49	241.6	4.9	6.2	16.6	ND
DHInt19	0.25	1.8	0.2	1.4	15.0	2.0	0.49	132.9	3.4	2.5	12.9	ND
DHInt20	0.31	3.6	1.0	2.4	30.3	7.5	0.68	180.0	11.1	11.8	18.5	ND
DHInt21	0.31	2.3	0.3	1.6	20.1	3.0	0.68	150.9	3.4	3.0	12.8	7.2
DHInt22	0.23	2.4	0.2	1.4	16.0	1.5	0.54	130.5	3.8	2.3	11.9	ND

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHInt23	0.21	2.1	0.2	1.5	14.4	1.1	0.47	126.0	3.4	5.8	13.2	ND
DHInt24	0.29	3.2	0.3	1.7	18.6	1.4	0.52	130.5	3.2	9.2	12.6	ND
DHInt25	0.29	2.8	0.4	1.5	15.8	2.6	0.50	93.6	3.3	6.1	17.1	28.6
DHInt26	0.23	2.6	0.2	1.5	14.5	3.0	0.49	159.1	3.8	1.2	15.3	ND
DHInt27	0.36	2.1	0.3	1.8	17.7	6.2	0.60	89.8	4.3	5.9	23.9	14.3
DHInt28	0.43	2.5	0.3	1.9	22.2	9.0	0.67	79.1	4.5	10.5	36.9	42.9
DHInt29	0.26	2.3	0.2	1.5	16.5	3.0	0.54	73.6	3.9	3.7	17.2	35.7
DHInt30	0.22	2.3	0.2	1.4	15.0	2.8	0.52	67.9	3.3	3.9	12.8	ND
DHInt31	0.24	2.6	0.3	1.5	17.7	2.4	0.56	103.1	3.0	5.7	15.1	42.9
DHInt32	0.31	2.4	0.3	1.6	19.9	2.7	0.64	86.3	3.3	5.3	16.8	ND
DHInt33	0.29	1.6	0.3	2.0	21.1	2.7	0.70	215.1	4.5	3.8	17.0	ND
DHInt34	0.30	2.3	0.4	2.4	23.6	2.4	0.81	104.0	3.8	4.6	17.0	ND
DHInt35	0.26	2.4	0.3	1.8	20.5	2.0	0.68	91.8	3.0	5.7	14.7	ND
DHInt36	0.24	1.7	0.3	1.8	19.6	2.8	0.61	75.0	3.0	5.0	17.0	ND
DHInt37	0.28	2.2	0.3	1.8	21.7	3.6	0.71	91.2	3.1	4.6	17.4	ND
DHInt38	0.56	2.7	0.9	3.7	37.1	17.3	1.08	94.7	6.2	14.8	117.0	ND
DHInt39	0.25	2.0	0.3	1.5	20.7	2.2	0.67	98.4	3.1	5.6	16.5	ND
DHInt40	0.20	1.1	0.3	0.6	11.1	0.3	0.48	40.5	1.3	5.2	6.6	ND
DHInt41	0.20	1.5	0.2	1.3	12.0	2.0	0.45	93.2	2.7	4.4	13.2	ND
DHInt42	0.24	0.7	0.3	1.3	14.9	9.3	0.55	54.7	3.8	9.2	23.0	ND
DHInt43	0.28	3.0	0.3	1.8	17.0	2.2	0.60	143.9	4.2	3.3	16.6	ND
DHInt44	0.29	1.6	0.3	1.4	16.0	1.4	0.59	64.6	3.7	6.4	18.1	ND
DHInt45	0.24	0.4	0.3	1.4	16.6	5.5	0.51	48.0	4.1	15.6	36.7	ND

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHInt46	0.21	2.7	0.2	1.5	13.9	8.8	0.48	111.8	3.3	6.6	13.6	14.3
DHInt47	0.28	1.5	0.3	1.4	15.6	3.4	0.54	64.0	3.6	8.6	18.8	14.3
DHInt48	0.28	3.9	0.3	1.4	16.7	2.3	0.55	149.9	3.8	4.4	16.8	ND
DHInt49	0.24	4.8	0.2	1.5	14.0	3.0	0.43	86.8	2.8	4.1	17.1	ND
DHInt50	0.20	0.8	0.3	1.4	18.3	5.9	0.57	50.9	3.3	9.1	22.0	7.2
DHInt51	0.16	2.9	0.2	1.0	13.1	1.0	0.43	95.9	2.7	1.4	9.9	ND
DHInt52	0.21	2.6	0.1	1.3	17.6	23.0	0.52	137.1	3.2	1.4	10.6	ND
DHInt53	0.23	2.1	0.4	1.8	19.5	3.1	0.54	72.8	2.5	4.4	19.9	ND

Table 2D: Trace metal concentrations of subtidal sediment for November 2015.

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHSubt1	1.67	6.0	1.0	2.4	68.2	77.6	2.34	186.7	12.3	28.5	107.3	139.1
DHSubt2	0.38	2.7	0.3	1.9	23.8	7.5	0.90	136.3	3.7	5.8	16.6	113.0
DHSubt3	0.63	2.4	0.4	2.1	30.7	10.2	1.26	103.0	4.9	9.0	25.3	78.3
DHSubt4	0.27	1.5	0.3	0.9	17.1	5.3	0.74	76.2	2.5	4.4	9.9	60.9
DHSubt5	0.40	2.3	0.3	1.1	20.0	7.3	0.88	82.5	3.3	8.1	15.4	34.8
DHSubt6	0.72	3.0	0.6	2.2	32.5	12.5	1.25	102.7	5.4	9.7	33.6	52.2
DHSubt7	0.42	3.1	0.3	1.3	22.0	5.6	0.83	79.2	3.3	9.4	15.3	69.6
DHSubt8	0.80	3.7	0.6	2.1	35.3	9.9	1.33	111.2	5.6	12.8	33.9	78.3
DHSubt9	0.51	3.8	0.6	1.5	24.7	5.4	0.96	96.2	4.0	6.9	17.5	52.2
DHSubt10	0.78	4.3	0.8	2.1	35.0	10.7	1.28	111.6	5.6	10.5	32.2	78.3
DHSubt11	0.56	3.1	0.6	1.8	27.1	7.7	1.04	94.5	4.5	7.5	21.1	113.0
DHSubt12	0.42	2.2	0.6	1.3	21.7	5.4	0.89	83.0	3.1	4.7	14.9	26.1
DHSubt13	0.43	4.4	0.4	1.2	21.6	4.8	0.83	87.7	3.3	6.7	16.6	113.0
DHSubt14	0.39	3.7	0.3	1.2	21.7	5.4	0.82	77.9	2.9	7.7	15.4	34.8
DHSubt15	0.34	3.9	0.3	1.3	19.5	4.6	0.80	85.6	2.9	4.3	13.8	26.1
DHSubt16	0.32	3.3	0.4	1.4	19.5	3.6	0.81	116.7	3.2	3.7	11.9	43.5
DHSubt17	0.36	3.0	0.3	1.3	21.1	3.8	0.75	73.2	3.2	3.2	14.3	156.5
DHSubt18	0.54	2.4	0.3	1.8	26.3	6.9	1.03	95.8	4.1	9.5	19.9	34.8
DHSubt19	0.49	2.9	0.4	1.4	25.6	7.8	1.05	90.0	4.0	8.4	19.3	26.1
DHSubt20	0.28	2.3	0.3	1.2	18.6	3.5	0.85	134.9	2.8	3.1	9.9	26.1
DHSubt21	0.37	2.0	0.2	1.4	21.2	6.4	0.87	100.2	3.2	5.7	14.7	121.7
DHSubt22	1.30	3.8	0.9	3.2	51.6	39.3	1.81	134.2	8.8	22.5	73.7	182.6

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHSubt23	0.44	3.0	0.3	1.8	24.9	8.5	0.97	155.6	4.0	8.8	19.8	34.8
DHSubt24	1.09	3.6	0.8	3.0	44.0	44.2	1.51	128.6	7.3	20.1	67.9	34.8
DHSubt25	0.40	2.4	0.3	1.6	22.3	11.2	0.75	141.1	4.0	8.2	22.0	8.7
DHSubt26	2.22	6.3	1.6	5.9	86.0	121.1	2.71	208.4	15.8	46.7	178.2	156.5
DHSubt27	1.28	2.8	1.0	3.4	52.6	37.1	1.66	105.8	8.9	23.7	80.9	139.1
DHSubt28	0.41	1.9	0.4	1.8	24.1	8.1	0.91	168.6	4.2	7.4	20.4	269.6
DHSubt29	1.68	3.8	1.2	5.3	65.5	53.8	2.15	168.6	12.0	32.6	127.6	147.8
DHSubt30	0.72	3.0	0.6	3.1	36.4	27.4	1.15	102.0	6.2	14.5	69.0	26.1
DHSubt31	1.21	3.9	0.9	4.1	49.3	41.1	1.65	120.4	9.5	26.6	98.9	191.3
DHSubt32	0.43	3.0	0.3	2.0	25.2	10.8	0.83	161.2	4.5	8.6	25.9	182.6
DHSubt33	0.46	2.5	0.3	1.8	25.0	8.6	0.93	158.2	4.4	7.3	22.1	26.1
DHSubt34	1.23	2.8	0.9	3.4	52.0	39.6	1.68	111.2	9.1	25.4	83.4	226.1
DHSubt35	1.50	3.2	1.2	4.1	63.2	71.8	1.93	145.3	11.5	35.4	128.5	130.4
DHSubt36	1.36	4.7	1.3	4.6	61.5	57.8	1.86	133.4	11.7	38.6	132.0	113.0
DHSubt37	0.72	2.3	0.7	2.4	36.8	23.3	1.14	97.7	6.3	16.4	63.4	60.9
DHSubt38	1.41	4.3	1.4	4.9	67.6	74.5	1.88	137.4	12.4	35.4	164.1	278.3
DHSubt39	2.14	6.1	2.3	7.1	93.6	114.2	2.78	185.4	19.4	55.5	225.0	200.0
DHSubt40	0.29	0.0	0.4	1.0	21.5	25.0	0.70	59.2	2.9	16.1	20.3	147.8
DHSubt41	0.25	1.7	0.2	1.1	17.2	4.2	0.60	98.4	2.9	3.6	11.9	200.5
DHSubt42	0.36	3.7	0.4	1.6	20.3	3.8	0.80	157.4	3.6	5.8	15.3	54.1
DHSubt43	0.31	3.8	0.3	1.1	18.8	2.4	0.63	111.9	3.0	7.0	14.0	43.2
DHSubt44	0.28	3.4	0.3	1.3	19.0	2.2	0.64	106.4	2.8	5.7	12.1	43.2
DHSubt45	1.34	5.1	1.2	3.8	61.3	89.1	1.70	129.8	9.7	51.7	159.2	367.6

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHSubt46	0.43	3.7	0.4	1.5	22.6	10.6	0.70	142.8	3.7	8.7	25.1	54.1
DHSubt47	1.43	4.7	1.1	3.7	57.6	44.6	1.73	160.0	9.3	28.9	101.0	324.3
DHSubt48	3.50	9.8	2.5	8.8	130.5	114.5	4.36	369.6	23.9	78.2	268.5	454.1
DHSubt49	0.49	2.1	0.5	1.7	29.6	7.9	0.92	154.1	4.7	8.2	25.6	64.9
DHSubt50	0.30	2.1	0.4	1.0	20.2	2.7	0.71	104.9	2.8	3.3	11.1	162.2
DHSubt51	0.34	1.3	0.3	1.6	22.6	3.7	0.79	101.8	3.3	5.8	11.5	108.1

Table 2E: Grain size composition and total organic carbon (TOC) of intertidal sediment for January 2016.

Sample Nr.	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHInt 1	0.16	1.21	0.59	1.49	3.06	3.28	14.28	41.75	27.15	6.91	0.13	1.01
DHInt 2	0.04	0.57	0.28	0.59	1.26	1.61	8.09	39.84	42.38	5.18	0.17	1.87
DHInt 3	0.17	1.09	0.45	1.04	2.08	2.21	9.99	43.33	33.29	6.30	0.04	1.92
DHInt 4	0.30	1.35	0.53	0.64	2.36	2.21	12.40	37.86	34.67	7.60	0.09	2.02
DHInt 5	0.05	0.59	0.44	0.79	1.32	1.53	8.24	26.89	50.36	9.56	0.23	1.94
DHInt 6	0.27	1.34	0.62	0.87	3.39	3.34	18.45	29.44	36.06	6.15	0.06	2.00
DHInt 7	0.08	0.74	0.65	1.82	4.70	4.88	19.68	30.45	30.36	6.56	0.08	1.79
DHInt 8	0.72	2.00	0.84	1.08	3.29	2.96	16.86	23.14	38.10	10.97	0.03	2.00
DHInt 9	0.02	0.48	0.52	1.33	2.70	3.06	17.00	34.18	35.72	4.96	0.03	1.90
DHInt 10	0.04	0.19	0.20	0.42	1.23	1.42	7.90	30.78	45.02	12.18	0.62	1.98
DHInt 11	0.28	1.20	0.40	0.50	1.49	1.47	10.23	24.80	46.74	12.46	0.42	2.02
DHInt 12	0.19	0.91	0.43	0.56	1.64	1.57	12.50	28.96	42.79	10.29	0.17	1.00
DHInt 13	0.01	0.44	0.23	0.70	1.47	1.75	12.76	37.31	36.50	8.63	0.21	1.00
DHInt 14	0.38	1.86	0.66	0.81	2.59	2.09	10.97	37.65	35.80	7.16	0.04	1.96
DHInt 15	0.02	0.25	0.24	0.50	0.85	1.71	7.06	31.41	46.08	11.60	0.28	2.00
DHInt 16	0.23	1.33	0.46	0.51	1.57	1.36	7.93	27.26	47.27	11.98	0.09	1.94
DHInt 17	0.04	0.61	0.74	0.65	1.85	2.06	12.74	36.03	37.19	7.84	0.25	0.97
DHInt 18	0.28	2.56	1.11	2.50	6.09	5.54	24.04	33.64	20.25	3.70	0.29	1.94
DHInt 19	0.12	1.66	0.76	0.97	2.69	2.27	18.28	25.35	37.38	10.39	0.12	1.98
DHInt 20	0.17	2.10	0.82	0.86	3.85	1.78	2.26	14.51	61.67	11.62	0.37	1.00
DHInt 21	0.69	1.18	0.45	0.49	1.74	1.81	17.11	24.80	42.24	9.43	0.05	1.05

Sample Nr.	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHInt 22	0.39	1.42	0.51	0.64	2.25	2.33	12.67	37.94	36.87	4.95	0.04	0.99
DHInt 23	0.04	0.87	0.46	0.46	1.38	1.30	9.95	30.95	44.91	9.61	0.07	2.00
DHInt 24	0.04	0.28	0.17	0.39	1.01	1.34	7.58	27.79	49.25	11.96	0.20	1.94
DHInt 25	0.18	1.39	0.44	0.46	1.48	1.43	8.57	26.50	44.78	14.21	0.55	1.98
DHInt 26	0.22	1.42	0.72	1.35	2.95	2.57	11.71	32.50	40.15	5.91	0.51	2.00
DHInt 27	0.33	0.60	0.46	0.87	3.11	3.46	17.90	6.88	52.09	11.44	2.87	1.96
DHInt 28	0.22	1.61	0.69	0.77	2.34	2.20	12.88	35.13	35.63	7.54	0.98	1.85
DHInt 29	0.08	0.30	0.24	0.74	1.77	2.25	12.76	35.53	36.49	8.64	1.21	2.25
DHInt 30	0.27	1.19	0.46	0.53	1.86	1.79	12.85	28.78	43.42	8.74	0.12	1.04
DHInt 31	0.04	0.22	0.17	0.52	1.53	1.60	9.22	38.64	39.58	8.12	0.37	1.94
DHInt 32	0.26	1.03	0.51	0.74	2.11	1.43	6.30	11.02	55.02	21.10	0.48	2.06
DHInt 33	0.10	0.80	0.68	1.98	5.40	5.40	22.91	34.30	24.31	3.94	0.18	1.05
DHInt 34	0.25	1.26	0.85	1.21	4.79	4.35	27.44	25.02	28.75	5.97	0.11	1.90
DHInt 35	0.53	0.85	0.91	1.65	3.88	3.79	17.52	31.47	33.69	5.54	0.16	0.92
DHInt 36	0.44	0.77	0.50	1.40	3.52	3.79	18.16	32.49	31.81	6.84	0.27	1.00
DHInt 37	0.52	0.69	0.28	0.96	2.93	2.88	14.04	33.98	35.47	8.12	0.13	1.96
DHInt 38	0.86	0.62	0.21	0.60	1.61	2.30	11.34	23.36	30.93	24.66	3.50	2.02
DHInt 39	0.09	0.82	1.29	0.60	3.58	3.24	19.23	35.69	29.39	5.68	0.40	1.01
DHInt 40	36.15	1.71	0.44	0.80	2.42	1.76	7.78	15.18	28.08	5.24	0.44	1.01
DHInt 41	0.19	0.29	0.21	0.33	0.88	1.10	7.13	33.93	46.64	9.15	0.15	0.97
DHInt 42	0.80	0.48	0.23	0.50	1.51	1.52	7.23	24.23	52.98	10.30	0.23	1.05
DHInt 43	0.15	0.63	0.35	0.85	0.91	1.15	5.96	28.37	52.27	9.35	0.02	1.01
DHInt 44	0.37	0.19	0.49	1.01	1.09	5.12	47.34	37.99	5.95	0.23	0.22	2.02

Sample Nr.	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHInt 45	0.10	0.45	0.25	0.49	1.27	0.91	18.53	36.17	36.00	5.76	0.07	1.01
DHInt 46	0.01	0.84	0.48	0.68	1.35	1.13	5.79	40.94	42.52	6.21	0.03	0.98
DHInt 47	0.11	0.12	0.10	0.31	0.63	0.88	8.01	42.62	39.90	7.01	0.30	1.89
DHInt 48	0.32	0.11	0.37	0.97	2.35	2.53	19.98	34.53	34.13	4.70	0.01	1.00
DHInt 49	0.03	0.21	0.30	0.60	1.23	0.84	5.20	21.83	57.16	12.54	0.06	0.00
DHInt 50	0.28	0.55	0.25	0.59	1.36	1.53	13.29	42.79	34.18	5.01	0.16	1.02
DHInt 51	0.19	0.39	0.35	0.76	2.75	5.55	49.00	27.75	11.27	1.97	0.02	0.93
DHInt 52	0.11	0.52	0.57	0.71	2.06	3.37	23.40	37.84	26.66	4.55	0.21	0.00
DHInt 53	1.14	1.43	0.59	1.49	3.85	5.14	21.03	35.76	25.23	4.08	0.25	0.99

Table 2F: Grain size composition and total organic carbon (TOC) of subtidal sediment for January 2016.

Sample Nr.	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHSubt1	0.05	0.12	0.08	0.13	0.37	0.61	7.52	21.76	41.35	22.67	5.35	4.49
DHSubt2	0.03	0.42	0.29	0.35	1.19	1.07	7.51	24.31	48.33	15.44	1.07	1.16
DHSubt3	0.13	4.77	2.41	3.50	10.92	6.27	14.11	15.14	18.24	15.71	8.79	9.52
DHSubt4	0.08	0.17	0.20	0.55	0.79	1.21	5.12	28.63	48.79	12.85	1.60	1.77
DHSubt5	0.16	0.82	0.51	0.70	2.30	2.12	11.44	26.04	43.36	11.73	0.81	1.83
DHSubt6	0.04	0.52	0.37	0.87	1.79	1.76	9.45	34.62	44.16	6.18	0.23	1.00
DHSubt7	0.09	0.99	0.51	0.65	2.17	1.90	10.71	21.25	46.61	14.22	0.92	1.98
DHSubt8	0.04	0.26	0.28	0.39	1.79	1.99	12.55	26.56	44.77	11.08	0.29	1.87
DHSubt9	0.01	0.09	0.14	0.41	0.69	0.90	5.77	23.32	50.15	17.04	1.50	1.92
DHSubt10	0.00	0.60	0.41	0.48	1.65	1.66	11.66	27.82	44.63	10.72	0.36	1.00
DHSubt11	0.01	0.30	0.50	0.46	1.62	1.59	13.56	43.49	27.89	10.18	0.41	1.87
DHSubt12	0.00	0.09	0.12	0.27	0.49	0.67	4.05	44.20	41.41	7.57	1.12	0.99
DHSubt13	0.04	0.60	0.64	0.93	5.29	4.98	25.67	28.88	26.85	5.97	0.15	1.87
DHSubt14	0.03	0.12	0.13	0.26	1.03	0.94	4.88	25.98	52.15	14.13	0.35	1.98
DHSubt15	0.03	0.65	0.33	0.38	1.49	1.65	12.75	28.43	43.19	10.97	0.14	1.01
DHSubt16	0.03	0.07	0.12	0.26	0.51	0.75	4.35	32.18	50.91	10.47	0.35	2.00
DHSubt17	0.07	1.46	0.74	1.04	3.62	3.21	17.32	34.33	33.19	4.94	0.08	2.00
DHSubt18	0.05	1.11	0.52	0.60	1.88	1.80	12.01	31.73	41.94	8.32	0.04	0.99
DHSubt19	0.07	0.18	0.28	0.49	0.90	0.77	4.28	25.94	55.73	10.49	0.86	1.98
DHSubt20	0.01	0.14	0.17	0.32	0.98	1.10	9.26	45.88	34.06	7.69	0.41	1.01
DHSubt21	0.28	1.58	0.52	0.67	2.63	2.89	19.72	34.14	31.11	6.26	0.19	1.94
DHSubt22	0.01	0.09	0.07	0.19	0.63	0.85	8.68	40.57	36.44	11.67	0.80	1.01

Sample Nr.	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHSubt23	0.04	0.23	0.95	1.13	3.19	2.33	12.27	24.22	37.85	14.94	2.86	3.06
DHSubt24	0.04	0.26	0.20	0.37	1.10	0.89	5.68	29.90	47.27	13.58	0.71	1.04
DHSubt25	0.05	1.21	0.51	0.64	2.43	3.52	38.11	30.06	18.94	4.30	0.24	1.00
DHSubt26	0.00	0.09	0.09	0.16	0.48	0.37	1.96	13.33	65.68	16.03	1.81	3.00
DHSubt27	0.09	1.10	0.47	1.15	2.74	2.51	14.21	43.89	28.34	5.06	0.44	1.82
DHSubt28	0.06	0.93	0.53	0.79	3.25	3.34	14.68	22.19	42.21	11.62	0.41	2.00
DHSubt29	0.38	0.30	0.15	0.37	0.72	1.20	4.48	17.56	25.39	34.49	14.97	5.15
DHSubt30	1.14	1.65	0.58	0.73	2.64	2.70	16.77	27.78	29.95	13.12	2.93	2.97
DHSubt31	1.40	0.69	0.23	0.65	1.27	1.73	10.62	30.25	33.96	16.95	2.26	1.96
DHSubt32	0.08	1.45	0.74	1.04	3.62	3.21	17.31	34.35	33.19	4.94	0.07	1.83
DHSubt33	0.08	0.76	0.57	1.02	2.52	2.26	31.36	12.63	40.30	8.02	0.47	1.01
DHSubt34	0.11	0.98	0.61	0.98	3.64	2.88	15.68	26.54	30.31	14.25	4.03	1.06
DHSubt35	0.29	0.52	0.66	1.46	3.05	3.29	14.35	30.81	25.74	13.47	6.36	3.53
DHSubt36	0.30	0.58	3.03	3.17	7.25	3.43	1.44	4.25	22.77	27.49	26.29	4.82
DHSubt37	1.15	0.90	0.33	0.71	1.68	1.96	10.26	32.04	35.30	13.21	2.47	10.34
DHSubt38	0.59	12.60	4.24	4.38	9.55	2.04	6.07	6.43	5.04	21.14	27.91	2.97
DHSubt39	0.05	0.16	0.68	0.52	2.21	3.14	14.72	33.31	36.95	8.02	0.25	14.58
DHSubt40	0.04	0.14	0.52	0.68	2.22	3.15	14.72	33.32	36.96	8.03	0.23	1.06
DHSubt41	0.00	0.11	0.12	0.33	0.56	0.75	3.80	36.33	49.80	7.80	0.40	0.99
DHSubt42	0.08	0.91	0.36	0.34	1.18	0.92	5.65	18.45	51.26	20.36	0.50	2.04
DHSubt43	0.14	1.18	0.45	0.56	1.72	1.40	13.98	20.69	44.92	14.30	0.66	2.17
DHSubt44	0.06	0.66	0.38	0.80	1.73	2.01	10.86	41.97	30.90	10.15	0.48	2.02
DHSubt45	0.26	2.13	1.03	1.17	1.07	1.42	8.31	22.23	40.78	16.30	5.30	5.00

Sample Nr.	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHSubt46	0.00	0.06	0.07	0.22	0.53	0.63	3.77	19.91	70.86	3.33	0.61	1.94
DHSubt47	0.30	2.39	1.25	1.60	5.75	5.25	21.21	29.16	24.95	6.67	1.47	1.80
DHSubt48	0.03	0.37	0.26	0.81	1.21	1.30	5.06	15.34	35.75	28.69	11.16	7.53
DHSubt49	0.04	0.14	0.07	0.35	1.12	1.92	12.77	35.50	38.10	8.87	1.12	1.00
DHSubt50	0.01	0.10	0.11	0.39	0.82	1.07	5.39	9.21	80.94	1.91	0.07	2.00
DHSubt51	0.02	0.17	0.16	0.48	1.45	1.68	12.84	43.58	34.20	5.09	0.34	2.00

Table 2H: Trace metal concentrations of intertidal sediment for January 2016.

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHInt 1	0.22	3.6	0.2	1.6	26.2	4.3	0.56	127	4.5	1.4	12.1	120
DHInt 2	0.25	3.8	0.2	1.5	25.4	4.1	0.49	124	4.5	4.2	13.4	88
DHInt 3	0.24	3.4	0.2	1.9	27.4	5.0	0.66	170	5.3	8.1	13.3	48
DHInt 4	0.26	2.5	0.1	1.5	24.1	4.5	0.54	109	3.7	5.6	12.7	32
DHInt 5	0.30	4.3	0.2	1.8	26.5	4.8	0.69	135	5.2	5.3	13.6	32
DHInt 6	0.36	3.9	0.2	2.1	30.0	5.8	0.61	138	11.8	4.1	15.0	64
DHInt 7	0.35	6.1	0.3	2.0	30.2	4.4	0.73	165	5.6	2.2	13.7	73
DHInt 8	0.40	6.2	0.3	1.7	27.1	4.8	0.62	163	4.9	4.4	15.6	104
DHInt 9	0.25	4.2	0.2	1.4	21.7	3.2	0.49	122	3.1	5.7	11.1	40
DHInt 10	0.46	6.1	0.3	1.8	26.4	6.1	0.63	87	4.6	9.0	21.2	24
DHInt 11	0.44	5.2	0.4	1.8	30.7	5.9	0.75	101	5.2	8.0	19.2	52
DHInt 12	0.30	5.3	0.2	1.6	27.6	4.5	0.63	88	4.8	3.6	14.3	24
DHInt 13	0.31	4.4	0.2	1.7	28.6	4.6	0.68	130	4.8	3.0	13.5	32
DHInt 14	0.25	2.5	0.1	1.4	22.7	4.2	0.48	115	3.7	2.5	13.0	120
DHInt 15	0.37	3.3	0.3	2.1	32.3	6.2	0.80	92	5.8	4.5	17.9	40
DHInt 16	0.36	2.7	0.4	1.8	27.1	4.9	0.61	147	4.8	6.4	16.9	104
DHInt 17	0.40	2.6	0.2	2.2	29.1	6.6	0.65	221	6.2	2.0	19.6	47
DHInt 18	0.32	3.1	0.3	2.4	31.0	8.3	0.74	278	7.5	7.0	19.0	ND
DHInt 19	0.37	2.8	0.3	1.9	25.4	7.3	0.59	164	5.0	7.9	19.1	24
DHInt 20	0.38	3.5	0.3	2.1	27.8	7.3	0.61	194	5.5	6.1	19.3	40
DHInt 21	0.33	3.5	0.2	1.9	29.9	5.2	0.66	135	4.9	4.5	16.3	16
DHInt 22	0.34	3.3	0.3	2.0	31.0	5.8	0.63	163	5.1	8.1	17.5	176

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHInt 23	0.36	2.0	0.3	2.2	32.3	5.8	0.75	169	5.9	2.7	20.4	48
DHInt 24	0.36	3.9	0.4	1.9	29.8	5.1	0.65	138	5.2	5.0	18.0	40
DHInt 25	0.53	5.0	0.5	2.1	31.1	6.4	0.74	114	5.6	6.5	22.3	24
DHInt 26	0.53	3.5	0.3	2.7	32.2	8.4	0.74	214	6.2	3.3	24.2	ND
DHInt 27	0.58	3.1	0.5	2.5	36.8	11.5	0.85	136	6.7	9.4	28.8	ND
DHInt 28	0.64	3.7	0.5	2.8	39.8	13.0	0.95	109	7.2	7.7	33.7	ND
DHInt 29	0.50	5.1	0.4	2.2	32.8	9.5	0.81	98	6.0	9.2	24.5	ND
DHInt 30	0.40	3.0	0.3	2.0	31.0	5.8	0.79	91	5.7	5.7	16.5	133
DHInt 31	0.48	5.0	0.4	2.5	33.9	8.8	0.86	184	6.6	5.9	23.9	ND
DHInt 32	0.58	4.6	0.4	2.7	35.3	9.7	0.87	113	5.9	5.8	26.8	ND
DHInt 33	0.44	3.4	0.3	2.7	32.6	7.6	0.84	227	7.0	10.3	23.7	ND
DHInt 34	0.36	2.7	0.3	2.8	27.4	5.7	0.69	90	4.0	0.2	20.3	ND
DHInt 35	0.40	1.7	0.3	2.4	33.0	5.4	0.80	105	4.7	7.0	19.3	ND
DHInt 36	0.42	3.4	0.4	2.7	35.5	6.7	0.91	104	5.3	4.2	21.5	66
DHInt 37	0.41	3.9	0.4	2.4	32.9	7.0	0.79	98	5.1	8.4	21.8	208
DHInt 38	0.65	2.6	0.9	3.6	45.5	14.8	1.17	100	8.2	12.4	68.5	163
DHInt 39	0.40	2.4	0.4	2.4	33.5	7.9	0.89	129	6.5	3.5	21.9	222
DHInt 40	0.42	2.2	0.3	1.3	25.7	4.3	0.84	45	3.3	4.0	11.4	230
DHInt 41	0.38	2.6	0.2	1.9	27.0	5.9	0.67	122	5.1	8.7	19.7	163
DHInt 42	0.32	1.3	0.2	1.3	27.5	17.2	0.57	51	4.7	3.8	22.9	104
DHInt 43	0.41	5.8	0.3	1.9	27.5	6.7	0.68	155	5.1	6.6	18.5	133
DHInt 44	0.39	3.7	0.2	1.9	30.8	6.7	0.76	81	4.9	4.7	19.1	96
DHInt 45	0.25	2.4	0.2	1.6	32.9	7.4	0.67	61	6.8	11.1	24.8	104

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHInt 46	0.41	5.4	0.3	2.0	31.2	5.8	0.74	143	5.5	6.6	18.7	156
DHInt 47	0.36	4.0	0.2	1.6	30.4	8.8	0.61	72	5.5	6.1	23.5	52
DHInt 48	0.31	6.9	0.3	1.5	24.4	5.4	0.52	146	3.9	6.5	15.5	96
DHInt 49	0.32	6.8	0.3	1.2	24.3	8.3	0.57	106	3.5	10.2	21.2	704
DHInt 50	0.23	1.7	0.3	1.4	33.6	9.6	0.67	66	5.5	7.4	24.0	193
DHInt 51	0.20	2.9	0.2	1.0	22.5	3.6	0.48	118	3.3	7.0	11.0	437
DHInt 52	0.27	3.6	0.3	1.5	26.9	4.6	0.60	138	4.4	2.5	12.9	296
DHInt 53	0.24	2.7	0.5	2.0	26.8	7.1	0.61	69	4.4	3.7	25.6	96

Table 21: Trace metal concentrations of subtidal sediment for January 2016.

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHSubt1	1.81	8.8	1.1	6.0	63.7	46.3	1.78	184	13.7	36.3	88.2	188
DHSubt2	0.68	4.5	0.5	2.2	35.9	17.4	1.03	105	6.7	7.3	30.8	102
DHSubt3	4.11	17.1	2.3	7.8	119.8	73.4	3.44	289	25.5	65.7	186.5	433
DHSubt4	0.70	5.6	0.5	1.3	34.4	13.6	0.94	107	6.1	7.5	34.0	180
DHSubt5	0.50	5.3	0.4	1.0	28.7	9.6	0.85	88	4.7	13.1	26.6	49
DHSubt6	0.39	5.0	0.2	2.8	27.0	7.1	0.74	128	4.7	6.5	18.2	106
DHSubt7	0.62	4.3	0.5	2.9	32.3	9.0	0.89	104	5.5	5.0	23.6	49
DHSubt8	0.48	4.7	0.3	2.0	29.8	6.1	0.81	115	5.0	5.8	18.5	106
DHSubt9	0.69	5.7	0.5	2.5	34.2	9.0	0.95	106	6.9	12.1	26.4	49
DHSubt10	0.44	3.8	0.3	1.7	27.4	5.9	0.74	116	4.4	6.5	18.6	101
DHSubt11	0.50	6.5	0.3	1.9	27.7	6.9	0.74	148	4.6	8.2	24.7	78
DHSubt12	0.49	3.6	0.3	1.9	29.2	12.3	0.83	92	5.5	9.8	27.3	41
DHSubt13	0.45	5.2	0.3	1.9	29.0	7.1	0.80	146	5.2	8.3	20.2	33
DHSubt14	0.49	4.3	0.3	1.8	27.8	6.9	0.75	88	4.3	6.1	22.6	33
DHSubt15	0.36	6.0	0.3	1.5	24.9	5.8	0.68	87	3.6	6.8	19.5	8
DHSubt16	0.57	7.3	0.4	1.9	26.3	8.0	0.73	94	4.6	2.3	25.4	171
DHSubt17	0.41	4.9	0.3	1.9	27.4	6.2	0.70	153	5.1	4.3	20.1	73
DHSubt18	0.30	4.2	0.2	1.7	25.3	5.5	0.68	120	4.1	5.9	14.6	24
DHSubt19	0.55	2.3	0.4	2.3	35.8	11.4	0.89	87	6.7	9.2	28.1	16
DHSubt20	0.42	5.3	0.2	1.6	27.7	8.2	0.74	83	4.6	10.1	21.2	114
DHSubt21	0.50	4.2	0.3	2.2	32.3	8.9	0.83	185	5.6	7.8	22.4	106
DHSubt22	0.61	3.1	0.4	2.1	35.1	13.4	0.88	98	6.2	11.4	28.3	16

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHSubt23	1.52	7.2	0.9	4.0	60.2	42.8	1.41	133	12.0	25.9	75.0	49
DHSubt24	0.51	2.5	0.3	1.8	25.7	9.1	0.67	73	4.2	9.3	25.1	82
DHSubt25	0.38	3.1	0.2	1.6	23.4	9.5	0.61	130	4.0	7.5	20.7	98
DHSubt26	0.84	4.6	0.5	2.7	35.7	19.6	1.02	100	6.9	15.4	44.0	186
DHSubt27	0.36	2.5	0.3	2.2	28.3	10.4	0.79	177	5.7	6.3	21.9	41
DHSubt28	0.49	4.8	0.3	2.5	29.6	10.8	0.86	184	6.2	6.1	26.8	359
DHSubt29	1.92	7.9	1.2	6.1	70.6	69.6	1.84	204	16.0	42.8	144.3	208
DHSubt30	0.63	3.7	0.5	3.1	34.8	23.4	0.86	86	6.6	13.1	54.6	24
DHSubt31	0.57	3.6	0.5	3.1	33.2	20.3	0.85	96	7.1	10.7	49.4	48
DHSubt32	0.33	4.1	0.2	2.2	26.2	9.1	0.69	200	5.9	7.3	21.8	56
DHSubt33	0.42	5.6	0.3	2.3	28.9	10.0	0.74	181	6.0	13.0	26.1	56
DHSubt34	0.52	3.7	0.4	2.4	34.2	13.1	0.93	82	6.8	11.4	28.7	40
DHSubt35	1.09	3.6	0.8	3.7	49.1	45.3	1.23	107	10.5	26.4	91.2	104
DHSubt36	1.24	4.1	1.0	4.1	59.1	50.3	1.50	117	12.8	34.7	107.4	80
DHSubt37	2.36	11.8	2.5	8.3	108.7	138.5	2.65	226	26.7	73.3	279.7	216
DHSubt38	0.61	3.0	0.7	3.4	42.2	27.0	1.04	94	9.5	19.6	75.8	48
DHSubt39	2.69	7.3	3.2	10.8	127.0	150.0	3.10	273	38.9	107.2	339.8	24
DHSubt40	0.29	0.2	0.3	1.6	31.4	10.7	0.71	65	6.5	7.5	19.9	ND
DHSubt41	0.34	4.4	0.3	1.6	25.9	9.2	0.61	70	4.6	9.9	20.4	ND
DHSubt42	0.49	5.1	0.4	2.1	28.9	10.9	0.72	109	4.8	9.0	27.8	ND
DHSubt43	0.43	4.7	0.4	1.8	30.3	9.3	0.70	80	5.4	9.9	23.1	28
DHSubt44	0.38	6.9	0.3	1.8	28.8	7.3	0.65	124	4.9	9.9	22.0	88
DHSubt45	1.40	5.8	0.9	4.3	64.8	91.4	1.41	127	12.6	62.5	158.0	312

Sample #	Al (%)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHSubt46	0.57	6.7	0.4	2.2	30.2	15.1	0.72	186	5.4	10.8	32.9	24
DHSubt47	0.53	6.9	0.4	1.7	30.5	12.9	0.62	76	4.7	11.9	32.6	48
DHSubt48	2.15	12.7	1.7	5.6	85.8	64.8	2.06	222	17.7	50.4	156.0	264
DHSubt49	0.42	4.3	0.4	1.7	32.2	10.1	0.63	92	6.3	5.1	24.0	ND
DHSubt50	0.26	1.6	0.1	1.3	24.4	4.6	0.48	87	3.6	6.3	12.9	40
DHSubt51	0.26	3.3	0.2	1.7	25.9	4.8	0.50	81	4.3	1.3	12.4	37

Table 2J: Grain size composition and total organic carbon (TOC) of intertidal sediment for May 2016.

Sample Nr.	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHInt1	0.36	1.51	0.65	0.99	2.02	2.53	13.57	33.86	38.69	5.79	0.04	1.83
DHInt2	0.07	1.08	0.50	0.76	1.54	1.93	11.25	34.72	41.90	6.21	0.03	1.85
DHInt3	0.08	1.12	0.67	1.05	2.28	2.49	12.10	31.77	39.81	8.55	0.07	1.94
DHInt4	0.04	0.59	0.46	0.80	1.75	2.18	11.77	33.79	42.12	6.44	0.06	1.69
DHInt5	0.12	0.70	0.37	0.69	1.74	2.25	11.18	28.49	47.31	7.16	0.00	1.00
DHInt6	0.14	1.05	0.57	1.04	2.53	3.05	14.33	31.64	39.77	5.82	0.05	1.98
DHInt7	0.13	1.20	0.80	1.77	4.03	4.57	19.11	28.63	33.70	6.02	0.04	1.02
DHInt8	0.08	0.89	0.56	0.95	2.18	2.59	12.89	24.18	42.83	12.79	0.08	2.00
DHInt9	0.08	1.03	0.76	1.19	2.64	3.39	17.17	30.77	37.09	5.88	0.00	1.02
DHInt10	0.22	0.87	0.42	0.73	1.46	1.89	8.57	22.27	49.74	13.54	0.29	3.03
DHInt11	0.13	1.00	0.38	0.68	1.19	1.64	8.89	24.43	50.20	11.19	0.26	2.00
DHInt12	0.31	1.43	0.60	1.06	1.86	2.11	10.19	27.39	44.95	9.80	0.31	2.00
DHInt13	0.08	0.89	0.52	0.87	1.81	2.25	12.55	32.17	41.17	7.62	0.07	1.01
DHInt14	0.08	1.01	0.57	0.98	1.72	2.11	10.94	31.27	43.26	8.02	0.05	2.00
DHInt15	0.15	0.42	0.28	0.50	0.92	1.11	6.02	22.64	52.85	14.83	0.28	2.02
DHInt16	0.06	0.78	0.46	0.77	1.51	2.02	10.97	29.21	44.61	9.50	0.11	1.98
DHInt17	0.07	0.76	0.44	0.50	1.51	1.95	12.83	34.72	39.88	7.34	0.00	1.01
DHInt18	0.09	1.03	0.63	1.13	2.33	2.62	13.52	29.08	39.61	9.89	0.08	2.02
DHInt19	0.14	1.00	0.59	0.99	1.93	2.12	11.51	30.19	41.48	9.96	0.08	1.01
DHInt20	0.02	0.46	0.34	0.59	1.48	2.03	13.64	42.47	33.90	5.07	0.00	1.01
DHInt21	0.12	0.76	0.40	0.64	1.19	1.42	9.50	39.24	40.80	5.93	0.02	1.00
DHInt22	0.20	1.55	0.82	1.33	2.69	3.09	14.66	34.09	37.43	4.10	0.03	1.85

Sample Nr.	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHInt23	0.05	0.58	0.26	0.44	1.04	1.42	8.35	29.77	48.65	9.41	0.03	1.01
DHInt24	0.13	0.92	0.44	0.71	1.50	1.78	9.28	25.90	49.99	9.30	0.05	1.01
DHInt25	0.03	0.61	0.36	0.60	1.27	1.67	10.42	26.75	44.65	13.21	0.43	2.06
DHInt26	0.09	1.24	0.67	1.10	2.16	2.61	13.84	32.25	38.52	7.42	0.11	1.00
DHInt27	0.07	1.00	0.76	1.32	2.69	3.34	19.20	30.21	36.11	5.19	0.11	1.00
DHInt28	0.17	1.09	0.91	1.87	4.67	5.13	21.13	27.09	30.62	6.59	0.74	1.00
DHInt29	0.52	1.63	1.07	2.28	5.10	5.41	21.05	31.31	24.23	6.01	1.40	2.02
DHInt30	0.03	0.54	0.48	0.94	2.24	3.05	14.96	34.88	37.53	5.23	0.13	1.00
DHInt31	0.05	0.38	0.30	0.52	1.02	1.37	7.47	22.34	55.14	11.20	0.21	1.00
DHInt32	0.46	0.90	0.59	1.17	2.91	3.35	14.45	27.52	35.70	12.48	0.46	1.01
DHInt33	0.03	0.65	0.72	1.90	5.66	6.60	27.03	34.77	19.41	3.17	0.06	1.98
DHInt34	0.09	0.72	0.58	1.34	3.22	3.65	16.10	32.06	34.57	7.54	0.12	1.00
DHInt35	0.56	0.89	0.78	1.75	3.80	4.21	17.19	29.73	32.95	8.08	0.09	1.98
DHInt36	0.75	0.92	0.77	1.53	3.80	4.60	19.22	29.83	30.73	7.69	0.15	2.00
DHInt37	0.20	0.55	0.36	0.83	2.13	2.89	14.19	28.82	40.49	9.45	0.11	2.02
DHInt38	1.12	1.04	0.46	0.80	1.80	2.34	11.18	21.95	28.86	26.20	4.23	1.96
DHInt39	0.02	0.53	0.49	1.02	2.62	3.45	18.75	34.16	31.86	6.88	0.21	1.87
DHInt40	1.38	0.96	0.63	1.40	4.02	5.72	21.50	31.55	27.93	4.78	0.13	1.94
DHInt41	0.10	0.63	0.41	0.61	1.31	1.58	8.72	27.70	49.54	9.37	0.02	1.89
DHInt42	0.71	0.84	0.47	0.66	1.21	1.51	6.75	22.69	48.87	15.81	0.48	2.00
DHInt43	0.08	0.71	0.39	0.58	1.13	1.16	6.38	22.55	53.65	13.28	0.07	2.00
DHInt44	0.11	0.75	0.38	0.63	1.14	1.36	7.34	22.94	49.57	15.60	0.17	1.01
DHInt45	1.30	0.88	0.36	0.54	1.01	1.21	6.23	23.38	51.89	13.08	0.13	1.00

Sample Nr.	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHInt46	0.12	1.16	0.50	0.75	1.22	1.25	6.07	21.11	55.90	11.87	0.04	1.98
DHInt47	0.05	0.47	0.36	0.59	1.03	7.64	1.48	23.68	50.13	14.15	0.43	2.06
DHInt48	0.11	0.96	0.62	1.13	2.57	2.91	12.55	24.93	43.31	10.91	0.00	1.01
DHInt49	0.04	0.59	0.39	0.66	1.33	1.53	8.94	25.14	47.52	13.80	0.06	1.12
DHInt50	0.06	0.86	0.44	0.93	1.41	2.49	10.75	33.34	40.62	8.81	0.29	2.17
DHInt51	0.00	0.11	0.10	0.18	0.54	1.32	17.52	46.86	29.35	4.01	0.01	0.00
DHInt52	0.02	0.21	0.22	0.47	1.60	2.50	13.50	41.27	33.88	6.31	0.02	1.00
DHInt53	2.58	2.08	0.90	1.70	4.33	5.25	21.74	31.94	24.54	4.82	0.13	0.97

Table 2K: Grain size composition and total organic carbon (TOC) of subtidal sediment for May 2016.

Sample Nr.	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHSubt1	0.24	2.30	1.28	1.67	2.70	2.44	8.39	19.75	42.08	16.72	2.43	4.55
DHSubt2	0.48	1.21	0.68	0.92	1.47	1.54	6.52	20.64	49.67	15.81	1.07	3.06
DHSubt3	0.16	1.42	0.84	1.10	1.75	1.64	7.43	22.08	48.59	14.08	0.91	2.17
DHSubt4	0.06	0.73	0.54	0.81	1.17	1.28	6.35	33.34	46.05	8.81	0.87	2.78
DHSubt5	0.34	1.26	0.73	1.08	1.77	2.32	11.35	22.76	43.86	13.70	0.82	2.56
DHSubt6	0.28	0.77	0.54	0.83	1.44	1.73	8.58	21.74	51.82	11.65	0.62	1.94
DHSubt7	0.22	1.76	0.93	1.25	1.84	2.07	8.36	22.58	48.40	11.57	1.02	2.73
DHSubt8	0.00	0.53	0.38	0.52	1.05	1.64	11.20	29.89	45.73	8.81	0.24	2.20
DHSubt9	0.00	0.37	0.38	0.65	1.57	2.08	12.07	25.65	47.94	8.93	0.35	2.00
DHSubt10	0.17	1.50	0.79	0.84	1.15	1.11	4.75	18.58	49.02	18.45	3.65	3.16
DHSubt11	0.06	1.15	0.74	0.77	1.12	1.11	4.97	17.73	54.34	15.98	2.02	2.00
DHSubt12	0.07	0.63	0.51	0.66	1.00	1.05	4.88	22.59	56.23	11.56	0.83	1.90
DHSubt13	0.06	0.86	0.76	1.37	3.42	4.60	22.43	30.06	29.24	6.76	0.44	2.15
DHSubt14	0.18	0.95	0.55	0.72	1.34	1.75	10.42	28.23	45.46	10.14	0.26	2.04
DHSubt15	0.19	1.30	0.65	0.95	1.85	2.25	12.21	27.21	42.00	11.08	0.30	2.17
DHSubt16	0.14	1.66	0.85	1.30	2.14	2.39	10.46	22.94	43.34	12.67	2.12	3.92
DHSubt17	0.18	1.26	0.76	1.19	2.46	2.95	12.16	25.86	39.26	11.53	2.40	2.91
DHSubt18	0.00	0.64	0.46	0.72	1.19	1.42	7.81	25.87	48.98	12.54	0.38	1.92
DHSubt19	0.19	2.84	1.50	1.83	3.04	2.76	11.36	26.72	38.22	9.94	1.60	2.91
DHSubt20	0.18	1.49	0.86	1.33	2.72	3.86	22.07	38.51	24.41	4.00	0.57	2.00
DHSubt21	0.88	6.73	2.63	4.05	6.36	5.85	17.55	22.77	24.17	7.62	1.39	4.17
DHSubt22	0.37	4.31	2.17	2.95	3.82	3.32	11.34	24.95	34.00	11.14	1.64	5.41

Sample Nr.	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHSubt23	0.53	3.06	1.26	1.70	2.62	2.64	10.28	23.46	39.86	12.90	1.71	3.13
DHSubt24	0.15	1.29	0.66	0.86	1.12	1.15	4.58	22.80	53.41	13.20	0.77	1.96
DHSubt25	0.12	1.47	0.79	1.35	2.67	3.90	31.01	33.67	18.78	5.42	0.81	2.97
DHSubt26	0.53	5.02	1.83	2.60	3.70	3.13	7.90	12.96	35.51	23.13	3.70	5.97
DHSubt27	0.41	3.43	1.78	2.49	4.78	5.28	23.80	33.03	20.60	4.22	0.17	1.01
DHSubt28	0.06	1.16	0.78	1.29	2.79	3.45	17.54	31.88	34.19	6.77	0.07	2.47
DHSubt29	0.62	5.47	2.52	4.10	6.43	5.33	15.21	20.17	21.31	13.34	5.49	4.05
DHSubt30	1.25	2.20	0.71	1.27	2.47	3.11	15.13	29.83	31.33	11.03	1.69	1.94
DHSubt31	0.78	4.64	2.07	3.24	5.40	4.84	15.49	22.09	23.96	14.48	3.02	4.29
DHSubt32	0.06	1.25	0.93	1.84	3.51	3.60	14.74	31.22	37.36	5.35	0.14	2.00
DHSubt33	0.09	0.92	0.73	1.38	2.79	3.03	11.85	26.55	45.79	6.54	0.33	2.04
DHSubt34	6.78	17.24	5.09	7.43	11.09	6.68	10.59	8.60	9.93	10.32	6.24	10.00
DHSubt35	3.20	22.16	6.71	7.52	8.25	4.48	7.73	7.56	9.75	12.64	9.99	10.00
DHSubt36	0.25	3.18	1.53	2.35	4.20	4.29	16.97	28.18	28.22	9.42	1.41	3.09
DHSubt37	0.52	8.38	3.69	4.34	4.85	3.25	7.29	10.80	19.84	24.53	12.51	7.94
DHSubt38	1.18	2.94	0.98	1.34	2.23	2.43	11.71	27.06	36.42	11.79	1.93	3.96
DHSubt39	2.27	13.30	5.26	6.01	4.90	3.66	7.32	9.16	13.87	17.99	16.26	10.26
DHSubt40	0.01	0.44	0.41	1.02	2.84	3.98	16.05	27.07	40.65	7.40	0.12	1.01
DHSubt41	0.07	0.58	0.36	0.51	1.02	1.27	7.12	53.15	26.89	8.93	0.11	1.96
DHSubt42	0.25	1.38	0.60	0.84	1.43	1.41	5.48	16.72	55.88	14.99	1.02	3.03
DHSubt43	0.05	0.78	0.46	0.61	1.01	1.27	7.84	30.52	46.53	10.47	0.46	2.00
DHSubt44	0.01	1.05	0.81	1.70	3.93	4.42	20.62	36.87	25.28	5.26	0.05	2.80
DHSubt45	1.70	12.91	5.17	7.90	10.20	6.35	11.02	10.86	14.16	12.69	7.03	10.00

Sample Nr.	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHSubt46	0.07	1.74	1.40	2.68	4.91	4.25	16.47	30.82	25.41	10.06	2.20	5.49
DHSubt47	0.23	1.98	1.22	2.05	4.24	4.70	20.63	28.83	24.04	9.39	2.69	2.83
DHSubt48	0.15	1.19	0.59	1.01	1.77	2.25	11.52	26.72	41.89	12.35	0.57	2.73
DHSubt49	0.04	0.62	0.41	0.73	1.63	2.48	14.02	28.17	40.46	10.51	0.93	2.50
DHSubt50	1.43	3.16	0.86	1.05	1.60	1.60	7.89	27.79	43.90	9.70	1.02	3.33
DHSubt51	0.05	1.02	0.58	1.14	3.33	4.68	23.80	36.10	25.17	3.99	0.13	1.98

Table 2L: Trace metal concentrations of intertidal sediment for May 2016.

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHInt1	2.8	3.5	9.2	1.6	4.4	0.13	1.9	0.2	5.7	0.53	101.1	266.6
DHInt2	3.0	4.4	9.6	1.6	4.0	0.16	3.4	0.3	6.3	0.54	97.8	46.3
DHInt3	3.5	4.4	11.4	1.6	3.8	0.16	2.1	0.2	5.5	0.50	122.6	52.1
DHInt4	3.1	5.1	10.0	1.2	2.7	0.11	2.1	0.2	2.0	0.40	73.9	98.5
DHInt5	3.3	5.7	9.6	1.3	3.4	0.12	3.1	0.2	4.9	0.52	80.5	34.7
DHInt6	2.5	7.2	9.6	1.3	3.3	0.13	4.1	0.2	4.3	0.49	96.2	57.9
DHInt7	2.8	2.7	10.8	1.7	4.3	0.15	4.4	0.2	8.0	0.60	115.6	23.1
DHInt8	3.8	2.2	12.5	1.8	4.5	0.20	4.0	0.3	9.5	0.71	133.4	17.3
DHInt9	2.2	1.7	8.2	1.5	4.1	0.12	3.3	0.2	5.3	0.53	101.0	ND
DHInt10	4.0	4.5	16.2	1.8	4.6	0.19	3.6	0.3	8.2	0.67	86.1	34.7
DHInt11	3.5	5.2	15.3	1.6	3.9	0.17	3.3	0.3	6.9	0.58	61.5	46.3
DHInt12	3.2	3.3	13.4	1.4	3.3	0.14	3.0	0.2	5.0	0.51	56.7	17.3
DHInt13	2.8	3.8	10.7	1.3	3.1	0.12	1.7	0.2	4.4	0.48	76.5	34.7
DHInt14	2.8	2.1	9.0	1.2	3.4	0.11	1.8	0.1	3.9	0.43	79.6	52.1
DHInt15	5.0	6.2	15.3	1.6	4.1	0.16	2.5	0.3	7.5	0.66	60.2	57.9
DHInt16	3.7	2.4	13.5	1.5	3.5	0.15	2.4	0.2	4.3	0.48	104.1	63.7
DHInt17	4.2	5.0	15.8	1.6	3.9	0.14	2.7	0.2	3.9	0.48	128.2	14.0
DHInt18	6.5	7.2	18.5	1.9	4.7	0.17	2.8	0.2	6.8	0.57	158.1	ND
DHInt19	5.7	5.5	17.4	1.8	4.1	0.14	3.1	0.2	4.4	0.50	132.6	17.3

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHInt20	6.2	4.1	15.7	1.7	4.4	0.15	2.8	0.3	5.9	0.51	132.8	21.1
DHInt21	4.4	4.9	13.2	1.7	4.0	0.14	3.9	0.2	5.7	0.49	119.6	26.0
DHInt22	3.6	5.1	11.1	1.4	3.5	0.12	3.3	0.2	3.7	0.43	103.3	21.1
DHInt23	3.9	5.3	11.9	1.6	4.3	0.13	3.1	0.2	6.5	0.56	108.0	11.1
DHInt24	3.2	4.6	11.8	1.6	2.8	0.21	3.9	0.2	4.0	0.50	100.3	3.7
DHInt25	3.9	6.7	15.4	1.6	3.2	0.24	4.0	0.3	6.0	0.63	71.9	11.1
DHInt26	5.7	8.2	17.2	1.8	3.4	0.20	3.6	0.2	4.2	0.52	122.8	18.5
DHInt27	6.5	8.7	16.5	1.8	3.5	0.21	2.6	0.2	5.1	0.58	117.3	40.7
DHInt28	7.7	6.8	22.5	1.7	3.0	0.22	2.7	0.3	5.7	0.60	49.3	63.0
DHInt29	11.2	6.6	29.7	2.0	3.4	0.27	2.7	0.3	6.9	0.64	60.4	40.7
DHInt30	5.1	6.4	19.8	1.7	3.5	0.19	2.7	0.2	5.1	0.60	91.0	21.1
DHInt31	8.9	7.5	24.1	2.3	5.2	0.29	3.9	0.3	9.8	0.73	165.1	48.1
DHInt32	7.2	6.4	25.5	2.0	2.9	0.21	3.1	0.3	4.9	0.56	53.5	18.5
DHInt33	6.7	6.9	17.6	2.0	4.1	0.18	2.3	0.2	3.4	0.48	179.6	11.1
DHInt34	3.9	3.4	14.7	2.3	2.6	0.16	2.3	0.3	4.0	0.52	50.5	25.9
DHInt35	2.9	2.6	13.1	1.6	2.3	0.15	2.2	0.2	2.7	0.49	50.2	11.1
DHInt36	4.6	5.4	16.9	1.9	3.2	0.17	1.7	0.3	6.0	0.59	50.9	55.5
DHInt37	4.4	6.0	16.9	1.8	3.5	0.16	2.2	0.3	6.4	0.53	49.9	28.1
DHInt38	14.8	12.1	72.9	2.9	5.6	0.29	3.0	0.9	13.0	0.82	50.1	63.0
DHInt39	5.3	7.9	16.6	1.7	3.6	0.16	2.1	0.3	5.6	0.63	69.0	11.1
DHInt40	2.8	5.4	4.4	1.3	3.2	0.18	0.7	0.2	3.5	0.50	43.2	3.7
DHInt41	3.7	6.5	11.4	1.3	2.9	0.16	2.7	0.2	4.3	0.49	67.9	18.5
DHInt42	11.0	13.9	29.3	1.3	3.4	0.22	0.3	0.3	8.1	0.57	33.6	18.5

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHInt43	4.9	5.8	14.4	1.6	3.6	0.21	4.0	0.2	7.2	0.58	102.9	28.1
DHInt44	4.2	7.6	16.0	1.3	3.3	0.20	2.3	0.2	6.7	0.51	40.2	35.1
DHInt45	6.7	27.0	39.6	1.2	2.8	0.16	1.4	0.2	4.6	0.48	36.9	3.7
DHInt46	3.3	4.3	13.3	1.3	2.5	0.19	4.1	0.2	4.5	0.51	94.5	ND
DHInt47	7.4	8.7	24.3	1.4	3.4	0.24	2.2	0.3	8.1	0.59	48.2	11.1
DHInt48	4.3	4.1	13.4	1.6	3.0	0.21	4.1	0.3	4.5	0.57	117.5	ND
DHInt49	6.2	4.8	14.0	1.9	4.4	0.21	3.4	0.4	8.7	0.81	107.2	ND
DHInt50	12.1	11.9	30.2	1.5	3.4	0.18	1.7	0.4	11.4	0.67	42.7	33.3
DHInt51	1.8	4.8	7.2	1.0	2.3	0.14	2.9	0.3	4.0	0.48	77.7	3.7
DHInt52	2.3	3.5	9.1	1.2	2.8	0.19	3.2	0.3	5.2	0.52	86.7	11.1
DHInt53	5.5	11.3	28.9	1.8	2.7	0.13	2.3	0.6	5.2	0.51	40.8	11.1

Table 2M: Trace metal concentrations of subtidal sediment for May 2016.

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHSubt1	26.5	17.0	76.2	4.8	7.5	0.80	5.5	1.4	36.2	1.26	108.5	125.0
DHSubt2	12.6	11.1	36.2	2.7	5.0	0.46	3.4	0.5	25.7	1.01	93.0	33.0
DHSubt3	11.6	10.2	30.8	2.3	4.1	0.38	2.8	0.5	23.0	0.90	70.5	80.1
DHSubt4	9.0	6.7	22.0	2.0	4.0	0.28	1.7	0.4	20.7	0.86	63.2	44.0
DHSubt5	7.9	5.2	24.9	1.8	2.8	0.33	4.0	0.4	17.2	0.70	69.5	74.6
DHSubt6	6.7	3.6	23.2	2.0	3.3	0.31	4.5	0.4	19.0	0.76	77.6	33.0
DHSubt7	8.3	6.5	28.2	2.1	3.1	0.38	3.7	0.4	19.4	0.78	70.6	66.0
DHSubt8	4.1	5.4	15.4	1.5	2.0	0.23	4.0	0.3	14.8	0.63	77.3	52.9
DHSubt9	5.0	4.1	16.9	1.7	2.5	0.26	3.8	0.3	15.6	0.60	107.9	125.7
DHSubt10	14.2	10.1	40.7	2.9	5.1	0.59	4.9	0.7	28.3	1.09	106.7	112.6
DHSubt11	9.9	9.5	31.5	2.6	4.2	0.47	4.0	0.6	23.7	0.97	95.2	36.7
DHSubt12	6.0	4.9	21.1	1.8	2.9	0.29	3.3	0.3	17.8	0.73	71.1	25.7
DHSubt13	6.2	5.9	19.6	1.7	2.4	0.28	4.6	0.3	14.6	0.62	136.2	62.4
DHSubt14	4.4	5.4	16.6	1.5	2.5	0.22	4.2	0.4	16.2	0.66	64.2	62.4
DHSubt15	5.3	6.2	19.5	1.5	2.5	0.23	4.2	0.3	15.9	0.63	60.9	36.7
DHSubt16	18.4	12.4	46.8	3.1	5.9	0.61	3.5	0.6	30.2	1.13	93.9	47.7

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHSubt17	18.1	13.4	43.9	2.4	3.9	0.50	4.6	0.6	22.7	0.90	104.2	66.0
DHSubt18	7.4	5.9	21.8	1.7	2.6	0.29	3.2	0.3	16.5	0.69	74.5	50.7
DHSubt19	21.8	14.8	52.9	2.7	4.7	0.59	3.9	0.5	26.3	0.98	79.3	51.4
DHSubt20	10.7	8.7	27.4	2.1	3.9	0.37	3.6	0.5	22.7	0.91	83.9	33.0
DHSubt21	44.4	29.3	95.8	4.0	8.2	1.08	6.4	0.8	42.3	1.49	116.6	73.4
DHSubt22	37.0	22.4	75.3	3.7	8.0	0.89	4.2	0.7	38.4	1.39	94.2	84.4
DHSubt23	33.3	19.2	66.7	3.2	6.4	0.80	4.5	0.6	32.5	1.18	89.7	117.4
DHSubt24	22.0	12.1	44.2	3.2	5.6	0.56	3.4	0.6	31.2	1.18	88.8	88.1
DHSubt25	23.2	15.0	49.1	2.4	4.8	0.51	3.5	0.5	26.9	1.01	84.1	62.4
DHSubt26	82.6	41.0	150.0	5.5	12.9	1.42	6.5	1.1	56.4	1.96	138.9	142.0
DHSubt27	6.6	6.7	18.5	1.3	1.1	0.18	1.9	0.2	11.2	0.57	46.5	139.4
DHSubt28	7.6	8.4	21.1	2.3	3.5	0.22	2.2	0.3	17.1	0.81	136.8	51.4
DHSubt29	51.9	32.1	119.4	6.5	8.2	0.96	5.0	0.9	42.1	1.70	145.0	40.3
DHSubt30	18.1	10.5	49.7	3.2	1.9	0.36	3.4	0.4	16.9	0.91	71.1	44.0
DHSubt31	46.8	29.0	121.2	5.4	6.8	1.02	5.4	0.9	37.8	1.57	104.8	120.8
DHSubt32	9.1	7.7	21.8	2.0	ND	0.24	3.8	0.3	8.3	0.66	149.8	81.9
DHSubt33	9.1	11.2	24.7	2.0	0.2	0.29	3.5	0.4	11.3	0.75	113.9	51.4
DHSubt34	130.7	81.9	275.6	8.9	20.1	2.39	10.0	2.1	90.6	3.30	213.5	183.7
DHSubt35	65.3	74.9	208.4	8.2	21.4	2.20	7.3	2.3	70.0	3.07	251.8	158.6
DHSubt36	27.6	18.0	59.3	2.8	6.9	0.50	2.8	0.6	19.0	0.95	76.4	29.3
DHSubt37	89.2	44.4	194.3	6.2	17.8	1.16	5.9	1.6	52.5	1.96	135.1	73.4
DHSubt38	30.2	19.3	76.4	2.9	7.0	0.48	3.3	0.6	19.8	0.95	61.7	81.1
DHSubt39	105.2	59.7	229.3	7.8	22.3	1.48	5.7	2.0	66.1	2.43	141.2	104.3

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHSubt40	3.4	2.7	7.1	0.8	1.7	0.13	ND	0.2	ND	0.35	28.1	77.2
DHSubt41	6.0	7.0	14.3	1.3	3.8	0.21	1.7	0.2	7.3	0.54	41.3	69.5
DHSubt42	12.5	12.1	34.6	2.2	5.4	0.43	4.3	0.4	13.9	0.77	63.8	46.3
DHSubt43	6.6	7.4	18.3	1.9	5.1	0.28	3.9	0.4	12.2	0.83	73.5	46.3
DHSubt44	4.1	3.6	11.9	1.1	1.9	0.20	2.7	0.2	1.2	0.48	60.0	440.5
DHSubt45	186.0	123.6	338.6	9.3	24.7	2.15	11.2	2.0	89.9	3.32	285.8	640.1
DHSubt46	56.4	35.7	119.7	4.4	11.3	1.19	7.0	0.9	41.2	1.67	141.9	148.6
DHSubt47	29.6	21.5	68.5	3.4	8.4	0.75	5.1	0.7	28.3	1.26	109.2	69.5
DHSubt48	9.2	10.3	25.6	1.9	5.4	0.34	4.5	0.4	12.0	0.76	104.0	23.1
DHSubt49	8.9	5.7	23.6	2.1	5.9	0.33	4.5	0.6	16.4	0.90	105.3	11.5
DHSubt50	14.8	11.4	27.3	3.6	6.2	0.39	3.2	0.5	16.0	0.95	100.3	440.5
DHSubt51	4.8	4.3	10.7	1.4	4.4	0.17	2.2	0.3	8.3	0.60	71.2	208.6

Table 2N: Grain size composition and TOC of intertidal sediment for August 2016.

Sample Nr.	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHInt1	0.13	1.75	0.87	1.80	3.59	1.42	19.10	35.44	30.33	5.52	0.04	0.95
DHInt2	0.17	1.85	0.66	1.11	2.00	0.82	12.64	33.02	40.56	6.96	0.21	1.35
DHInt3	0.94	2.67	0.78	1.46	2.50	1.10	14.97	32.93	34.97	7.30	0.37	1.43
DHInt4	0.05	1.21	0.55	1.01	1.88	0.70	14.05	40.39	34.62	5.33	0.20	1.18
DHInt5	0.15	1.14	0.51	0.91	1.84	0.75	13.24	36.30	39.18	5.93	0.05	0.96
DHInt6	0.21	1.66	0.70	1.51	3.30	1.31	18.59	35.28	32.13	5.20	0.10	1.25
DHInt7	0.15	1.26	0.75	1.72	3.95	1.53	24.09	32.61	29.03	4.88	0.04	1.65
DHInt8	0.11	0.92	0.53	1.19	2.37	0.98	17.55	30.68	37.98	7.62	0.05	1.88
DHInt9	0.09	0.92	0.49	0.93	2.10	1.00	27.39	36.43	26.75	3.90	0.00	1.25
DHInt10	0.00	0.34	0.19	0.62	0.88	0.37	7.72	23.24	54.01	12.45	0.19	1.76
DHInt11	0.50	0.96	0.47	0.97	1.68	0.52	11.61	27.86	45.21	9.66	0.54	2.00
DHInt12	0.24	0.93	0.37	0.70	1.10	0.47	9.31	31.36	46.06	9.26	0.20	1.39
DHInt13	0.25	1.54	0.61	1.17	2.03	0.77	16.30	33.45	36.33	7.39	0.16	1.57
DHInt14	1.03	2.78	0.94	1.58	2.48	0.79	14.24	32.73	36.12	6.86	0.45	1.81
DHInt15	1.29	2.91	0.79	1.27	1.78	0.53	9.11	24.92	43.63	12.34	1.42	2.35
DHInt16	0.56	1.57	0.42	0.67	0.97	0.36	7.25	23.02	50.62	14.26	0.32	1.49
DHInt17	1.11	4.27	1.33	1.90	3.10	1.13	16.93	31.24	30.96	7.15	0.87	2.02
DHInt18	0.12	2.42	1.48	2.86	6.14	2.13	29.77	34.23	18.13	2.65	0.07	1.26
DHInt19	1.05	2.73	0.66	0.99	1.69	0.61	12.73	33.24	36.98	8.62	0.70	1.64
DHInt20	0.20	1.55	0.59	0.95	1.78	0.58	13.27	39.34	34.67	6.62	0.44	1.42
DHInt21	0.55	1.99	0.61	0.90	1.40	0.52	10.11	37.54	40.91	5.34	0.14	1.50
DHInt22	0.12	1.14	0.51	1.09	2.23	0.93	15.68	37.04	36.84	4.33	0.08	1.05

Sample Nr.	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHInt23	0.27	1.17	0.41	0.68	1.20	0.53	9.22	32.17	46.46	7.88	0.02	1.01
DHInt24	0.05	1.13	0.44	0.80	1.46	0.56	9.99	26.46	50.62	8.46	0.04	1.19
DHInt25	0.14	0.91	0.39	0.72	1.21	0.44	8.14	25.94	48.49	12.95	0.67	1.54
DHInt26	0.59	2.82	0.97	1.80	3.14	1.18	14.54	34.49	33.62	6.07	0.78	1.25
DHInt27	0.31	2.29	0.95	1.77	3.27	1.04	17.61	37.71	30.11	4.15	0.81	1.22
DHInt28	0.38	1.54	0.71	1.63	3.88	1.26	19.78	34.20	28.61	6.68	1.33	1.64
DHInt29	0.50	2.36	1.02	2.15	4.71	1.78	22.14	34.72	22.29	6.39	1.93	1.79
DHInt30	0.30	1.77	0.97	2.14	4.23	1.29	16.84	29.96	30.50	10.51	1.49	2.79
DHInt31	1.28	3.16	0.75	0.99	1.58	0.40	8.19	23.15	43.09	15.89	1.52	2.09
DHInt32	1.63	4.52	1.14	1.85	3.34	1.04	16.13	28.34	29.49	9.83	2.69	2.02
DHInt33	0.13	1.05	0.81	2.20	5.22	1.88	24.61	35.92	23.32	4.74	0.12	0.95
DHInt34	0.70	1.57	0.78	1.80	3.79	1.38	19.72	35.09	28.78	6.14	0.25	1.03
DHInt35	0.72	1.91	0.97	2.13	4.16	1.28	18.32	29.95	29.90	7.72	2.93	2.04
DHInt36	0.58	1.55	0.76	1.62	3.49	1.41	20.22	33.47	29.05	7.51	0.34	1.25
DHInt37	2.91	3.67	0.76	1.33	2.56	0.92	15.03	28.33	34.61	8.96	0.93	2.20
DHInt38	1.28	1.75	0.56	1.02	1.90	0.64	12.47	23.18	26.39	26.17	4.64	2.00
DHInt39	1.91	4.15	1.23	2.19	3.99	1.14	21.72	33.86	23.39	5.22	1.23	1.89
DHInt40	0.26	0.70	0.39	1.05	3.30	1.65	23.65	35.49	27.86	5.57	0.09	0.68
DHInt41	0.17	0.72	0.31	0.61	1.09	0.50	9.38	38.53	41.54	7.11	0.05	1.03
DHInt42	0.17	0.38	0.18	0.33	0.62	0.30	4.86	20.85	54.68	17.30	0.32	1.12
DHInt43	0.29	1.05	0.34	0.50	0.84	0.28	4.87	20.86	56.53	14.37	0.06	1.33
DHInt44	0.37	0.66	0.24	0.41	0.76	0.33	6.23	25.80	49.27	15.68	0.24	1.50
DHInt45	1.04	0.88	0.42	0.85	1.68	0.64	9.95	31.78	43.51	9.15	0.09	1.15

Sample Nr.	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHInt46	0.22	1.03	0.36	0.71	1.08	0.41	5.68	24.10	54.42	11.91	0.09	1.68
DHInt47	0.13	0.64	0.33	0.64	1.30	0.54	9.84	29.81	46.05	10.45	0.28	1.57
DHInt48	0.17	0.78	0.44	0.96	2.08	0.88	13.51	30.63	41.84	8.72	0.01	1.57
DHInt49	0.19	0.90	0.42	0.82	1.37	0.53	11.08	32.13	42.33	10.20	0.03	1.35
DHInt50	0.35	0.65	0.30	0.68	1.54	0.58	10.66	37.62	38.13	9.27	0.23	1.15
DHInt51	0.17	1.02	0.41	0.79	1.83	0.80	21.09	41.68	25.60	6.57	0.05	1.03
DHInt52	0.15	1.15	0.55	1.19	3.46	2.18	31.95	18.41	37.62	3.31	0.03	1.06
DHInt53	2.78	2.28	0.87	1.85	4.25	1.58	22.09	34.34	24.95	4.82	0.19	1.35

Table 20: Grain size composition and TOC of subtidal sediment for August 2016.

Sample Nr.	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHSubt1	0.11	1.03	0.57	1.26	1.82	0.50	7.53	19.09	40.29	22.33	5.47	5.10
DHSubt2	0.13	0.91	0.39	0.64	0.91	0.25	4.93	18.48	52.62	18.39	2.34	2.59
DHSubt3	0.21	1.42	0.60	0.93	1.67	0.58	9.97	27.90	43.52	11.73	1.46	2.34
DHSubt4	0.15	0.92	0.41	0.82	1.24	0.35	8.14	35.61	41.58	9.11	1.66	2.78
DHSubt5	0.07	0.58	0.26	0.49	0.88	0.43	9.22	31.88	41.88	12.23	2.09	1.97
DHSubt6	0.11	0.92	0.43	0.78	1.27	0.39	6.49	20.47	51.08	14.51	3.54	2.47
DHSubt7	0.14	1.12	0.53	1.09	2.05	0.76	13.79	28.43	42.20	9.05	0.84	1.81
DHSubt8	0.06	0.81	0.46	0.89	1.63	0.61	11.58	30.36	41.30	11.22	1.08	1.92
DHSubt9	0.02	0.55	0.36	0.68	1.11	0.40	8.57	23.84	43.41	16.92	4.14	2.85
DHSubt10	0.04	0.51	0.43	0.98	2.11	0.80	15.13	34.92	37.95	6.47	0.67	1.41
DHSubt11	0.08	0.60	0.33	0.70	1.15	0.38	9.73	26.07	45.92	13.14	1.88	2.13
DHSubt12	0.05	1.00	0.47	0.87	1.51	0.49	8.80	32.93	47.12	6.26	0.50	1.40
DHSubt13	0.01	0.49	0.54	1.38	3.31	1.41	23.07	32.60	29.23	7.27	0.69	2.13
DHSubt14	0.08	0.80	0.46	0.80	1.35	0.40	9.16	24.55	48.44	12.86	1.10	2.41
DHSubt15	0.08	1.06	0.53	0.96	1.64	0.56	9.76	24.76	47.22	12.49	0.95	2.45
DHSubt16	0.05	0.44	0.27	0.57	1.03	0.42	8.23	22.67	52.75	13.21	0.37	2.16
DHSubt17	0.10	1.44	0.06	1.08	1.97	0.76	14.01	34.52	38.77	6.62	0.67	1.80
DHSubt18	0.17	1.23	0.41	0.81	1.43	0.57	10.27	42.31	31.43	10.67	0.68	1.91
DHSubt19	0.29	1.20	0.62	1.07	1.44	0.41	6.60	20.72	48.82	15.53	3.30	3.18
DHSubt20	0.14	1.08	0.47	1.03	2.16	1.00	24.72	44.12	21.61	3.28	0.41	1.28
DHSubt21	0.13	1.07	0.45	0.86	2.06	1.03	20.35	36.31	30.80	6.19	0.74	1.69
DHSubt22	0.09	1.40	0.67	1.21	2.26	0.67	9.65	28.14	38.24	14.11	3.56	3.55

Sample Nr.	% +2000µ	% +1000µ	% +850µ	% +710µ	% +500µ	% +425µ	% +300µ	% +212	% +150	% +63µ	% - 63µ	% TOC
DHSubt23	0.07	1.43	0.65	1.21	2.24	0.76	13.76	38.23	29.16	10.79	1.70	2.05
DHSubt24	0.49	1.92	0.70	1.10	1.56	0.34	6.58	22.94	48.66	13.75	1.96	2.28
DHSubt25	0.49	6.62	2.42	3.20	4.12	1.09	23.96	26.77	15.14	7.16	9.02	6.14
DHSubt26	0.83	3.25	1.02	1.72	2.45	0.48	7.07	12.21	42.32	24.39	4.25	4.74
DHSubt27	0.19	2.62	1.06	2.05	3.62	1.31	22.43	37.62	23.74	4.40	0.96	1.64
DHSubt28	0.87	5.02	1.37	2.14	3.47	1.03	19.52	27.35	28.18	7.49	3.55	2.61
DHSubt29	4.47	7.30	2.37	3.39	5.12	0.57	14.62	17.52	18.56	16.16	9.93	6.09
DHSubt30	0.73	1.58	0.58	1.02	2.01	0.97	16.49	30.13	29.87	13.77	2.84	1.87
DHSubt31	0.71	2.32	0.79	1.30	2.25	0.74	14.38	27.48	31.69	15.40	2.93	2.47
DHSubt32	1.31	5.98	1.77	2.60	4.00	1.12	15.89	30.28	28.45	5.23	3.39	2.48
DHSubt33	1.11	4.83	1.40	1.93	3.17	0.84	15.16	26.09	34.84	8.04	2.60	2.66
DHSubt34	0.83	6.83	2.19	3.23	4.58	0.93	22.95	30.70	15.70	6.38	5.68	4.75
DHSubt35	0.36	4.33	1.84	3.12	4.46	1.00	15.10	20.38	24.31	17.52	7.58	4.08
DHSubt36	0.61	4.52	1.90	2.78	3.60	0.57	8.09	12.09	20.43	28.57	16.83	6.62
DHSubt37	1.31	7.16	2.14	3.09	3.67	0.73	7.00	8.74	17.13	29.48	19.54	9.16
DHSubt38	2.20	8.44	2.80	4.35	5.43	0.90	11.01	12.66	17.52	20.58	14.11	10.51
DHSubt39	1.94	7.89	1.93	2.43	2.67	0.63	4.72	4.85	13.21	44.18	15.53	10.27
DHSubt40	2.00	4.16	1.84	4.53	10.84	3.28	33.01	22.37	13.77	3.14	1.05	2.11
DHSubt41	0.15	1.26	0.53	1.10	2.11	0.69	12.61	27.48	43.41	9.17	1.50	2.80
DHSubt42	0.06	1.24	0.54	1.09	1.97	0.60	12.08	32.37	39.07	10.31	0.66	2.42
DHSubt43	0.24	1.88	0.71	1.20	2.04	0.48	7.17	19.28	51.45	14.44	1.11	1.41
DHSubt44	0.35	2.66	0.90	1.47	2.86	1.15	18.43	37.68	24.63	6.77	3.10	3.23
DHSubt45	0.24	2.82	1.29	2.38	3.92	1.02	14.06	23.38	33.59	14.17	3.14	4.50

Sample Nr.	% +2000μ	% +1000μ	% +850μ	% +710μ	% +500μ	% +425μ	% +300μ	% +212	% +150	% +63μ	% - 63μ	% TOC
DHSubt46	0.24	1.40	0.41	0.78	1.68	0.72	10.87	24.71	44.94	13.74	0.50	2.01
DHSubt47	0.03	0.65	0.43	0.87	1.89	0.64	14.49	32.10	34.13	11.54	3.24	2.71
DHSubt48	0.22	1.75	0.72	1.27	2.22	0.95	13.48	30.20	35.52	9.71	3.97	2.65
DHSubt49	0.17	0.95	0.48	1.07	3.52	2.37	30.51	26.20	29.00	5.07	0.66	2.27
DHSubt50	0.04	0.68	0.46	1.22	2.98	1.66	19.34	33.94	32.66	6.41	0.62	1.38
DHSubt51	0.16	2.51	0.95	2.04	4.68	1.16	22.48	33.34	28.87	3.44	0.38	1.47

Table 2P: Trace metal concentrations of intertidal sediment for August 2016.

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHInt1	5.8	12.6	12.1	2.1	4.8	0.17	2.2	0.4	15.7	0.71	98.7	78.4
DHInt2	7.7	15.8	17.6	2.2	4.6	0.25	3.4	0.4	15.5	0.67	109.3	117.6
DHInt3	9.3	8.0	24.0	3.0	5.7	0.36	2.9	0.7	19.9	0.91	141.0	125.5
DHInt4	7.2	10.2	16.2	2.8	6.4	0.28	1.9	0.7	19.2	0.97	113.3	149.0
DHInt5	6.1	10.4	13.7	2.0	4.3	0.22	3.7	0.5	15.1	0.67	96.5	78.4
DHInt6	6.6	9.7	14.4	2.2	5.1	0.23	4.6	0.5	15.0	0.71	106.4	125.5
DHInt7	4.1	9.6	13.6	1.8	3.5	0.24	5.0	0.4	14.2	0.62	107.1	164.7
DHInt8	3.6	9.1	16.4	2.0	4.2	0.26	4.8	0.5	15.3	0.64	122.7	133.3
DHInt9	3.5	13.9	12.5	1.8	4.4	0.19	4.2	0.3	15.8	0.58	106.8	125.5
DHInt10	6.4	8.7	18.5	1.8	3.8	0.30	5.5	0.5	14.3	0.61	73.6	94.1
DHInt11	6.9	14.7	23.0	2.2	5.1	0.33	3.2	0.6	17.6	0.76	76.9	78.4
DHInt12	4.1	7.9	19.8	2.2	5.9	0.24	4.1	0.6	18.7	0.79	70.6	39.2
DHInt13	4.9	12.7	18.1	2.4	5.3	0.28	2.7	0.6	18.4	0.82	106.2	31.4
DHInt14	7.5	8.8	22.1	2.4	5.6	0.34	2.5	0.6	18.8	0.85	109.8	47.0
DHInt15	12.3	17.8	32.5	2.9	6.9	0.49	2.4	0.9	22.8	1.02	76.7	109.8
DHInt16	7.7	9.4	22.8	2.4	5.4	0.32	2.1	0.6	18.0	0.79	62.5	86.3
DHInt17	9.4	17.2	31.2	2.8	6.7	0.42	2.1	0.6	19.3	0.79	160.0	211.8
DHInt18	7.1	12.4	22.2	3.2	8.3	0.26	2.0	0.8	21.8	1.00	226.0	7.8
DHInt19	7.6	15.5	23.2	2.3	5.4	0.34	3.9	0.4	16.5	0.69	124.2	ND
DHInt20	8.7	15.1	22.5	2.6	5.1	0.32	3.7	0.5	16.5	0.68	144.9	7.8
DHInt21	8.6	11.0	21.6	2.6	5.3	0.33	6.9	0.6	17.9	0.78	137.9	0.0
DHInt22	6.7	10.9	16.0	2.1	4.8	0.25	4.0	0.4	15.3	0.65	118.7	ND

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHInt23	6.6	9.9	16.8	2.1	4.7	0.23	2.9	0.4	15.8	0.67	113.9	133.3
DHInt24	6.4	8.7	17.3	2.2	5.0	0.29	4.6	0.5	16.3	0.73	111.6	258.8
DHInt25	7.9	14.7	22.7	2.1	4.4	0.34	6.5	0.6	16.3	0.72	74.4	62.7
DHInt26	9.7	15.4	25.8	2.6	5.3	0.40	1.9	0.5	16.6	0.72	140.6	23.5
DHInt27	11.9	13.7	29.7	2.8	6.6	0.43	3.5	0.6	19.0	0.83	142.5	125.5
DHInt28	12.7	14.9	34.5	2.8	6.4	0.46	1.6	0.7	21.7	0.93	70.2	ND
DHInt29	15.9	15.4	42.2	3.0	6.7	0.48	2.6	0.8	23.2	0.94	75.1	78.4
DHInt30	20.6	24.9	60.3	3.7	6.7	0.77	4.1	1.1	25.7	1.12	89.0	12.2
DHInt31	16.5	18.0	42.4	2.8	6.2	0.58	5.7	0.7	21.1	0.93	75.3	12.2
DHInt32	15.4	17.0	46.5	3.5	7.9	0.59	3.5	0.9	23.8	1.05	84.9	ND
DHInt33	6.2	13.3	21.4	2.4	4.9	0.26	3.5	0.3	13.3	0.56	162.9	ND
DHInt34	6.7	10.3	23.7	2.5	4.1	0.32	3.8	0.5	16.3	0.66	58.9	ND
DHInt35	11.9	15.1	36.1	3.1	6.3	0.52	1.9	0.9	22.1	0.91	80.7	ND
DHInt36	8.4	13.4	23.9	2.3	3.5	0.27	2.9	0.5	14.6	0.61	47.3	4.9
DHInt37	14.7	28.2	43.5	3.3	5.8	0.61	3.2	0.9	20.9	0.86	72.7	12.2
DHInt38	20.6	17.7	90.9	4.0	7.0	0.57	2.3	1.6	27.8	1.13	67.0	26.7
DHInt39	12.1	16.8	35.7	2.5	5.2	0.49	1.9	0.7	19.1	0.77	84.0	12.2
DHInt40	4.8	8.0	8.3	1.3	2.5	0.20	0.3	0.1	11.5	0.43	44.5	ND
DHInt41	6.8	10.0	16.0	2.0	3.5	0.24	2.7	0.5	13.3	0.60	99.3	4.9
DHInt42	9.4	5.7	24.9	1.7	6.2	0.28	ND	0.2	15.2	0.63	38.9	12.2
DHInt43	6.2	12.1	17.2	1.9	2.8	0.25	4.4	0.4	12.8	0.57	92.6	4.9
DHInt44	6.5	18.2	20.4	1.7	3.6	0.27	2.6	0.4	15.1	0.65	48.4	4.9
DHInt45	9.4	12.3	29.8	2.1	5.6	0.21	0.0	0.4	16.7	0.77	48.7	19.4

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHInt46	6.8	9.4	15.7	2.1	3.5	0.23	4.3	0.6	14.8	0.79	110.5	121.3
DHInt47	9.0	14.5	23.1	1.7	3.9	0.22	0.6	0.6	16.0	0.78	56.6	19.4
DHInt48	7.0	10.6	14.4	1.8	3.1	0.19	6.1	0.5	13.5	0.68	120.8	4.9
DHInt49	7.6	14.4	15.4	1.7	2.8	0.17	4.7	0.4	12.6	0.62	82.1	12.2
DHInt50	12.3	9.6	27.4	1.7	3.4	0.15	1.7	0.3	15.2	0.66	42.3	26.7
DHInt51	6.0	4.8	11.9	2.0	3.5	0.16	2.2	0.5	16.0	0.75	113.8	4.9
DHInt52	5.7	11.8	11.4	1.6	3.1	0.17	2.7	0.4	14.8	0.66	97.6	19.4
DHInt53	10.2	17.5	37.7	2.4	2.8	0.15	1.8	0.9	13.9	0.65	56.4	19.4

Table 2Q: Trace metal concentrations of subtidal sediment for August 2016.

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHSubt1	42.4	31.9	90.9	5.2	9.6	1.16	8.5	1.5	38.0	1.51	121.5	ND
DHSubt2	24.1	14.3	41.2	3.2	6.1	0.61	4.5	0.9	24.4	1.05	84.1	ND
DHSubt3	23.0	17.2	35.8	2.7	5.2	0.52	2.7	0.7	20.7	0.85	65.3	37.0
DHSubt4	20.8	14.7	30.8	3.7	7.6	0.50	1.6	1.0	28.5	1.32	89.5	22.2
DHSubt5	14.7	12.9	26.2	2.0	3.0	0.45	3.3	0.4	12.9	0.63	49.2	22.2
DHSubt6	18.6	17.4	39.4	2.9	6.0	0.74	4.0	0.9	20.8	1.01	80.4	29.6
DHSubt7	11.8	11.0	21.3	1.9	3.4	0.40	3.1	0.4	12.6	0.64	63.5	ND
DHSubt8	13.8	9.8	24.5	2.1	3.6	0.46	3.9	0.5	14.5	0.70	72.0	7.4
DHSubt9	20.6	20.6	40.4	3.4	6.4	0.72	6.1	1.1	26.5	1.17	104.3	7.4
DHSubt10	10.6	6.7	17.8	1.9	3.5	0.35	6.7	0.4	16.3	0.63	88.9	ND
DHSubt11	14.5	11.5	28.1	3.3	6.9	0.57	5.5	1.1	25.3	1.22	110.0	7.4
DHSubt12	11.2	11.5	17.3	2.6	4.9	0.33	1.9	0.6	17.4	0.88	114.1	0.0
DHSubt13	12.3	13.8	20.6	2.4	3.8	0.38	5.4	0.7	16.8	0.82	144.2	0.0
DHSubt14	13.0	9.9	26.2	2.3	3.9	0.40	5.2	0.6	16.1	0.75	69.5	22.2
DHSubt15	14.2	16.0	27.2	2.3	4.1	0.42	5.7	0.7	16.9	0.79	72.9	51.9
DHSubt16	10.4	17.5	20.5	2.1	3.6	0.35	5.4	0.6	14.8	0.64	76.1	133.3
DHSubt17	11.4	13.1	21.0	3.0	5.7	0.40	3.5	0.9	20.6	1.07	133.4	51.9
DHSubt18	12.7	16.4	23.6	2.2	4.6	0.38	4.9	0.7	17.9	0.82	70.8	0.0

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHSubt19	28.4	18.3	57.7	3.4	6.8	0.71	3.7	1.0	25.7	1.12	93.4	103.7
DHSubt20	10.9	9.2	18.5	2.3	4.0	0.32	4.5	0.6	16.5	0.80	77.9	88.9
DHSubt21	12.9	14.5	23.8	2.6	4.9	0.41	4.7	0.8	21.6	1.00	81.0	59.3
DHSubt22	44.1	30.5	80.3	4.0	8.5	1.12	4.3	1.4	34.9	1.44	93.0	244.5
DHSubt23	24.4	26.8	42.5	3.6	7.8	0.64	4.0	1.1	28.8	1.41	96.7	22.2
DHSubt24	22.9	23.5	43.7	3.1	5.9	0.60	4.0	1.0	23.3	1.04	82.4	29.6
DHSubt25	38.2	48.5	101.0	6.2	15.9	1.58	5.4	2.3	44.6	1.91	181.2	111.1
DHSubt26	58.8	44.1	104.5	5.2	11.2	1.42	5.5	1.8	40.8	1.68	141.5	70.2
DHSubt27	17.3	16.2	30.2	2.9	5.5	0.37	2.3	0.8	19.8	0.95	125.8	49.1
DHSubt28	20.6	25.3	48.4	3.7	7.6	0.67	2.3	1.0	24.7	1.15	125.2	7.0
DHSubt29	65.6	55.0	149.6	7.6	16.7	1.84	8.3	2.4	54.8	2.18	177.0	119.3
DHSubt30	22.5	18.7	57.3	3.9	6.5	0.53	1.6	1.0	24.0	1.04	76.0	217.5
DHSubt31	24.6	23.4	62.9	4.1	7.7	0.68	3.3	1.2	27.1	1.24	84.8	21.0
DHSubt32	19.7	22.9	45.1	4.3	8.7	0.69	4.1	1.4	26.0	1.30	159.6	28.1
DHSubt33	20.5	22.4	49.2	4.3	9.0	0.75	3.0	1.4	28.1	1.42	159.4	35.1
DHSubt34	26.5	31.5	65.0	4.3	10.1	0.91	4.2	1.4	32.3	1.46	114.8	28.1
DHSubt35	63.4	44.3	126.1	5.4	12.5	1.37	7.3	1.9	44.9	1.79	131.9	119.3
DHSubt36	89.3	57.4	179.5	6.8	17.8	1.63	6.3	2.6	56.3	2.14	185.9	112.3
DHSubt37	90.9	61.3	214.9	8.0	20.5	1.75	7.3	3.0	58.8	2.28	194.8	140.3
DHSubt38	114.0	72.2	254.5	8.2	23.4	1.87	7.6	3.4	67.4	2.41	151.3	147.4
DHSubt39	97.9	70.9	214.5	9.5	30.8	1.76	1.9	3.4	72.6	2.60	278.7	119.3
DHSubt40	109.0	44.8	68.6	2.3	7.4	0.48	0.7	0.8	29.4	1.03	62.8	35.1
DHSubt41	20.9	22.3	39.6	2.5	6.1	0.54	2.6	0.8	23.2	0.92	65.4	42.1

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (%)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (%)	Mn (ppm)	Hg (ppb)
DHSubt42	16.3	17.5	35.0	2.7	6.0	0.52	5.1	0.8	22.5	0.94	69.5	14.0
DHSubt43	12.5	14.9	24.4	2.3	4.8	0.37	4.6	0.8	19.9	0.88	68.3	28.1
DHSubt44	30.0	22.6	64.8	3.9	9.1	0.96	8.2	1.2	33.5	1.36	103.1	63.1
DHSubt45	78.8	60.2	170.2	4.8	16.1	1.33	7.7	1.7	53.2	1.69	103.7	182.4
DHSubt46	16.9	24.7	38.5	2.4	5.3	0.54	7.1	0.7	20.2	0.85	92.5	105.3
DHSubt47	24.3	24.0	56.6	3.0	6.9	0.74	5.4	1.0	27.1	1.08	80.8	56.1
DHSubt48	24.2	29.6	60.3	3.2	7.6	0.79	5.1	1.1	29.6	1.17	82.2	164.7
DHSubt49	11.4	15.1	27.7	2.0	4.9	0.34	5.4	0.9	18.9	0.75	90.8	109.8
DHSubt50	9.0	16.7	23.1	2.7	7.6	0.34	1.0	1.1	23.0	1.04	109.6	94.1
DHSubt51	9.1	14.8	22.1	2.2	5.7	0.33	1.2	0.7	20.0	0.75	84.6	125.5

Grain Size		Descriptive term	
phi	mm		
-10	1024	Very Large	Boulder
		Large	
-9	512	Medium	
-8	256	Small	
-7	128	Very small	
-6	64	Very coarse	Gravel
-5	32	Coarse	
-4	16	Medium	
-3	8	Fine	
-2	4	Very fine	
-1	2	Very coarse	Sand
0	1	Coarse	
1	500	Medium	
2	250	Fine	
3	125	Very fine	
4	63	Very coarse	Silt
5	31	Coarse	
6	16	Medium	
7	8	Fine	
8	4	Very fine	
9	2	Clay	

Figure 2A: Sediment grain size scale adopted in the GRADISTAT program. modified from Udden (1914) and Wentworth (1922).

Sorting (σ_G)	
Very well sorted	< 1.27
Well sorted	1.27 – 1.41
Moderately well sorted	1.41 – 1.62
Moderately sorted	1.62 – 2.00
Poorly sorted	2.00 – 4.00
Very poorly sorted	4.00 – 16.00
Extremely poorly sorted	> 16.00

Figure 2B: Sediment sorting scale adopted in the GRADISTAT program. modified from Udden (1914) and Wentworth (1922).

ANNEXURE 3:

Biomonitoring Baseline Monitoring Data

Table 3A: Trace metal concentrations in mussel tissue for November 2015.

Sample #	Al (ppm)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHBM1	679.9	2.6	1.9	3.2	9.0	29.9	985.4	151.1	15.4	3.3	140.1	71.8
DHBM3	324.6	3.2	2.3	2.1	2.2	21.5	446.0	67.3	2.0	7.0	135.0	81.1
DHBM4	274.4	2.1	4.1	1.4	2.1	23.5	359.3	67.1	1.5	5.7	128.9	360.2
DHBM5	190.9	1.9	2.8	0.8	1.6	12.4	245.0	75.7	1.1	4.4	108.3	16.0
DHBM9	163.5	1.7	1.1	0.3	1.3	15.7	242.5	64.2	0.9	4.0	135.6	ND
DHBM13	70.5	2.4	1.2	0.5	1.1	11.2	148.9	42.4	0.8	4.9	118.4	155.5
DHBM15	106.2	2.3	1.3	0.6	1.0	10.9	156.5	53.9	0.9	3.6	135.2	90.4
DHBM18	345.9	2.9	1.8	0.8	2.2	23.6	458.9	125.5	2.2	3.7	152.9	295.0
DHBM19	268.7	1.1	1.6	0.6	2.1	21.5	385.4	80.8	2.2	2.1	110.0	136.9
DHBM20	493.4	2.0	1.8	0.7	3.0	18.7	493.6	64.5	1.8	3.6	138.9	ND
DHBM21	406.8	1.7	2.0	0.9	2.9	24.7	563.0	119.1	2.7	5.3	151.0	60.9
DHBM22	742.4	1.4	3.2	2.3	5.6	44.3	970.3	374.1	5.0	7.5	220.8	ND
DHBM26	254.7	1.3	10.8	0.6	1.9	20.8	328.7	66.6	1.4	1.8	142.3	34.6
DHBM27	289.4	2.0	6.7	0.8	2.3	21.2	381.5	62.3	1.1	2.9	126.0	52.2
DHBM28	404.7	2.6	6.4	0.4	2.3	12.2	428.7	52.9	1.0	2.6	125.0	60.9
DHBM30	363.7	1.4	1.8	0.7	9.5	16.3	462.4	65.0	1.7	29.4	147.4	629.9
DHBM32	270.5	-0.1	1.1	0.4	2.3	18.4	409.3	49.8	2.1	4.3	75.1	ND
DHBM34	274.7	2.4	2.7	0.7	2.2	20.5	409.8	82.1	1.5	3.0	138.1	ND

Table 3B: Trace metal concentrations in mussel tissue for January 2016.

Sample #	Al (ppm)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHBM7	208.5	1.0	0.5	0.6	3.7	26.4	205.8	243.7	3.5	3.3	201.1	2068.9
DHBM8	339.3	1.6	0.6	0.6	3.8	19.6	257.1	175.9	2.7	0.5	169.1	68.7
DHBM9	224.7	2.2	0.6	0.5	3.8	12.7	231.5	113.9	1.4	3.2	167.5	173.8
DHBM10	328.4	1.1	0.8	0.7	4.3	24.2	246.8	233.2	3.2	3.3	198.2	344.6
DHBM11	434.0	1.0	0.7	0.7	4.9	19.2	325.2	108.3	6.1	ND	166.7	137.7
DHBM12	271.3	2.2	0.5	0.7	7.0	11.7	226.3	63.2	9.2	2.7	118.2	275.6
DHBM14	396.5	1.5	0.6	1.0	4.5	20.0	293.4	196.3	5.0	3.9	237.0	482.5
DHBM15	139.3	1.7	0.1	0.7	3.6	13.3	340.2	104.7	29.1	5.9	132.9	ND
DHBM16	98.3	1.9	0.1	0.5	3.9	10.0	157.9	94.2	2.5	6.3	121.8	1156.2
DHBM17	506.1	1.0	0.2	0.7	8.4	16.4	410.4	140.6	4.6	5.7	167.7	ND
DHBM18	82.5	1.7	0.4	0.7	4.8	19.7	308.7	162.3	5.3	3.4	182.0	ND
DHBM19	122.2	1.2	0.5	0.7	3.9	13.3	198.7	152.8	5.3	ND	303.6	ND
DHBM20	102.9	1.5	0.6	0.6	9.6	20.1	293.2	107.1	3.1	3.3	143.0	ND
DHBM21	145.1	1.5	0.6	0.9	4.8	15.0	224.2	149.4	4.9	3.7	190.5	ND
DHBM22	313.2	1.3	ND	0.7	7.0	16.4	306.6	214.1	4.4	9.0	202.2	ND
DHBM23	190.5	1.2	0.1	0.4	3.9	11.1	203.4	54.0	2.4	0.3	127.7	ND
DHBM26	145.7	2.8	3.5	0.4	4.5	10.9	217.0	28.5	6.7	2.4	102.6	ND
DHBM27	124.9	1.5	4.8	0.4	8.6	7.2	193.7	27.6	5.9	0.0	128.2	68.7
DHBM28	77.7	1.5	3.7	0.2	3.5	7.2	122.5	31.7	1.4	2.0	128.0	ND
DHBM29	139.4	1.9	0.5	0.4	2.5	11.0	131.3	100.4	3.7	ND	123.0	57.8
DHBM30	54.3	1.7	0.4	0.4	2.8	8.9	162.1	51.3	1.5	1.8	104.3	137.7
DHBM31	282.7	2.1	0.4	0.5	4.3	10.7	219.1	71.0	5.3	0.2	111.2	1861.8

Sample #	Al (ppm)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)
DHBM32	77.9	1.6	0.5	0.6	4.2	13.4	165.5	122.1	4.7	ND	156.6	137.7
DHBM33	124.7	1.2	0.6	0.6	4.1	19.6	196.4	208.7	4.2	1.9	194.7	ND
DHBM34	236.2	2.0	0.4	0.6	3.9	13.8	287.1	131.6	4.6	1.3	147.6	433.1
DHBM35	247.5	1.5	0.7	0.8	4.4	19.8	282.3	74.0	3.9	3.1	107.1	137.7
DHBM36	268.8	1.1	0.4	0.7	4.2	14.1	296.6	138.5	2.0	3.1	138.7	206.6

Table 3C: Trace metal concentrations in mussel tissue for May 2016.

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (ppm)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (ppm)	Mn (ppm)	Hg (ppb)
DHBM12	10.7	3.4	137.8	0.4	2.1	273.0	4.3	0.2	2.0	386.3	28.6	377.4
DHBM14	10.2	4.3	162.2	0.5	2.9	214.0	4.6	0.2	2.3	291.2	34.5	151.0
DHBM16	13.2	4.1	149.8	0.5	2.1	192.2	3.7	0.3	1.7	347.4	16.7	0.1
DHBM18	10.0	4.4	140.3	0.4	1.9	91.6	3.4	0.1	1.6	346.6	22.2	151.0
DHBM20	8.2	4.7	139.9	0.3	1.9	163.3	2.9	0.1	2.3	235.1	22.7	ND
DHBM21	8.5	4.8	126.3	0.4	2.0	115.4	3.0	0.2	1.9	186.5	9.7	75.5
DHBM22	10.6	4.3	171.7	0.4	2.7	29.5	3.6	0.2	1.6	117.2	32.6	151.0
DHBM23	8.1	3.9	125.7	0.4	2.4	31.0	2.9	0.2	1.0	97.7	14.3	ND
DHBM30	12.5	5.2	137.4	0.4	2.2	107.3	3.9	0.3	2.0	216.8	15.2	ND
DHBM31	13.5	4.2	143.2	0.4	1.8	177.3	3.9	0.1	2.0	329.3	19.1	0.1
DHBM33	15.2	5.0	248.6	0.4	2.2	159.8	3.3	0.2	1.4	259.4	26.5	75.5
DHBM34	10.4	4.4	144.8	0.4	1.9	117.7	2.7	0.1	1.4	195.0	30.8	151.0
DHBM36	13.3	6.7	159.6	0.5	2.1	154.9	3.6	0.2	1.7	313.2	35.5	1056.7
DHBM46	11.9	4.1	175.6	0.6	2.5	402.7	3.5	0.3	1.6	499.0	24.4	1056.7
DHBM47	13.3	4.0	166.1	0.6	2.4	230.7	5.6	0.5	1.6	349.4	46.7	151.0
DHBM48	8.6	2.4	130.5	0.3	1.7	98.7	4.3	0.1	0.9	162.0	23.8	151.0
DHBM29	10.3	3.8	114.5	0.3	1.5	240.8	3.9	0.1	0.8	330.1	25.7	ND
DHBM7	5.1	5.3	129.8	0.5	1.6	236.7	3.6	0.4	1.0	346.2	15.8	905.7
DHBM9	11.4	2.8	120.2	0.3	1.7	114.7	4.5	0.1	1.1	218.1	18.5	75.5

Table 3D: Trace metal concentrations in mussel tissue for August 2016.

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (ppm)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (ppm)	Mn (ppm)	Hg (ppb)
DHBM 2	Insufficient											800.0
DHBM 3	Insufficient											218.2
DHBM 4	Insufficient											654.5
DHBM 5	75.7	12.4	415.0	0.9	4.2	823.3	2.8	2.4	6.1	1806.1	145.5	145.5
DHBM 7	26.0	20.5	281.5	0.7	2.0	533.5	1.1	1.2	4.3	1050.0	156.8	363.6
DHBM 8	30.7	21.7	323.4	0.8	2.1	736.5	2.0	1.0	4.5	1348.4	243.5	363.6
DHBM 10	34.2	19.2	394.8	1.1	3.0	1103.1	2.0	1.1	7.4	1944.0	129.8	872.7
DHBM 12	17.7	4.7	132.7	0.5	1.2	422.2	0.5	0.7	2.6	798.5	71.1	ND
DHBM 14	23.8	9.0	290.2	1.1	2.7	782.7	0.6	0.8	4.1	1374.6	270.7	ND
DHBM 16	16.6	15.0	242.7	0.8	1.5	507.4	1.4	0.9	3.3	943.8	77.2	91.0
DHBM 18	9.3	16.1	226.8	0.6	1.4	406.5	1.9	0.9	2.8	800.8	62.3	ND
DHBM 19	8.0	17.6	184.6	0.6	1.8	409.4	1.4	1.1	2.7	845.2	60.2	ND
DHBM 20	17.8	20.6	207.6	1.8	3.7	696.2	1.6	1.1	4.6	1318.6	426.1	ND
DHBM 21	10.8	12.1	226.2	0.5	1.9	369.0	2.0	0.7	2.7	777.2	113.0	ND
DHBM 29	20.3	7.6	153.3	0.3	0.9	255.2	1.8	0.7	2.2	537.9	50.8	363.6
DHBM 30	15.9	21.2	237.1	0.8	1.7	461.4	2.2	1.2	3.7	979.3	100.1	436.4
DHBM 31	9.2	2.7	177.9	0.3	0.9	219.3	1.2	0.6	1.4	458.2	73.4	218.2
DHBM 32	13.4	14.4	242.3	1.4	3.9	751.4	1.1	1.1	4.0	1226.1	305.6	ND
DHBM 33	11.4	10.2	214.0	0.6	2.5	708.3	1.1	1.0	4.0	1251.9	105.9	727.4
DHBM 34	8.0	28.9	294.4	0.6	2.5	814.9	0.3	1.1	4.3	1319.9	98.9	272.8
DHBM 35	17.5	19.8	250.2	1.3	2.5	809.3	3.0	1.5	4.9	2139.6	108.5	654.5



Deepening, Lengthening and Widening of Berth 203 to 205, Pier 2, Container
Terminal, Port of Durban
Central Sandbank Mitigation Plan
Final

Sample #	Cu (ppm)	Pb (ppm)	Zn (ppm)	Co (ppm)	Ni (ppm)	Al (ppm)	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (ppm)	Mn (ppm)	Hg (ppb)
DHBM 36	3.4	14.9	178.4	0.3	1.3	381.2	1.3	0.6	2.3	661.0	45.2	ND

ANNEXURE 4 - Invertebrates Baseline Monitoring Data

Table 4A: Species list. including intertidal species name. abundance for this survey.

Species	Abundance							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Aonides oxycephala	0	0	0	1	5	2	1	1
Aricidea sp	0	0	0	0	0	0	1	0
Arabella iricolor	2	3	1	1	0	1	0	1
Arabella sp	1	0	0	0	0	0	2	0
Armandia intermedia	0	1	0	0	3	0	1	0
Aphroditidae sp1	0	2	0	1	0	1	0	1
Ceratoneries erythraensis	0	0	0	9	0	13	37	20
Ceratoneries sp.	0	0	5	0	0	0	1	0
Chaetopterus varieopedatus	0	0	0	1	0	0	0	0
Cirriformia saxatilis	0	1	4	15	0	6	3	0
Cirriformia tentaculata	0	0	1	0	0	0	0	0
Cirratulus africanus	0	0	0	0	3	0	0	0
Cirratulus sp	0	2	0	0	1	11	0	0
Dendronereis arborifera	8	6	21	17	10	14	61	121
Diopatra neapolitana capensis	0	0	0	0	1	0	0	0
Dorvilleidae sp	0	0	0	0	0	0	0	5
Glycera alba	5	1	0	0	0	11	2	0
Glycera convoluta	52	39	24	62	30	29	22	36
Glycera natalensis	0	74	200	73	75	81	183	93
Glycera subaenea	1	13	7	15	4	4	4	8
Glycinde capensis	0	8	0	1	2	0	1	0
Goniada sp	1	0	0	0	0	0	0	0
Grubeulepis geayi	0	1	0	0	0	0	0	0
Heteromastus filiformis	1	0	0	0	0	0	0	0
Jasmineiraa elegans	0	0	0	0	1	0	0	1
Laeonereis ankyloseta	1	0	0	1	5	0	0	0
Laonice cirrata	0	6	24	8	0	0	0	0
Leonnates persicus	0	0	1	0	0	0	0	0
Magelonia cincta	0	37	37	24	18	33	28	17
Magelonia capensis	0	0	0	0	0	0	0	1
Malacoceros indicus	0	0	0	0	4	0	0	25

Species	Abundance							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Maldanidae sp	0	0	0	0	1	0	0	0
Marphysa depressa	0	2	0	0	1	1	0	0
Capitella capitata	0	0	0	3	1	30	12	51
Nephtys dibranchis	1	0	0	0	0	1	0	0
Nephtys sphaerocirrata	0	5	4	3	6	2	1	1
Nereis caudata	1	13	7	6	1	3	1	1
Nereis succinea	1	4	0	0	0	0	0	0
Nereis willegi	0	8	3	0	1	0	0	0
Notomastus latericeus	0	2	3	0	1	2	4	0
Orbinia bioreti	99	104	180	162	73	46	154	80
Phyllodoceidae sp	1	2	2	0	0	1	1	0
Platynereis dumerilii	2	0	0	0	1	0	0	0
Poecilochaetus serpens	0	6	4	1	7	2	8	1
Prionospio malmgreni/blocki	0	0	0	0	0	2	0	0
Prionospio saldanha	0	12	1	3	0	4	0	0
Prionospio sexoculata	5	20	51	18	8	229	251	93
Scoloplos johnstonei	25	7	20	11	20	15	11	9
Scolecopsis squamata	5	0	9	14	0	7	5	5
Spio filicornis	0	0	0	0	13	39	56	25
Sigambra parva	3	5	5	4	10	7	2	17
Syllides longocirrata	0	0	2	0	0	0	0	0
Syllis sp1	3	2	1	1	3	3	3	1
Syllis sp2	0	0	2	0	0	0	0	0
Terebellides stroemi	0	0	0	1	0	0	0	0
Hirudinea sp.	0	0	30	4	3	37	64	19
Dotilla fenestrata	87	89	125	37	43	35	62	31
Hymenosoma orbiculare	0	0	0	0	1	1	2	1
Spiroplax spiralis	132	159	149	91	151	101	74	58
Paratyloplax blephariskios	2	0	2	0	0	0	0	0
Portunus pelagicus	0	0	0	0	1	0	0	0
Macrophthalmus grandidieri	2	7	1	2	6	2	3	2

Species	Abundance							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Ampliscid	0	0	2	0	0	0	0	0
caprelid	0	0	0	3	0	5	0	0
Lysianassa certina	0	1	3	0	1	0	0	0
Grandidierella bonnieroides	0	0	0	0	1	0	8	3
Melita sp	38	4	13	4	3	29	18	27
Periculodes longimanus	0	0	0	2	1	2	0	0
Urothoe elagans	0	0	0	0	0	0	0	0
Urothoe pinnata	2	5	1	0	0	0	0	0
Urothoe tumorosa	0	2	0	5	1	11	2	0
Betaeus jucundus	3	4	4	2	1	4	3	4
Gastrosuccus sp.	0	27	1	0	0	0	2	51
Penaeus canaliculatus	4	0	0	0	0	0	0	0
Penaeus japonicus	0	0	0	0	1	0	0	0
Metapenaeopsis andamdonensis	0	7	2	0	3	4	4	2
Metapenaeus stebbingi	2	0	0	0	0	0	0	0
Callianassa kraussi	172	123	197	244	53	71	192	173
Upogebia africana	0	0	1	1	1	0	0	0
Diogenes sp.	0	0	0	1	0	0	1	0
Cyathura estuaria	0	2	1	0	0	0	0	0
Excirolana latipes	69	73	59	102	44	44	139	44
Eurydice natalensis	12	44	31	9	3	7	8	6
Eurydice longicornis	0	0	0	0	0	0	0	0
Nassarius arcularius	0	0	0	0	1	0	0	0
Nassarius kraussianae	8	19	1	3	10	0	23	6
Natica taeniata	0	1	1	0	0	0	4	0
Polinices mamilla	1	3	1	7	2	1	1	10
Anodontia edentula	0	0	1	2	0	0	3	1
Donax bertini	0	0	0	0	0	1	0	0
Dosinia hepatica	23	46	56	17	16	39	47	15
Eumarcia paupercula	0	5	8	0	1	9	10	0
Fulvia laevigata (papyracea)	0	0	1	0	3	1	0	0
Heterodonax ludwigii	0	3	7	9	2	5	15	17
Macoma sp	0	0	0	0	3	1	26	21
Paphia textile	0	2	0	1	1	1	1	1

Species	Abundance							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Pitar abbreviatus	2	0	0	0	0	0	0	0
Solen cylindraceus	1	2	5	1	2	9	34	14
Tellina natalensis	0	0	4	3	0	0	0	0
Theora lata	0	1	0	1	1	0	0	0
Actiniaria sp/cerianthid	0	75	52	29	11	75	68	25
Sipunculida	14	10	4	3	21	37	8	6
Platyhelminthes	2	5	4	14	9	8	2	0
Nemertea	7	16	32	44	40	36	41	34

Table 4B: Species list. including intertidal species name. biomass for this survey.

Species	Biomass							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Aonides oxycephala	0	0	0	0.0069	0.0064	0.0089	0.0067	0.0121
Aricidea sp	0	0	0	0	0	0	0.0009	0
Arabella iricolor	0.0877	0.3436	0.0937	0.0454	0	0.0644	0	0.2661
Arabella sp	0.0009	0	0	0	0	0	0.4989	0
Armandia intermedia	0	0.0014	0	0	0.0055	0	0.0563	0
Aphroditidae sp1	0	0.0542	0	0.014	0	0.035	0	0.0774
Ceratoneries erythraensis	0	0	0	0.4218	0	0.1745	1.5868	0.6576
Ceratoneries sp.	0	0	0.1118	0	0	0	0.0017	0
Chaetopterus varieopedatus	0	0	0	0.1281	0	0	0	0
Cirriformia saxatilis	0	0.581	0.5384	1.8505	0	0.5166	0.791	0
Cirriformia tentaculata	0	0	0.0038	0	0	0	0	0
Cirratulus africanus	0	0	0	0	0.0834	0	0	0
Cirratulus sp	0	0.0065	0	0	0.0224	0.0775	0	0
Dendronereis arborifera	0.0396	0.2283	0.2519	0.4036	0.0877	0.0693	0.4928	4.8374
Diopatra neapolitana capensis	0.0863	0	0	0	0.1141	0	0	0
Dorvilleidae sp	0	0	0	0	0	0	0	0.0151
Glycera alba	0.0782	0.0323	0	0	0	0.2216	0.0325	0
Gycera convoluta	1.0313	0.89331	1.7961	2.6573	1.1394	2.0682	3.7419	4.9153
Glycera natalensis	0	0.4523	1.0027	0.6554	0.5082	0.4029	0.68687	0.7822
Glycera subaenea	0.2247	0.6459	0.3759	2.3242	0.5955	0.6589	0.4794	3.4849
Glycinde capensis	0	0.0101	0	0.0194	0.0063	0	0.0045	0
Goniada sp	0.0129	0	0	0	0	0	0	0
Grubeulepis geayi	0	0.3019	0	0	0	0	0	0
Heteromastus filiformis	0.0067	0	0	0	0	0	0	0
Jasmineiraa elegans	0	0	0	0	0.0058	0	0	0.0016
Laeonereis ankyloseta	0.0235	0	0	0.1451	0.1802	0	0	0
Laonice cirrata	0	0.043	0.0392	0.0779	0	0	0	0
Leonnates persicus	0	0	0.0391	0	0	0	0	0
Magelonia cincta	0	0.0996	0.2149	0.2208	0.0715	0.1255	0.2371	0.2412
Magelonia capensis	0	0	0	0	0	0	0	0.0078
Malacoceros indicus	0	0	0	0	0.1159	0	0	0.7015
Maldanidae sp	0	0	0	0	0.0119	0	0	0
Marphysa depressa	0	1.024	0	0	0.501	0.1344	0	0
Capitella capitata	0	0	0	0.0132	0.0015	0.0273	0.04	0.0724
Nephtys dibranchis	0.0093	0	0	0	0	0.0253	0	0
Nephtys sphaerocirrata	0	0.02	0.0159	0.0125	0.0063	0.0143	0.0031	0.0021
Nereis caudata	0.0173	0.1507	0.0214	0.0777	0.001	0.0278	0.0049	0.0037

Species	Biomass							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Nereis succinea	0.0054	0.1284	0	0	0	0	0	0
Nereis willegi	0	0.1104	0.0239	0	0.0401	0	0	0
Notomastus latericeus	0	0.0162	0.0051	0	0.0023	0.0067	0.1573	0
Orbinia bioreti	1.1599	1.6061	2.9772	2.5941	5.766	1.2488	2.4588	1.3031
Phyllodocidae sp	0.0009	0.141	0.0021	0	0	0.0014	0.0048	0
Platyneries dumerilii	0.1055	0	0	0	0.8062	0	0	0
Poecilochaetus serpens	0	0.0137	0.0065	0.0021	0.017	0.009	0.0628	0.0016
Prionospio malmgreni/blocki	0	0	0	0	0	0.007	0	0
Prionospio saldanha	0	0.0749	0.0049	0.0081	0	0.0039	0	0
Prionospio sexoculata	0.0117	0.0228	0.4013	0.0556	0.0091	0.1637	0.2115	0.0904
Scoloplos johnstonei	0.1657	0.0574	0.0481	0.1184	0.3397	0.1952	0.1493	0.0719
Scolecopsis squamata	0.0138	0	0.0117	0.6461	0	0.0583	0.032	0.0377
Spio filicornis	0.003	0.0071	0.0195	0.0739	0.0977	0.0156	0.01	0.0736
Sigambra parva	0	0	0	0	0.0157	0.1111	0.3705	0.0688
Syllides longocirrata	0	0	0.0065	0	0	0	0	0
Syllis sp1	0.0032	0.0104	0.0003	0.0002	0.0029	0.0058	0.0031	0.0032
Syllis sp2	0	0	0.0148	0	0	0	0	0
Terebellides stroemi	0	0	0	0.0018	0	0	0	0
Hirudinea sp.	0	0	0.0246	0.0038	0.0095	0.0598	0.072	0.0378
Dotilla fenestrata	13.2672	6.24221	13.4084	10.1605	8.624	2.3396	14.4468	14.1812
Hymenosoma orbiculare	0	0	0	0	0.0282	0.0106	0.0862	0.1236
Spiroplax spiralis	3.039	4.7558	5.2168	4.4044	2.0528	2.4286	3.1882	2.5527
Paratyloidiplax blephariskios	0.2774	0	1.814	0	0	0	0	0
Portunus pelagicus	0	0	0	0	0.1824	0	0	0
Macrophthalmus grandidieri	1.2727	2.7057	2.237	4.6519	0.1767	2.0336	3.2089	1.4158
Ampliscid	0	0	0.0016	0	0	0	0	0
caprellid	0	0	0	0.0006	0	0.0019	0	0
Lysianassa certina	0	0.0027	0.0039	0	0.0022	0	0	0
Grandidierella bonnieroides	0	0	0	0	0.0023	0	0.0118	0.0037
Melita sp	0.0254	0.0089	0.0158	0.0103	0.004	0.0429	0.0242	0.0412
Periculodes longimanus	0	0	0	0.0029	0.0005	0.003	0	0
Urothoe elagans	0	0	0	0	0	0	0	0
Urothoe pinnata	0.0021	0.0103	0.0002	0	0	0	0	0
Urothoe tumerosa	0	0.0031	0	0.006	0.0003	0.0192	0.002	0
Betaeus jucundus	0.0503	0.0942	0.1004	0.0166	0.0052	0.0955	0.0999	0.1357
Gastrosuccus sp.	0	0.0554	0.0003	0	0	0	0.0019	0.1361
Penaeus canaliculatus	0.382	0	0	0	0	0	0	0
Penaeus japonicus	0	0	0	0	0.539	0	0	0
Metapenaeopsis andamonesis	0	1.6768	0.0437	0.0173	0.1645	0.4604	0.4026	0.117

Species	Biomass							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Metapenaeus stebbingi	0.0448	0	0	0	0	0	0	0
Callinassa kraussi	23.9831	10.3487	17.8997	38.9642	4.3463	3.3605	25.9517	26.205
Upogebia africana	0	0	0.0764	0	0.0189	0	0	0
Diogenes sp.	0	0	0	0.1583	0	0	0.4791	0
Cyathura estuaria	0	0.007	0.0121	0.0608	0	0	0	0
Excirolana latipes	0.8873	0.4194	0.837	0.9861	0.5993	0.4341	1.3813	0.4412
Eurydice natalensis	0.1001	0.2522	0.2534	0.0389	0.0129	0.0392	0.1347	0.1119
Eurydice longicornis	0	0	0	0	0	0	0	0
Nassarius arcularius	0	0	0	0	9.8623	0	0	0
Nassarius kraussianae	1.2908	3.7211	0.3034	0.6155	1.2314	0	4.2701	1.2691
Natica taeniata	0	0.0518	0.71	0	0	0	1.6834	0
Polinices mamilla	7.4036	13.7315	0.2981	29.8793	8.5021	0.8781	2.1632	34.3898
Anodontia edentula	0	0	0.2183	0.3647	0	0	0.4433	0.1831
Donax bertini	8.0711	7.2358	41.1886	27.3364	11.9679	8.0014	28.1991	14.2013
Dosinia hepatica	0	0	0	0	0	0.1018	0	0
Eumarcia paupercula	0	1.6439	0.9496	0	0.0075	0.7673	6.0744	0
Fulvia laevigata (papyracea)	0	0	0.0118	0	0.9805	0.2653	0	0
Heterodonax ludwigii	0	1.1068	0.9174	8.3772	0.2038	0.6489	4.0048	3.0375
Macoma sp	0	0	0	0	2.4244	0.0974	6.8173	19.6415
Paphia textile	0	0.1011	0	0	0.0094	0.0841	0.0463	0.0486
Pitar abbreviatus	0.4637	0	0	0.0345	0	0	0	0
Solen cylindraceus	0.0081	0.0995	0.623	0.0748	0.6085	0.9702	7.6704	2.6756
Tellina natalensis	0	0	0.9335	0.2339	0	0	0	0
Theora lata	0	0.147	0	0.0492	0.1101	0	0	0
Actiniaria sp/cerianthid	0	0.2665	0.1675	0.0906	0.0383	0.2182	0.1932	0.0837
Sipunculida	0.0755	0.0676	0.0153	0.0047	0.1072	0.1579	0.078	0.1426
Platyhelminthes	0.0094	0.0475	0.0114	0.0624	0.1228	0.0519	0.047	0
Nemertea	0.7466	0.3759	5.3739	0.8285	0.668	1.1784	0.2755	8.5629

Table 4C: Species list. including subtidal species name. abundance for this survey.

Species	Abundance							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Armandia intermedia	18	116	22	23	78	248	196	17
Aonides oxycephala	0	0	6	0	17	14	18	10
Amaena trilobata	0	0	0	0	2	0	0	0
Aphroditidae sp1	3	4	9	14	18	9	2	5
Aphroditidae sp2	0	6	1	0	0	0	0	1
Arabella iricolor	0	0	0	0	0	0	1	0
Arenicola sp. (loveni)	5	0	9	0	0	2	0	0
Branchiommia nigromaculata	0	5	0	0	0	3	1	2
Boccardia sp	0	0	0	0	0	0	1	0
Capitella capitella	2	26	8	5	22	25	49	48
Ceratoneries erythraensis	0	0	0	0	3	5	6	3
Chaetopterus varieopedatus	0	0	0	0	12	0	2	0
Cirriformia sp	45	29	5	4	42	25	14	10
Cirriformia tentaculata	11	5	4	11	9	6	16	9
Cirratulus africanus	0	8	0	0	2	0	0	0
Cirratulus chrysoderma	0	2	0	0	0	2	1	0
Cirratulus sp	9	21	23	6	32	38	54	18
Cossura coasta	0	0	0	0	7	1	2	0
Dendronereis arborifera	0	0	0	1	0	1	1	1
Dioptra cuprea	0	0	2	0	0	0	1	0
Diopatra neapolitana capensis	1	2	0	1	4	4	1	3
Dipolydora caeca	0	0	8	1	0	3	0	11
Glycera alba	4	1	0	0	12	8	1	0
Gycera convoluta	34	7	82	85	63	22	3	3
Glycera natalensis	51	50	106	109	195	77	303	107
Glycera subaenea	24	48	29	16	33	50	79	80
Glycinde capensis	34	131	33	26	87	15	179	88
Goniada emerita	0	0	1	0	0	0	0	0
Harmonthoe dictyophora	1	0	0	0	0	0	0	0
Haploscoloplos sp.	0	0	0	2	2	1	10	1
Jasmineiraa elegans	110	29	1	7	18	6	12	33
Laonice cirrata	15	20	6	2	2	8	0	1
Laeonereis ankyloseta	1	0	0	0	0	0	0	1
Leonnates decipiens	2	0	1	0	0	1	0	0
Leonnates persicus	0	0	0	0	0	1	0	0
Loanalia capensis	0	0	1	0	0	0	0	0
Lumbrineris heteropoda heteropoda	0	0	0	0	0	1	0	1
Lysidice sp.	0	0	0	0	0	0	0	1
Magelonia cincta	3	11	13	5	8	3	3	0
Malacoceros indicus	0	0	1	4	4	0	0	4

Species	Abundance							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Maldanidae	0	0	1	1	6	0	0	0
Marphysa depressa	0	2	0	1	1	3	0	0
Marphysa posteriobranchia	0	0	1	0	0	0	0	1
Namalycastis indica	0	0	0	0	0	1	0	0
Nephtys dibranchis	5	0	0	0	0	3	8	1
Nephtys sphaerocirrata	19	35	57	68	138	104	148	19
Nereis caudata	59	55	11	40	4	8	9	42
Nereis succinea	6	5	2	1	0	0	0	0
Nereis sp2 (long nueropod)	0	0	7	0	1	0	0	0
Notomastus sp	26	152	36	19	12	13	35	13
Onuphis eremita	0	0	0	1	0	0	0	0
Orbinia bioreti	1	0	0	24	11	6	2	22
Owenia fusiformis	0	0	1	0	0	0	0	0
Paradialychone filicaudata	0	0	0	0	0	0	0	0
Phyllodoce castanea	10	0	0	0	1	0	0	0
Phyllodoce capensis	6	23	2	4	4	3	1	1
Platyneries dumerilii	0	0	0	0	0	0	0	0
Pectinaria sp	1	0	0	0	0	0	0	0
Poecilochaetus serpens	115	122	8	29	66	22	109	46
Polydora sp 1	0	0	1	0	2	1	0	0
Polyopthalmus pictus	0	3	0	1	0	0	0	0
Polyphysia crassa	7	0	0	4	0	0	0	0
Prionospio blocki	0	0	0	2	0	0	0	0
Prionospio pinnata	0	0	0	0	0	5	1	0
Prionospio sexoculata	13	3	19	15	34	44	23	11
Prionospio saldanha	0	0	1	0	1	12	0	2
Scoloepris squamata	1	0	0	5	0	0	0	0
Scoloplos johnstonei	14	22	19	27	23	20	83	38
Scoloplos marsupialis	0	0	0	1	2	0	0	0
Sphaerodoropsis benguellorum	0	0	0	0	1	0	0	0
Spiophanes bombyx	0	0	0	5	15	0	3	0
Spio filicornis	0	0	0	0	15	7	7	0
Sigambra parva	38	48	14	2	82	8	25	24
Syllis sp1	0	0	1	1	0	2	2	0
Terebellidae sp 1	0	0	2	0	0	1	0	0
Hirudineasp.	0	0	5	26	7	6	2	0
Ostracoda	0	0	0	1	0	0	0	0
Hymenosoma orbiculare	0	0	0	0	1	0	0	0
Spiroplax spiralis	18	37	32	19	42	22	20	8
Paratyloidiplax blephariskios	156	218	159	328	115	151	284	170
Xanthid sp	0	0	1	0	0	0	0	0
Unknown Brachyura	2	0	4	0	0	0	0	0

Species	Abundance							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Grandidierella bonnieroides	0	0	0	0	2	2	1	3
Lysianassa certina	8	3	0	0	0	0	0	0
Melita sp	5	9	2	0	0	2	2	0
Paramoera capensis	0	0	0	0	1	2	0	0
Periculodes longimanus	0	0	0	10	9	3	0	0
Urothoe pinnata	2	13	0	38	7	0	0	1
Urothoe tumorosa	66	18	12	60	7	12	14	0
Athanas djiboutensis	0	0	0	0	1	0	0	0
Alpheus sp	0	0	0	2	0	6	1	3
Betaeus jucundus	3	0	2	3	1	0	1	0
Carid sp.	5	5	0	2	0	24	2	8
Gastrosuccus sp.	0	26	0	0	0	0	0	0
Harpilius sp.	0	0	1	0	0	0	0	0
Leptochela robusta	0	0	3	0	0	0	0	0
Metapenaeopsis (andonenesis) sp	1	2	0	9	7	2	0	2
Penaeus japonicus	0	0	0	0	0	1	0	0
Philocheras megalochir	3	0	0	0	0	0	0	0
Salmones rostratus	0	0	0	2	0	0	0	0
Albunea sp.	0	0	0	0	1	0	0	0
Callianassa kraussi	36	19	7	81	19	18	14	21
Paguroidea sp1	0	0	0	0	1	2	6	1
Upogebia africana	29	19	7	7	4	4	6	5
Cyathura estuaria	2	7	8	10	8	12	5	10
Excirolana natalensis	40	85	61	98	54	44	54	50
Harpisquilla harpax	0	2	0	0	0	0	1	0
Siphonodentalium booceras	3	0	0	0	0	0	0	0
Hydatina physis	0	1	0	0	0	0	1	0
Hydatina sp	0	0	0	1	0	2	0	0
Nassarius kraussianae	7	16	33	73	67	95	140	50
Nassarius bicallosus	1	2	0	0	0	0	1	0
Nassarius gemmuliferus	0	0	0	0	1	0	0	0
Natica gualteriana	0	0	0	2	6	0	0	0
Natica taeniata	6	2	5	5	3	6	20	8
Polinices mamilla	1	2	6	3	3	3	4	1
Rictaxiella sp	0	0	0	0	1	0	0	0
Anodontia edentula	0	5	0	0	2	2	0	0
Donax bertini	0	0	0	0	0	1	0	1
Dosinia hepatica	2	32	21	6	11	33	42	19
Eumarcia paupercula	0	4	11	7	20	28	25	8
Fulvia laevigata	69	48	12	0	48	39	17	29
Heterodonax ludwigii	0	17	5	10	5	8	40	27
Marcoma sp	0	0	0	0	11	2	23	23
Paphia textile	3	14	4	3	2	3	23	5

Species	Abundance							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
<i>Solen cylindraceus</i>	0	0	0	0	0	5	9	3
<i>Tellina natalensis</i>	1	6	3	2	4	4	3	4
<i>Tellina prismatica</i>	7	7	0	1	1	2	45	5
<i>Theora lata</i>	48	40	2	2	1	7	0	8
<i>Tivela rejecta</i>	0	0	0	0	0	2	0	0
<i>Echinocardium cordatum</i>	1	1	1	0	1	0	0	0
<i>Ophiuroidea</i> sp	6	14	32	12	46	18	23	10
<i>Branchiostoma</i> sp.	0	0	7	1	0	2	2	0
<i>Actinaria</i> sp	0	0	5	5	8	13	1	0
<i>Sipunculida</i>	36	31	18	36	36	34	57	16
<i>Platyhelminthes</i>	4	5	7	76	20	13	5	3
<i>Nemertea</i>	88	104	176	152	147	182	301	103
<i>Chaetognath</i> sp.	0	0	1	1	0	0	0	0

Table 4D: Species list. including subtidal species name. biomass for this survey.

Species	Biomass							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Armandia intermedia	0.0138	0.1072	0.0236	0.0585	0.0891	0.2566	0.1826	0.0219
Aonides oxycephala	0	0	0.0367	0	0.0628	0.0829	0.2764	0.1636
Amaena trilobata	0	0	0	0	0.0121	0	0	0
Aphroditidae sp1	0.017	0.0202	0.0594	0.0724	0.1175	0.2277	0.0201	0.0934
Aphroditidae sp2	0	0.0475	0.0071	0	0	0	0	0.0081
Arabella iricolor	0	0	0	0	0	0	0.1187	0
Arenicola sp. (loveni)	0.2192	0	0.1275	0	0	0.0021	0	0
Branchiomma nigromaculata	0	0.2437	0	0	0	1.4936	0.0101	0.0061
Boccardia sp	0	0	0	0	0	0	0.0012	0
Capitella capitella	0.0569	0.3528	0.1334	0.0426	0.3584	0.4111	0.7251	1.084
Ceratoneries erythraensis	0	0	0	0	0.3078	0.0254	0.0338	0.0405
Chaetopterus varieopedatus	0	0	0	0	0.6231	0	0.2453	0
Cirriformia sp	4.58751	7.2604	1.7246	0.4283	5.9953	2.6877	1.8833	3.6806
Cirriformia tentaculata	0.8147	0.0149	0.1488	0.171	0.6987	0.9595	0.6036	0.0975
Cirratulus africanus	0	0.5657	0	0	0.663	0	0	0
Cirratulus chrysoderma	0	0.4545	0	0	0	0.0125	0.0122	0
Cirratulus sp	0.3574	0.1327	0.0846	0.1967	1.795	0.2132	0.3974	0.048
Cossura coasta	0	0	0	0	0.05	0.0041	0.0011	0
Dendronereis arborifera	0	0	0	0.0077	0	0.0113	0.0236	0.0031
Dioptra cuprea	0	0	0	0	0	0	0.0061	0
Diopatra neapolitana capensis	0.0005	0.064	0	0.0019	0.0568	0.0121	0.0078	0.1064
Dipolydora caeca	0	0	1.7757	0.0006	0	0.0027	0	0.0365
Glycera alba	0.2673	0.0324	0	0	0.8206	0.1537	0.0165	0
Gycera convoluta	0.8607	0.4058	1.59349	1.37926	2.2895	0.9813	0.0218	0.2497
Glycera natalensis	0.5857	0.3072	0.39166	1.2544	1.7568	0.3853	1.2783	0.7319
Glycera subaenea	2.7273	5.043	2.6454	1.841	1.823	3.2612	8.1962	7.4048
Glycinde capensis	0.1179	0.4184	0.08339	0.0677	0.2532	0.0802	0.5607	0.1748
Goniada emerita	0	0	0.0057	0	0	0	0	0
Harmonthoe dictyophora	0.0039	0	0	0	0	0	0	0
Haploscoloplos sp.	0	0	0.0097	0	0.0242	0.0079	0.2438	0.0225
Jasmineiraa elegans	0.1848	0.2056	0	0.1092	0.051	0.0206	0.0438	0.044
Laonice cirrata	0.0895	0.2671	0.0671	0.0535	0.042	0.1257	0	0.0192
Laeonereis ankyloseta	0.0149	0	0	0	0	0	0	0.006
Leonnates decipiens	0.0575	0	0.0219	0	0	0.0435	0	0
Leonnates persicus	0	0	0	0	0	0.0391	0	0
Loanalia capensis	0	0	0.0039	0	0	0	0	0
Lumbrineris heteropoda heteropoda	0	0	0	0	0	0.1097	0	0.0051
Lysidice sp.	0	0	0	0	0	0	0	0.0025
Magelonia cincta	0.0156	0.0759	0.0404	0.0633	0.0406	0.0247	0.0572	0
Malacoceros indicus	0	0	0.0076	0.0417	0.0385	0	0	0.0475

Species	Biomass							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Maldanidae	0	0	0.0008	0.0232	0.113	0	0	0
Marphysa depressa	0	0.0861	0	0	0.0521	0.2047	0	0
Marphysa posteriobranchia	0	0	0.0224	0	0	0	0	0.1337
Namalycastis indica	0	0	0	0	0	0.0291	0	0
Nephtys dibranchis	0.0353	0	0	0	0	0.0702	0.0531	0.0075
Nephtys sphaerocirrata	0.1139	0.2899	0.2658	0.2415	0.2268	0.1475	0.102	0.0325
Nereis caudata	0.1773	0.3754	0.0393	0.117	0.0124	0.0629	0.0353	0.2383
Nereis succinea	0.0258	0.1074	0	0.024	0	0	0	0
Nereis sp2 (long nueropod)	0	0	0.0401	0	0.0007	0	0	0
Notomastus sp	0.33805	4.1399	1.3038	0.3878	0.2109	0.127	1.4123	0.4342
Onuphis eremita	0	0	0	0.0282	0	0	0	0
Orbinia bioreti	0.0124	0	0	0.1027	0.0964	0.0824	0.026	0.3148
Owenia fusiformis	0	0	0.0057	0	0	0	0	0
Paradialychone filicaudata	0	0	0	0	0	0	0	0
Phyllodoce castanea	0.072	0	0	0	0.003	0	0	0
Phyllodoce capensis	0.0313	0.1581	0.0303	0.0245	0.028	0.006	0.0147	0.0135
Platyneries dumerilii	0	0	0	0	0	0	0	0
Pectinaria sp	0.0006	0	0	0	0	0	0	0
Poecilochaetus serpens	0.2336	0.3166	0.0299	0.0635	0.1913	0.075	0.4286	0.0806
Polydora sp 1	0	0	0.0051	0	0.0039	0.0004	0	0
Polyopthalmus pictus	0	0.0364	0	0.0201	0	0	0	0
Polyphysia crassa	0.7034	0	0	0	0	0	0	0
Prionospio blocki	0	0	0	0.0091	0	0	0	0
Prionospio pinnata	0	0	0	0	0	0.0267	0.004	0
Prionospio sexoculata	0.0283	0.0126	0.0277	1.0427	0.0286	0.0341	0.0243	0.009
Prionospio saldanha	0	0	0.0022	0	0.0009	0.0059	0	0.0023
Scoloepris squamata	0.0039	0	0	1.0441	0	0	0	0
Scoloplos johnstonei	0.0358	0.1725	0.2456	3.184	0.1139	0.1047	0.3611	0.2559
Scoloplos marsupialis	0	0	0	0.0961	0.1004	0	0	0
Sphaerodoropsis benguelarum	0	0	0	0	0.018	0	0	0
Spiophanes bombyx	0	0	0	0.0052	0.1498	0	0.0133	0
Spio filicornis	0	0	0	0	0.09	0.0509	0.0504	0
Sigambra parva	0.1752	0.2227	0.0437	0.0115	0.4065	0.0361	0.0847	0.0796
Syllis sp1	0	0	0.0011	0.0005	0	0.0099	0.0017	0
Terebellidae sp 1	0	0	0.0115	0	0	0.0104	0	0
Hirudineasp.	0	0	0.006	0.0212	0.007	0.0052	0.002	0
Ostracoda	0	0	0	0.0005	0	0	0	0
Hymenosoma orbiculare	0	0	0	0	0.0215	0	0	0
Spiroplax spiralis	0.2554	1.134	0.896	0.516	0.6123	0.3403	0.5112	0.1349
Paratyloidiplax blephariskios	24.3366	26.8417	17.2291	42.3042	9.5637	22.3357	29.5508	21.6491
Xanthid sp	0	0	0.0788	0	0	0	0	0
Unknown Brachyura	0.0836	0	0.0793	0	0	0	0	0

Species	Biomass							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Grandidierella bonnieroides	0	0	0	0	0.002	0.0027	0.0015	0.0048
Lysianassa certina	0.0063	0.0059	0	0	0	0	0	0
Melita sp	0.0037	0.0213	0.0053	0	0	0.0024	0.002	0
Paramoera capensis	0	0	0	0	0.0101	0.0172	0	0
Periculodes longimanus	0	0	0	0.0095	0.0087	0.0143	0	0
Urothoe pinnata	0.0021	0.0119	0	0.0328	0.004	0	0	0.0025
Urothoe tumorosa	0.0433	0.0866	0.0079	0.0838	0.0078	0.0162	0.103	0
Athanas djiboutensis	0	0	0	0	0.0184	0	0	0
Alpheus sp	0	0	0	0.0559	0	1.0354	0.2939	0.1881
Betaeus jucundus	0.0102	0	0.0492	0.0904	0.241	0	0.1043	0
Carid sp.	0.2766	0.0394	0	0.0491	0	0.3182	0.1454	0.4339
Gastrosuccus sp.	0	0.2097	0	0	0	0	0	0
Harpilius sp.	0	0	0.0078	0	0	0	0	0
Leptochela robusta	0	0	0.0747	0	0	0	0	0
Metapenaeopsis (andonenes) sp	0.0021	0.0412	0	0.0953	0.2454	0.0484	0	0.3657
Penaeus japonicus	0	0	0	0	0	1.0297	0	0
Philocheras megalochair	0.0197	0	0	0	0	0	0	0
Salmones rostratus	0	0	0	0.0297	0	0	0	0
Albunea sp.	0	0	0	0	0.7933	0	0	0
Callianassa kraussi	0.3592	0.4128	0.0657	1.9708	0.0489	0.1482	0.4347	1.8313
Paguroidea sp1	0	0	0	0	0.0695	0.1186	0.4377	0.0192
Upogebia africana	0.4497	2.2406	1.6478	4.3546	1.7634	0.6927	0.1518	0.1471
Cyathura estuaria	0.0016	0.0197	0.0095	0.0044	0.0155	0.0106	0.0079	0.0171
Excirolana natalensis	0.288	0.5746	0.429	1.0211	0.3054	0.3484	0.3127	0.4153
Harpisquilla harpax	0	0.0518	0	0	0	0	0.5751	0
Siphonodentalium booceras	0.0138	0	0	0	0	0	0	0
Hydatina physis	0	1.1303	0	0	0	0	2.3992	0
Hydatina sp	0	0	0	0.0068	0	0.095	0	0
Nassarius kraussiance	1.0945	6.9409	7.1524	16.0285	12.123	26.2097	31.5762	9.2749
Nassarius bicallosus	2.0489	6.0956	0	0	0.009	0	4.9333	0
Nassarius gemmuliferus	0	0	0	0	0.53	0	0	0
Natica gualteriana	0	0	0	0.095	0.385	0	0	0
Natica taeniata	1.4466	0.3514	0.9607	1.782	0.2266	1.2103	4.2301	2.3778
Polinices mamilla	0.5322	1.4265	13.3048	4.8442	17.0732	13.1892	10.0024	3.113
Rictaxiella sp	0	0	0	0	0.033	0	0	0
Anodontia edentula	0	1.2102	0	0	0.5594	5.262	0	0
Donax bertini	0	0	0	0	0	0.0243	0	0.0497
Dosinia hepatica	0.1166	10.3905	6.1305	1.84	4.9377	9.2881	11.9125	4.5062
Eumarcia paupercula	0	2.2588	1.5402	0.7335	3.5405	5.4675	8.0092	0.931
Fulvia laevigata	2.5248	10.9276	1.7877	1.5799	5.6555	4.2209	1.5012	1.9414
Heterodonax ludwigii	0	19.0327	2.8707	5.2357	0.2329	2.0113	6.39	2.7779
Marcoma sp	0	0	0	0	1.4417	0.4914	9.4533	6.6145
Paphia textile	4.11	6.4202	14.6597	15.3803	9.758	3.581	98.9062	23.3722

Species	Biomass							
	Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Solen cylindraceus	0	0	0	0	0	0.2957	2.1933	0.6471
Tellina natalensis	0.1821	1.7879	0.464	0.6621	0.3581	0.8298	0.3602	0.9962
Tellina prismatica	0.5344	0.4826	0	0.0593	1.044	0.2761	3.57968	0.2342
Theora lata	4.4279	4.44071	0.1037	0.058	0.0224	0.1837	0	0.155
Tivela rejecta	0	0	0	0	0	0.1284	0	0
Echinocardium cordatum	2.3041	2.9925	5.9139	0	0.3654	0	0	0
Ophiuroidea sp	0.1141	0.4175	1.5625	0.5984	1.202	0.7068	1.6173	0.3838
Branchiostoma sp.	0	0	0.0272	0.0239	0	0.0075	0.0309	0
Actiniaria sp	0	0	0.0838	0.0271	0.0065	0.0337	0.0035	0
Sipunculida	0.3068	0.7816	0.0907	0.2278	0.3238	0.2138	0.4354	0.1031
Platyhelminthes	0.0056	0.0242	0.039	0.2172	0.1292	0.0598	0.0156	0.0212
Nemertea	0.7076	0.9717	0.7306	0.6743	0.8676	0.7908	1.8649	0.5744
Chaetognath sp.	0	0	0.0006	0	0	0	0	0

Table 4E: Macrofauna found during this survey. Phylum is the highest level of classification. with classes in phyla. and several orders within a class.

Phylum	Order & class	Description
Arthropoda	Crustacea	
	Amphipoda	Crustaceans with no carapace and laterally compressed body
	Isopoda	Crustaceans typically flattened dorso-ventrally
	Copepoda	Small crustaceans
	Decapoda	Have ten legs. crabs. lobsters. prawns
	Anomura	Decapod crustaceans. including hermit crabs
	Euphausacea	Small crustaceans. krill
	Brachyura	Decapod crustaceans. crabs
	Cumacea	Small marine crustaceans. hooded shrimp or comma shrimp
Mollusca	Bivalvia	laterally compressed bodies enclosed by two hinged shell (mussels. clams. oysters)
	Gastropoda	Molluscs. includes snails and slugs
Annelida	Polychaeta	Bristle Worms: body segment. bear many bristles. called chaetae
Nematoda	Roundworms	
Sipuncula	Peanut worms	
Echinodermata	Ophiurida	Echinoderms. brittle stars
	Spatangoida	Echinoderms. heart urchins

ANNEXURE 5:

Bird Baseline Monitoring Data

Table 5A: Species list with common name and total abundance as counted in this survey between October 2014 and September 2016.

Common name	Total abundance (October 2014- September 2015)	Total abundance (October 2015- September 2016)	Grand Total
African black oystercatcher	0	1	1
African Fish Eagle	9	9	18
African openbill	0	2	2
African Pied wagtail	24	25	49
African sacred ibis	151	52	203
African Spoonbill	3	5	8
Arctic Tern	0	430	430
Bar-tailed godwit	3	2	5
Black-headed Gull	0	2	2
Black-headed Heron	2	3	5
Blacksmith lapwing	608	438	1046
Black-winged stilt	0	422	422
Brown-throated martin	10	0	10
Cape Cormorant	78	47	125
Cape Gannet	5	24	29
Cape wagtail	5	6	11
Caspian Tern	16	50	66
Cattle egret	2	7	9
Common greenshank	563	210	773
Common ringed plover	141	104	245
Common sandpiper	14	9	23
Common Tern	32	181	213
Common whimbrel	535	298	833
Curlew sandpiper	411	90	501
Egyptian goose	261	579	840
Eurasian curlew	0	26	26
Giant Kingfisher	0	4	4
Goliath Heron	43	34	77
Great Egret	1	0	1
Greater flamingo	0	21	21
Greater Sand plover	1	0	1
Green-backed Heron	0	1	1
Grey Heron	94	136	230
Grey plover	147	68	215
Grey-headed Gull	1226	606	1832
Hadedda ibis	91	107	198
Hamerkop	0	1	1

Hartlaubs Gull	0	2325	2325
Kelp gull	736	438	1174
Lesser Black-backed gull	4	130	134
Lesser Crested Tern	125	817	942
Little Egret	195	178	373
Little Grebe	0	1	1
Little stint	1	171	172
Malachite Kingfisher	2	1	3
Osprey	6	15	21
Parasitic Jaeger	0	3	3
Pied Kingfisher	16	11	27
Pink-backed Pelican	89	77	166
Purple Heron	1	0	1
Red knot	0	180	180
Red-billed teal	2	0	2
Reed Cormorant	66	102	168
Ruddy turnstone	47	22	69
Ruff	1	0	1
Sanderling	4	0	4
Sandwich Tern	11	147	158
Spur-winged goose	1		1
Subantarctic Skua	5	0	5
Swift Tern	643	804	1447
Terek sandpiper	85	11	96
Water Thick-knee	13	11	24
Wattled lapwing	0	273	273
White-breasted Cormorant	170	218	388
White-faced duck	2	0	2
White-fronted plover	0	94	94
White-throated swallow	5	10	15
Wire-tailed swallow	0	10	10
Wood sandpiper	0	2	2
Woolly-necked stork	17	13	30
Yellow-billed duck	2	0	2
Grand Total	6725	10064	16789

Table 5B: Water-associated birds recorded to date in Durban Bay (Port of Durban). excluding rare vagrant species (Data source: David Allan. partially published data. See Allan et al. 1999; McInnes et al. 2005 & Allan 2012).

Piscivore		Invertebrate feeder	
Little grebe	Tachybaptus ruficollis	Cattle egret	Bubulcus ibis
Great white pelican	Pelecanus erythrorhynchos	Woolly-necked stork	Ciconia episcopus
Pink-backed pelican	Pelecanus rufescens	African openbill	Anastomus lamelligerus
Cape gannet	Morus capensis	African sacred ibis	Threskiornis aethiopicus
White-breasted cormorant	Phalacrocorax carbo	Hadedda ibis	Bostrychia hagedash
Cape cormorant	Phalacrocorax capensis	Greater flamingo	Phoenicopterus ruber
Reed cormorant	Phalacrocorax africanus	African black oystercatcher	Haematopus moquini
African darter	Anhinga rufa	Common ringed plover	Charadrius hiaticula
Greater frigatebird	Fregata minor	White-fronted plover	Charadrius marginatus
Grey heron	Ardea cinerea	Chestnut-banded plover	Charadrius pallidus
Black-headed heron	Ardea melanocephala	Kittlitz's plover	Charadrius pecuarius
Goliath heron	Ardea goliath	Three-banded plover	Charadrius tricollaris
Purple heron	Ardea purpurea	Greater Sand plover	Charadrius leschenaultii
Great egret	Egretta alba	Grey plover	Pluvialis squatarola
Little egret	Egretta garzetta	Blacksmith lapwing	Vanellus armatus
Yellow-billed egret	Egretta intermedia	Wattled lapwing	Vanellus senegallus
Black heron	Egretta ardesiaca	Ruddy turnstone	Arenaria interpres
Squacco heron	Ardeola ralloides	Terek sandpiper	Xenus cinereus
Green-backed heron	Butorides striata	Common sandpiper	Actitis hypoleucos
Black-crowned night heron	Nycticorax nycticorax	Wood sandpiper	Tringa glareola
Black stork	Ciconia nigra	Common redshank	Tringa totanus
Yellow-billed stork	Mycteria ibis	Marsh sandpiper	Tringa stagnatilis
African spoonbill	Platalea alba	Common greenshank	Tringa nebularia
African fish eagle	Haliaeetus vocifer	Red knot	Calidris canutus
Osprey	Pandion haliaetus	Curlew sandpiper	Calidris ferruginea
Subantarctic skua	Catharacta antarctica	Little stint	Calidris minuta
Heuglin's gull	Larus heuglini	Sanderling	Calidris alba
Grey-headed gull	Chroicocephalus cirrocephalus	Broad-billed sandpiper	Limicola falcinellus
Hartlaubs gull	Larus hartlaubii	Ruff	Philomachus pugnax
Franklin's gull	Larus pipixcan	Bar-tailed godwit	Limosa lapponica
Caspian tern	Sterna caspia	Eurasian curlew	Numenius arquata
Swift tern	Sterna bergii	Common whimbrel	Numenius phaeopus
Lesser crested tern	Sterna bengalensis	Black-winged stilt	Himantopus himantopus
Sandwich tern	Sterna sandvicensis	Sooty tern	Sterna fuscata
Common tern	Sterna hirundo	White-throated swallow	Hirundo albigularis
Arctic tern	Sterna paradisaea	Wire-tailed swallow	Hirundo smithii
Little tern	Sterna albifrons	Brown-throated martin	Riparia paludicola

White-winged tern	Chlidonias leucopterus	Cape wagtail	Motacilla capensis
Pied kingfisher	Ceryle rudis	Glossy ibis	Plegadis falcinellus
Giant kingfisher	Megaceryle maxima	Painted snipe	Rostratula benghalensis
Malachite kingfisher	Alcedo cristata	Pied avocet	Recurvirostra avosetta
Great crested grebe	Podiceps cristatus	Yellow wagtail	Motacilla lava
White-chinned petrel	Procellaria aequinoctialis	Herbivore	
Cory's shearwater	Calonectris diomedea	Lesser flamingo	Phoenicopterus minor
Saddle-billed stork	Ephippiorhynchus senegalensis	White-faced duck	Dendrocygna viduata
Whiskered tern	Chlidonias hybridus	White-backed duck	Thalassornis leuconotus
Mangrove kingfisher	Halcyon senegaloides	Egyptian goose	Alopochen aegyptiacus
Omnivore		Hottentot teal	Anas hottentota
Hamerkop	Scopus umbretta	Spur-winged goose	Plectropterus gambensis
Yellow-billed duck	Anas undulata	Red-knobbed coot	Fulica cristata
Cape teal	Anas capensis		
Red-billed teal	Anas erythrorhyncha		
Water Thick-knee	Burhinus vermiculatus		
Parasitic Jaeger	Stercorarius parasiticus		
Kelp gull	Larus dominicanus		
Lesser Black-backed gull	Larus fuscus		
African Pied wagtail	Motacilla aguimp		
Southern giant petrel	Macronectes giganteus		
Dwarf bittern	Ixobrychus sturmii		
Eurasian bittern	Botaurus stellaris		
Cape shoveller	Anas smithii		

ANNEXURE 6: ‘

Fish Baseline Monitoring Data

Table 6A: Fish species list. including species name and abundance for this survey.

Species	Common Name	Abundance							
		Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Acanthopagrus berda	River bream	2	3	22	14	7	37	2	1
Ambassis dussumieri	Bald Glassy	1451	24975	202984	91	3141	586494	363949	86577
Amblyrhynchotes honckenii	Evileye blaasop	12	1	13	7	0	5	10	22
Argyrosomus japonicus	Dusky kob	2	1	531	0	85	2	0	0
Arothron hispidus	Whitespotted blaasop	3	0	0	0	0	4	0	0
Arothron immaculatus	Black edged Blaasop	0	9	13	38	1	72	0	27
Caranx heberi	Blacktipped kingfish	1	8	20	142	4	47	0	4
Caranx papuensis	Brassy kingfish	0	3	0	19	8	0	0	0
Crenidens crenidens	White karateen	45	20	5	0	22	342	119	178
Diplodus capensis	Blacktail	21	4	32	0	5	6	41	1
Elops machnata	Springer	0	0	0	0	2	0	0	0
Epinephelus malabaricus	Malabar rockcod	0	0	4	0	0	50	0	0
Favonigobius melanobranchus	Black throat goby	2	13	21	0	8	111	5	2
Favonigobius reichei	Tropical sand goby	0	0	0	58	0	5	0	0
Gerres filamentosus	Threadfin pursemouth	137	113	49	1	27	170	260	111
Gerres longirostris	Smallscaled pursemouth	24	34	111	0	3	141	118	82
Gerres methueni	Evenfin pursemouth	0	6	0	0	46	52	1	115
Gerres sp.	Juvenile pursemouth	0	63	0	10	0	12	0	0
Glossogobius callidus	River goby	1	0	4	0	0	0	0	0
Herklotsichthys quadramaculata	Blueline herring	0	0	0	521	0	51	0	0
Heteromycteris capensis	Cape sole	0	0	4	1419	0	6	0	0
Hilsa kelee	Razor belly	0	0	0		0	2009	121	35
Himantura gerrardi	Sharpnose stingray	2	10	4	0	0	11	0	0
Himantura uarnak	Honeycomb ray	0	0	0	0	3	0	0	3
Lactoria cornuta	Longhorn cowfish	2	1	0	0	0	0	0	1
Lagocephalus inermis	Moontailed blaasop	1	0	0	2	0	0	0	0
Leiognathus elongatus	Elongate slimy	0	0	0	0	1	0	0	0
Leiognathus equulus	Pony-Slimy	35	577	2119	0	211	3521	1173	4159
Lithognathus mormyrus	Sand steenbras	0	0	0		0	0	3	0
Liza dumerilii	Groovy mullet	82	190	1046	258	99	321	271	348
Liza luciae	St Lucia mullet	0	0	0	16	0	0	0	1
Liza macrolepis	Large scale mullet	0	0	4	204	1	0	0	0

Species	Common Name	Abundance							
		Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
<i>Liza richardsonii</i>	Southern mullet	0	0	0	0	9	0	0	0
<i>Liza tricuspidens</i>	Stripped mullet	0	0	3	0	0	0	0	0
<i>Lutjanus fulviflamma</i>	Dory snapper	0	0	4	6	0	0	0	0
<i>Monodactylus argenteus</i>	Moony	0	0	0		0	0	20	3
<i>Mugilid sp.</i>	Juvenile mullet	0	41	0	0	11	53	0	77
<i>Myxus capensis</i>	Freshwater mullet	0	14	31	0	0	0	216	1
<i>Platycephalus indicus</i>	Bartailed flathead	18	21	37	0	24	47	64	15
<i>Pomadasys commersonnii</i>	Spotted grunter	102	40	277	15	33	314	235	242
<i>Pomadasys kaakan</i>	Cock grunter	0	5	56	0	0	0	0	0
<i>Pomadasys olivaceum</i>	Piggy grunter	16	184	0	53	0	8	0	0
<i>Pomatomus saltatrix</i>	Elf (Shad)	0	6	0	0	1	1	3	8
<i>Psammogobius knysnaensis</i>	Knysna goby	1	5	0	34	0	0	0	0
<i>Pseudorhombus arsius</i>	Large tooth Flounder	6	20	20	89	3	115	5	64
<i>Rhabdosargus sarba</i>	Natal stumpnose	40	234	125	10	9	22	81	44
<i>Rhinobaous annulatus</i>	Sandshark	0	0	1	120	0	0	0	0
<i>Sardinella gibbosa</i>	Gold-striped sardine	0	0	364	0	0	0	663	8
<i>Scomberoides tol</i>	Needlescaled queenfish	173	82	87	5	205	29	133	79
<i>Secutor ruconius</i>	Pugnose soapy	0	0	0		0	0	1	7
<i>Sillago sihama</i>	Silver sillago	52	30	429	0	46	277	170	554
<i>Sphyrna jello</i>	Pickhandle Baracuda	1	24	8	0	0	78	0	5
<i>Stolephorus holodon</i>	Thorny anchovy	0	1116	610	0	2	1245	6164	11531
<i>Synodus sp.?</i>	Lizard fish	0	1	0	0	0	0	0	0
<i>Terapon jarbua</i>	Thornfish	0	1	23	0	0	44	16	11
<i>Tetrosomus concatenatus</i>	Triangular boxfish	0	1	0	20	0	0	0	0
<i>Thyrssa vitrirostris</i>	Orange mouth glass nose	0	340	0	0	0	0	0	42
<i>Trichiurus lepturus</i>	Largehead hairtail (Walla walla)	0	0	0		0	0	0	3
<i>Tylosaurus crocodilus</i>	Crocodile needle fish	4	16	97	0	16	101	0	0
<i>Upeneus vittatus</i>	Yellow-banded goatfish	0	0	8	1	0	1	0	0
<i>Valamugil buechanani</i>	Bluefin Mullet	0	1	0	0	0	0	0	0
<i>Valamugil robustus</i>	Robust mullet	0	34	0	0	0	107	0	0
<i>Yongeichthys nebulosus</i>	Shadow goby E	3	6	50	0	0	120	28	173
	Goby A	0	0	0	0	1	0	0	0
	Goby B	0	0	0	0	5	0	0	0
	Juvi karenteen	0	0	0	0	42	0	0	0

Table 6A: Fish species list. including species name and biomass for this survey.

Species	Common Name	Biomass							
		Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
Acanthopagrus berda	River bream	416.00	312.00	391.00	2537.40	1136.00	18531.00	53.74	16.00
Ambassis dussumieri	Bald Glassy	1433.00	31603.38	186028.00	94726.00	3436.00	476556.00	402484.50	121756.00
Amblyrhynchotes honckenii	Evileye blaasop	1821.22	10.00	61.97	453.77	0.00	218.00	3556.10	2079.04
Argyrosomus japonicus	Dusky kob	0.66	0.00	1060.00	0.00	24.00	2.00	0.00	0.00
Arothron hispidus	Whitespotted blaasop	26.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arothron immaculatus	Black edged Blaasop	0.00	868.03	733.85	0.00	51.00	2337.00	0.00	2095.86
Caranx heberi	Blacktipped kingfish	70.55	640.00	349.00	1169.43	2752.00	2969.00	0.00	216.41
Crenidens crenidens	White karanteen	414.00	256.00	16.00	852.00	148.00	1220.00	1170.50	8547.81
Diplodus capensis	Blacktail	757.12	99.00	456.00	77.12	3.00	84.00	1135.63	127.94
Elops machnata	Springer	0.00	0.00	0.00	0.00	3236.00	0.00	0.00	0.00
Epinephelus malabaricus	Malabar rockcod	0.00	0.00	619.32	0.00	0.00	2200.00	0.00	0.00
Favonigobius melanobranchus	Black throat goby	3.00	0.00	6.00	8.00	5.00	56.00	3.00	2.00
Favonigobius reichei	Tropical sand goby	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00
Gerres filamentosus	Threadfin pursemouth	1553.99	2340.00	584.00	226.00	483.00	4714.00	2102.31	1811.22
Gerres longirostris	Smallscaled pursemouth	480.13	583.00	430.88	1225.20	44.00	5831.00	643.53	1370.91
Gerres methueni	Evenfin pursemouth	0.00	1267.00	0.00	240.00	4740.00	3180.00	110.63	786.33
Gerres sp.	Juvenile pursemouth	0.00	30.00	0.00	0.00	0.00	7.00	0.00	0.00
Glossogobius callidus	River goby	1.00	61.00	5.00	0.00	0.00	0.00	0.00	0.00
Herklotsichthys quadramaculata	Blueline herring	0.00	0.00	0.00	0.00	0.00	51.00	0.00	0.00
Heteromycteris capensis	Cape sole	0.00	0.00	4.00	0.00	0.00	3.00	0.00	0.00
Hilsa kelee	Razor belly	0.00	0.00	0.00	0.00	0.00	3414.00	1079.48	1428.67
Himantura gerrardi	Sharpnose stingray	2488.82	30822.06	1800.65	902.72	0.00	50991.00	0.00	0.00
Himantura uarnak	Honeycomb ray	0.00	0.00	0.00	17632.90	6102.00	0.00	0.00	8075.71
Lactoria cornuta	Longhorn cowfish	39.83	50.00	0.00	0.00	0.00	0.00	0.00	1.72
Lagocephalus inermis	Moontailed blaashop	113.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leiognathus elongatus	Elongate slimy	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Leiognathus equulus	Pony-Slimy	152.00	2121.00	3182.00	2544.00	1077.00	26853.00	2647.50	6503.33
Lithognathus mormyrus	Sand steenbras	0.00	0.00	0.00	0.00	0.00	0.00	27.13	0.00
Liza dumerilii	Groovy mullet	6458.53	13405.00	13760.70	29052.21	6603.00	18697.00	14486.86	19451.39
Liza luciae	St Lucia mullet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00
Liza macrolepis	Large scale mullet	0.00	0.00	91.00	0.00	354.00	0.00	0.00	0.00
Liza richardsonii	Southern mullet	0.00	0.00	0.00	0.00	442.00	0.00	0.00	0.00
Liza tricuspidens	Striped mullet	0.00	0.00	1299.00	185.32	0.00	0.00	0.00	0.00
Lutjanus fulviflamma	Dory snapper	0.00	0.00	8.00	0.00	0.00	0.00	0.00	0.00
Monodactylus argenteus	Moony	0.00	0.00	0.00	0.00	0.00	0.00	420.00	113.33
Mugilid sp.	Juvenile mullet	0.00	21.00	0.00	0.00	3.00	49.00	0.00	37.67
Myxus capensis	Freshwater mullet	0.00	740.00	1434.00	20645.34	0.00	0.00	826.00	556.62
Platycephalus indicus	Bartailed flathead	980.11	5357.02	2471.79	1778.53	1617.00	251.00	1513.87	1713.85
Pomadasys commersonnii	Spotted grunter	4944.96	1797.00	3303.28	3894.33	1041.00	5469.00	1896.51	1961.76
Pomadasys kaakan	Cock grunter	0.00	232.00	1792.00	0.00	0.00	0.00	0.00	0.00
Pomadasys olivaceum	Piggy	219.87	89.00	0.00	48.00	0.00	6.00	0.00	0.00
Pomatomus saltatrix	Elf (Shad)	0.00	8.00	0.00	0.00	1.00	1.00	163.58	1368.33

Species	Common Name	Biomass							
		Spring 2014	Summer 2015	Autumn 2015	Winter 2015	Spring 2015	Summer 2016	Autumn 2016	Winter 2016
<i>Psammogobius knysnaensis</i>	Goby	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Pseudorhombus arsius</i>	Large tooth Flounder	117.00	137.00	180.74	720.28	62.00	4399.00	117.02	2870.21
<i>Rhabdosargus sarba</i>	Natal stumpnose	396.00	493.00	1129.91	800.18	371.00	787.00	2118.31	2199.14
<i>Rhinobaous annulatus</i>	Sandshark	0.00	0.00	355.72	0.00	0.00	0.00	0.00	0.00
<i>Sardinella gibbosa</i>	Gold-striped sardine	0.00	0.00	1500.00	148.00	0.00	0.00	3248.00	30.33
<i>Scomberoides tol</i>	Needlescaled queenfish	4755.97	2751.00	1040.97	1284.68	35674.00	161.00	1597.69	3130.83
<i>Secutor ruconius</i>	Pugnose soapy	0.00	0.00	0.00	0.00	0.00	0.00	16.00	56.67
<i>Sillago sihama</i>	Silver sillago	595.87	78.89	1572.60	1306.12	770.00	1311.00	975.27	4508.64
<i>Sphyrna jello</i>	Pickhandle Baracuda	2609.23	26385.77	1395.60	1093.22	0.00	281508.00	0.00	170.00
<i>Stolephorus holodon</i>	Thorny anchovy?	0.00	487.00	952.00	140.00	2.00	792.00	13531.50	33396.00
<i>Synodus sp.?</i>	Lizard fish	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Terapon jarbua</i>	Thornfish	0.00	7.00	234.00	21.54	0.00	731.00	172.67	423.61
<i>Tetrosomus concatenatus</i>	Triangular boxfish	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Thryssa vitrirostris</i>	Orange mouth glass nose	0.00	410.00	0.00	0.00	0.00	0.00	0.00	1471.67
<i>Trichiurus lepturus</i>	Largehead hairtail (Walla walla)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	416.67
<i>Tylosaurus crocodilus</i>	Crocodile needle fish	561.77	3100.14	617.48	0.00	2532.00	15722.00	0.00	0.00
<i>Upeneus vittatus</i>	Yellow-banded goatfish	0.00	0.00	29.04	0.00	0.00	481.00	0.00	0.00
<i>Valamugil buechanani</i>	Bluefin mullet	0.00	1000.00	0.00	0.00	0.00	1054.00	0.00	0.00
<i>Valamugil cunnesius</i>	Longarm mullet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Valamugil robustus</i>	Robust mullet	0.00	1395.00	0.00	0.00	0.00	4748.00	0.00	0.00
<i>Yongeichthys nebulosus</i>	Shadow goby	49.00	0.00	878.00	204.00	0.00	1350.00	60.00	1995.89
	Goby A	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
	Goby B	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00
	Juvi karenteen	0.00	0.00	0.00	0.00	15.00	0.00	0.00	0.00