Coastal Systems Research Group
Ecosystem Services Competence Area

Draft Report

Long-Term Ecological Monitoring for the Port of Mossel Bay

Summer Survey made in 2013

March 2013

Report Details

Prepared for:	Mr Nelson Mbatha Senior Manager: Environmental Transnet National Ports Authority South Africa
Prepared by:	Coastal Systems Research Group Ecosystem Services Competence Area Natural Resources and the Environment CSIR
Authors:	Brent Newman Sumaiya Arabi Steven Weerts
Contact person:	Brent Newman PO Box 17001 Congella 4013 Durban South Africa Telephone: (031) 242 2377 Telefax: (031) 261 2509 Email: bnewman@csir.co.za
Date:	March 2013
For bibliographic purposes this report should be cited as:	CSIR (2013) Long-Term Ecological Monitoring for the Port of Mossel Bay: Summer Survey made in 2013. CSIR Report CSIR/NRE/ECOS/IR/2013/0056/C.

Executive Summary

Transnet National Ports Authority of South Africa has commissioned Long-Term Ecological Monitoring Programmes for seven of the eight ports that it operates along the South African coastline. The purpose of the monitoring programme is to track long-term changes in environmental quality in the ports, to determine what management action (if any) is required to improve environmental quality, and to provide a yardstick against which to evaluate the success of management action that may be implemented to improve environmental quality.

The monitoring programme sampling design for each port was originally developed by the South African Environmental Observation Network (SAEON, Elwandle Node). The monitoring programme comprises bi-annual (summer and winter surveys), which differ in the scope of the physical, chemical and biological parameters and media monitored. The summer survey focuses on water quality while the winter survey focuses on water quality, sediment quality, benthic macrofauna community composition and structure, and bioaccumulation of contaminants by mussels.

Transnet National Ports Authority appointed the Coastal Systems research group of the CSIR to perform surveys for the 2013 monitoring campaign. This report analyses and summarises the findings of a summer survey made in and near the Port of Mossel Bay on the 19th of February 2013.

Water quality in and near the Port of Mossel Bay during the 2013 summer survey was good, and was by some way the best for any port surveyed in the summer of 2013. The most significant impairment was due to elevated faecal indicator bacteria counts at one station in the port. If not for these high bacteria counts then water quality at this station would have been considered excellent. Anomalies for pH and dissolved oxygen at two stations, and ammonia concentrations that were high relative to other nutrients imply some anthropogenic impairment of water quality in the port. However, the magnitude of impairment was minimal and does not change the conclusion regarding the water quality classification.

There was evidence that a discharge was influencing water quality in the port. The source and quality of the discharge should be identified and monitored.

From a programmatic perspective the monitoring of BTEX, total petroleum hydrocarbon and polycyclic aromatic hydrocarbon concentrations in surface water samples should be discontinued if the concentrations of these chemicals are also low in the winter survey. Most organic contaminants, for various reasons, tend not to remain in solution but rather settle from the water column and accumulate in sediment. The findings of the survey discussed in this report and surveys performed in 2011 (CSIR 2011) show that hydrocarbon concentrations in the water column were invariably low, and usually below the method detection limit. The effort and finances expended on monitoring these chemicals in water samples could be used to increase the suite of chemicals monitored (e.g. by adding polychlorinated biphenyls) in sediment and biological tissue. These so-called ‘fate compartments’ are where organic chemicals are more likely to accumulate if they are frequent but low level contaminants of the water column, and where these chemicals are more likely to exert adverse ecological effects.

Table of Contents

List of Tables

List of Figures

1. Introduction

Transnet National Ports Authority of South Africa has commissioned Long-Term Ecological Monitoring Programmes for seven of the eight ports that it operates along the South African coastline. The purpose of the monitoring programme is to track long-term changes in environmental quality in the ports, to determine what management action (if any) is required to improve environmental quality, and to provide a yardstick against which to evaluate the success of management action that may be implemented to improve environmental quality.

The monitoring programme sampling design for each port was originally developed by the South African Environmental Observation Network (SAEON, Elwandle Node). The monitoring programme comprises bi-annual (summer and winter surveys), which differ in the scope of the physical, chemical and biological parameters and media monitored. The summer survey focuses on water quality while the winter survey focuses on water quality, sediment quality, benthic macrofauna community composition and structure, and bioaccumulation of contaminants by mussels.

Transnet National Ports Authority appointed the Coastal Systems research group of the CSIR to perform surveys for the 2013 monitoring campaign. This report analyses and summarises the findings of a summer survey made in and near the Port of Mossel Bay on the 19th of February 2013.

2. Brief Description of the Port

The Port of Mossel Bay is situated on the southern Cape coastline, in the town of Mossel Bay (22°8'E, 34°10'S). The port is small compared to other South African ports and essentially comprises a single basin (Figure 1).

3. Material and Methods

3.1. Sampling design

A suite of physical, chemical and biological water quality parameters (or indicators) were measured *in situ* and in discrete surface water samples collected at five stations (the primary stations; Figure 1). Two of the stations (4 and 5) are situated beyond the port bounds and are consequently referred to in this report as the marine stations. *In situ* measurements only were made at an additional four stations (the secondary stations are denoted with the prefix ‘Y’ in Figure 1).

3.2. Fieldwork

Port environments are affected by multiple anthropogenic influences and disturbances, including accidental spillages (e.g. cargo loading) and the introduction of contaminants from surrounding urban and industrial areas (e.g. via surface runoff or atmospheric deposition). Environmental monitoring programmes should be designed to measure the cumulative impact of these influences and disturbances, but not necessarily to discriminate between them. However, a waterside disturbance intentionally avoided in this monitoring programme is the influence of vessel propeller wash on the physical, chemical and biological characteristics of the water column. During tugboat assisted movements of large vessels the bottom sediment in ports is usually disturbed by propeller wash. Plumes of suspended sediment provide a tangible manifestation and impact of this disturbance. Less tangible impacts include the release of contaminants adsorbed onto or otherwise immobilised in sediment through its mechanical disturbance (i.e. agitation) and/or changes in its chemistry (i.e. changes in redox state through exposure to oxygen) that in turn cause contaminants to be released from the sediment. These impacts are, however, usually of a short-term nature – the suspended sediment will settle and many contaminants released from sediment are usually rapidly scavenged from the water column. To prevent these short-term impacts unduly influencing ‘typical’ water quality in ports, field measurement and sampling was not performed in a particular area of a port within at least one hour after a large vessel movement was observed. This was considered sufficient time for sediment driven into suspension to settle and for (possibly) mobilised contaminants to be scavenged from the water column or to be sufficiently diluted so as to not significantly influence water quality.

At primary and secondary stations a Yellow Springs Instrument 6600 multiparameter water quality

Figure 1. Aerial view of the Port of Mossel Bay showing the positions where water quality was monitored on the 19th of February 2013. At stations denoted with the prefix 'Y' only *in situ* water quality monitoring was performed. Aerial view reproduced from Google Earth©.

sonde was used to profile temperature, salinity, pH, turbidity, dissolved oxygen and chlorophyll-*a* through the water column. Probes of the sonde were calibrated prior to fieldwork with the exception of the chlorophyll-*a* probe. Chlorophyll-*a* concentrations were generated by default algorithms of the sondes software. The sonde was programmed to log at three second intervals. The sondes probes were held about 30 cm below the water surface for approximately one minute to equilibrate, held in place for an additional minute, and then slowly lowered through the water column. On contact with the bottom the sonde was raised about 30 cm and held in place for approximately three minutes. This was considered sufficient time for disturbed sediment to settle and disperse and still allow for a one minute period of logging of bottom water physical, chemical and biological characteristics representative of the undisturbed condition. Field staff also moved approximately one meter along the vessel from which monitoring was performed in a further attempt to avoid the influence of disturbed sediment on the measurements. Holding the sonde in surface and bottom waters for an extended period provided an estimate of the short-term variability in water column physical, chemical and biological characteristics.

A major advantage of *in situ* instruments is that they allow the measurement of near-continuous profiles of physical, chemical and biological parameters through the water column, thereby eliminating the collection of discrete water samples at arbitrarily defined depths that might not encapsulate revealing and informative clines. Unfortunately, the technology does not exist for the *in situ* measurement of many physical, chemical and biological parameters that are of interest in water quality monitoring programmes (e.g. metal and nutrient concentrations). This accounts for the need to collect discrete water samples for analysis in the laboratory.

Discrete surface water samples were collected at primary stations using a National Institute of Oceanography bottle (90 cm in length, 5 litre capacity). The bottle was lowered vertically into the water column until submerged and triggered. On retrieval the bottle was inverted several times to ensure the water sample was well-mixed. Aliquots of water were then transferred to pre-cleaned and sterilised (where appropriate) high density polyethylene or glass containers. Samples were kept cool on ice in the field and until delivery to the laboratory, where they were held at 4°C until analysis. Analyses were initiated within four days of sample collection, but usually within 12 - 16 hours. Samples destined for microbiological analysis were kept cool on ice in the field and until delivery to the laboratory, where they were processed within 24 hrs of collection. Samples destined for chlorophyll-*a* analysis were processed within 4 - 6 hrs of collection and analysed within 24 hrs.

3.3. Laboratory Analyses

3.3.1. Faecal indicator bacteria

Escherichia coli were detected and enumerated using the Escherichia Partition Method with NA-MUG agar as per Method 9222G in Standard Methods for Water and Wastewater (1992). Faecal streptococci/enterococci were detected and enumerated using a membrane filtration method as per Method 9230C in Standard Methods for Water and Wastewater (1992), using m Enterococcus agar.

3.3.2. Total suspended solids

Total suspended solids concentrations were determined gravimetrically. Water samples were vigorously agitated and a 500 ml aliquot was then vacuum filtered through pre-dried and pre-weighed 0.45 µm pore size membrane filters. The filters were dried at 105°C for 2 hrs and re-weighed. The total suspended solids concentration was determined as the difference in the dry weight of filters before and after filtration. Total suspended solids concentrations are presented on a $mg.l^{-1}$ basis.

3.3.3. Nutrients

Water samples were vacuum filtered through 0.45 µm pore size membrane filters. The (dissolved) concentrations of nitrite-nitrogen (NO_2^-), nitrite and nitrate-nitrogen (NO_x), total ammoniacal-nitrogen (sum of NH_3^+ and NH_4^+) and orthophosphate-phosphorous (PO_4^{3-}) in the filtrate were measured colourimetrically using a four-channel flow injection Bran and Luebbe AutoAnalyzer II. Silica (SiO_2) was measured spectrophotometrically. Note that while orthophosphate-phosphorous is considered an inorganic form of phosphate, the (molybdenum) method that was used to quantify concentrations is not selective for orthophosphate (Koroleff 1983, Zhang and Berberian 1997) and a fraction of organic phosphorous is probably also incorporated in reported concentrations. Nutrient concentrations are reported on a µM basis.

3.3.4. Chlorophyll-*a*

Between 500 - 750 ml of water was vacuum filtered through Whatman GF/F filters (47 mm) in the field. The filters were transferred to a test tube containing 10 ml of 90% (v/v) acetone and left to extract in the dark at 4°C for 24 hrs. Chlorophyll-*a* concentrations were then determined using a pre-calibrated Turner Instruments 10-AU fluorometer. Chlorophyll-*a* concentrations are presented on a $\mu g.l^{-1}$ basis.

3.3.5. Metals

Metals targeted for analysis are those for which guidelines are provided in the South African Water Quality Guidelines for Coastal Marine Waters. Dissolved metals[1] were concentrated by adding a chelating agent to vacuum filtered (0.45 µm pore size membrane filter) water samples. The metal-chelate complex was extracted using an organic solvent, the latter then removed by heating. The metal-chelate complex was then dissolved in dilute nitric acid before concentrations in solution were detected and quantified using inductively coupled plasma mass emission spectroscopy. In the case of mercury, samples were analysed using a direct mercury analyser. Metal concentrations are concentrations are presented on a $\mu g.l^{-1}$ basis with the exception of mercury, which is presented on a $ng.l^{-1}$.

3.3.6. Hydrocarbons

A liquid-liquid method was used to quantitatively extract analytes from water samples. Hexane was employed as the extracting solvent. The samples were concentrated and the analytes detected using gas chromatography-mass spectrometry. Quantitation was accomplished by comparing responses of major ions relative to an internal standard. Hydrocarbon concentrations are presented on a $\mu g.l^{-1}$ basis.

3.4. Data Analysis

3.4.1. General

Perhaps the most important objective of environmental quality monitoring programmes of the type discussed in this report is to determine whether the values and concentrations of physical,

---

[1] Although arsenic is technically a metalloid (i.e. a semi-metal), in the interests of simplicity it is referred to as a metal in this report.

chemical and biological parameters (the indicators) measured in the environmental media of interest (e.g. water, sediment) are within acceptable ranges or not. This is important since it determines whether management intervention is required to improve environmental quality and the parameters that need to be targeted in this context. A common approach to assessing environmental quality is the use of an index that summarises data for different indicators into a unitless value, based on predefined classification criteria for the component indicators, and which is then compared to a classification system that defines the quality into a narrative category (e.g. good, fair, poor). An index approach is useful for communicating findings to decision-makers and audiences that do not have the technical expertise to understand long and often complex technical reports that emanate from monitoring programmes. However, many scientists are loathe to use this approach since an index can hide or accentuate complexities and anomalies in the data, including short- and long-term water and sediment quality problems (Hallock 2002). This is particularly so if surveys are only performed periodically, and especially for the water column. The reason is that many of the physical, chemical and biological characteristics of aquatic systems are inherently variable, often at the system level, making an assessment of environmental quality based on generic criteria for acceptability and unacceptability problematic. In anthropogenically impacted systems a further layer of variability is introduced since contamination events are themselves variable in extent, magnitude and frequency, again especially for the water column.

Determining whether indicator values and concentrations are ‘acceptable’ or ‘unacceptable’ is usually accomplished by comparison to environmental quality guidelines derived to be protective of a beneficial use (e.g. ecosystem functioning, recreational use). There are nevertheless several complexities associated with this approach, especially in the context of the Long-Term Ecological Monitoring Programme discussed in this report.

First, environmental quality guidelines do not constitute pass/fail criteria and are thus not ‘bright lines’ that indicate the onset of adverse biological effects. Indeed, the term guideline implies that they are a guide rather than a standard for decision-making. Environmental quality guidelines are often derived to be protective of a beneficial use over large regions, but may not apply to all systems within a region because of natural differences between systems. For example, the South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment, DWAF 1995a) are intended for application in all South African coastal marine waters, although there are caveats for some parameters from a regional perspective. Furthermore, if the guidelines are not derived from empirical data for the region in question but adopted from another jurisdiction, then they may not be appropriate in all situations, or indeed in any situation. The significance in this case is that many workers use guidelines derived for another region, when there are no guidelines available for the region in question. The recommended approach is to use indicators in a weight-of-evidence approach, that is, using multiple lines of evidence (i.e. multiple indicators) to reach a conclusion on environmental quality. Where possible, the findings should be compared and calibrated to empirical data for regional background or reference conditions for the study area in question.

Second, consideration must to be given to both the magnitude and duration of guideline exceedance. A minor or short-term exceedance of a guideline has different ecological and management implications compared to a substantial or long-term exceedance. Thus, simply counting how many environmental quality indicators at a sampling station exceed their respective guidelines is to some extent meaningless beyond identifying the problematic indicators. This scorecard approach to environmental quality assessment, of which one is used in this study, consequently only provides a general understanding of environmental quality unless scientifically defensible (e.g. based on toxicological data) parameter values and concentrations are used to compile the scorecard and there is some understanding of the magnitude and duration of guideline exceedance.

Third, a critical factor that has not received sufficient attention in South Africa is whether the level of ecological protection (i.e. environmental quality) within port environments should be the same as for anthropogenically un-impacted or minimally impacted coastal systems. Although it is desirable for the same level of protection to be accorded to all coastal systems, the reality is that environmental quality in most port environments is bound to be impaired, even if only minimally. Maintaining the same environmental quality in ports as that in anthropogenically un-impacted systems is virtually impossible, or will at the very least be extremely expensive. A situation can thus arise in a port of an indicator routinely exceeding a guideline in spite of on-going and determined efforts by the port operating authority to control the source and cause of the exceedance. In recognition of this problem environmental authorities in some jurisdictions (e.g. state of Queensland in Australia) have begun to define environmental quality objectives at the system specific level, based on defined beneficial uses. Thus, the level of environmental quality that must be met in port environments is relaxed relative to the level in, for example, an area with high conservation value. It should, however, be noted that the degree of relaxation is not pronounced and the definition of different environmental quality objectives (essentially guidelines) does not imply tacit approval for unregulated environmental degradation. Furthermore, in the South African context different ports have different ecological values, and different areas within the same port may have different ecological values. Applying a standard set of environmental quality objectives for all ports will therefore be inappropriate.

Fourth, environmental quality guidelines, and particularly water quality guidelines, are most useful for interpreting data collected at frequent intervals and over relatively long periods, rather than data generated through once-off measurements. The reason is that, as stated above, periodic excursions of physical, chemical and biological parameters outside of target ranges is not necessarily adverse for an ecosystem. Prolonged excursions do, however, not only signal a problem but also an increased probability for adverse ecological effects. Also, contamination events, or indeed anomalous natural events (e.g. upwelling) may overly influence the understanding of water quality. It is for this reason that some jurisdictions have defined instantaneous (acute) and longer-term (chronic) guidelines for various physical, chemical and biological indicators in the water column. The South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment, DWAF 1995a) do not, however, discriminate between acute and chronic effects.

In spite of these limitations the Long-Term Ecological Monitoring Programme makes an extremely valuable and important contribution to our understanding of environmental quality in South African ports. A major strength of the Long-Term Ecological Monitoring Programme is that is of an integrated nature, in that sediment and biological communities are also monitored. These provide a more conservative and longer timeframe understanding of environmental quality compared to water quality *per se*. Also, by repeating surveys on an annual basis it will be possible to ‘filter’ out anomalous events coinciding with specific surveys and to track long-term changes in port environmental quality.

3.4.2. Water quality

The average (±standard deviation) of one minute intervals of data logged *in situ* with the multiparameter water quality sonde is used to summarise the short-term variability of physical, chemical and biological parameter values and concentrations in surface and bottom waters. The data are displayed as symbols with error bars in graphs, but only the average value or concentration is provided in appendices. *In situ* profiles of physical, chemical and biological parameters are presented graphically and interpreted visually, that is, by examining for anomalies in profiles at and between stations.

As stated previously, chlorophyll-*a* concentration was measured *in situ* using an un-calibrated probe on the multiparameter water quality sonde, that is, the concentrations were generated by default algorithms of the sondes software. The conversion of chlorophyll-*a* concentration to microalgal biomass is dependent on many factors, including the species and condition of the microalgae, and is approximate even when the sonde is calibrated. Consequently, chlorophyll-*a* concentration should be considered a relative rather than true measure

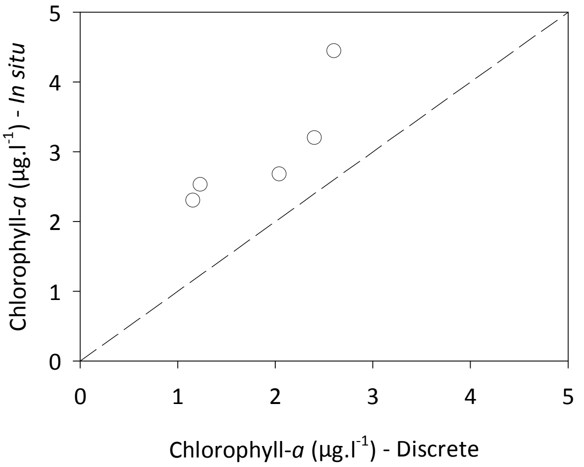

Figure 2. Relationship between chlorophyll-*a* concentration measured *in situ* with an un-calibrated multiparameter water quality sonde in the Port of Mossel Bay on the 19th of February 2013 and in discrete water samples with a calibrated laboratory-based fluorometer. The diagonal dashed line represents a 1:1 line.

of microalgal biomass. Nonetheless, chlorophyll-*a* concentration measured *in situ* provides useful information on the (relative) variability of microalgal biomass through the water column at and between stations.

Since chlorophyll-*a* concentration was also measured in discrete surface water samples using a fluorometer in the laboratory, the difference in concentration measured by the sonde and fluorometer is useful for estimating the uncertainty associated with *in situ* measurements. Using a 1:1 line as a measure of similarity it is evident that the sonde somewhat overestimated chlorophyll-*a* concentration relative to the fluorometer (Figure 2). Differences between the fluorometer and sonde are inevitable because the measurements were not made on the same water sample (i.e. *in situ* versus discrete).

In some cases the values and concentrations of physical, chemical and biological parameters measured *in situ* and in discrete water samples are assessed relative to the South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment and Recreational Use, DWAF 1995a,b; Table 1). The guidelines define target values and concentrations, or ranges of values and concentrations, for a suite of physical, chemical and biological parameters in coastal marine waters of South Africa. Whether the guidelines are appropriate for the assessment of water quality in port environments is debatable because many South African ports show physical, chemical and biological characteristics more similar to estuarine than marine environments. This is in spite of a strong marine influence evident in most ports. Also, the South African Water Quality Guidelines for

Table 1. South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment and Recreational Use; DWAF 1995 a,b). The target value or concentration indicates the value or concentration of an indicator below, above or between which an adverse effect to ecological or human health is not expected.

Indicator	Target Value or Concentration
Temperature	The maximum acceptable variation in ambient temperature is ±1°C.
Salinity	33 - 36
pH	7.3 - 8.2
Dissolved oxygen	Should not fall below 5 mg.l^{-1} 99% of the time and below 6 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.
Nutrients	Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for dissolved oxygen.
Bacteria	Maximum acceptable count per 100 ml: 100 in 80% of samples and 2 000 in 95% of samples.
Arsenic	12 µg.l^{-1}
Cadmium	4 µg.l^{-1}
Copper	5 µg.l^{-1}
Chromium	8 µg.l^{-1}
Mercury	0.3 µg.l^{-1}
Nickel	25 µg.l^{-1}
Lead	12 µg.l^{-1}
Zinc	25 µg.l^{-1}

Coastal Marine Waters (Natural Environment; DWAF 1995a) do not provide guidelines for certain parameters. Consequently, scientists from the Coastal Systems research group of the CSIR defined classification criteria for certain physical, chemical and biological parameters. This was done primarily to allow a scorecard assessment of water quality into three categories, namely good, fair and poor. Whether the classification criteria are appropriate is uncertain since in some cases the criteria are based on international guidelines or on best professional judgement. The reader should, consequently, not consider a poor classification as providing incontrovertible proof that water quality is impaired to the extent that adverse ecological effects are likely. However, the criteria are considered sufficiently robust to identify impaired water quality. As more data are generated through the Long-Term Ecological Monitoring Programme it will become apparent whether there is a need to revise the classification criteria.

4. Results and Discussion[2]

4.1. Temperature

Temperature affects numerous physical and chemical processes in aquatic systems, such as the solubility of certain chemicals. Cold water, for example, is able to hold more oxygen than warm water. Temperature also triggers biological processes through its control on organism metabolic rates and reproductive cycles. In the context of the Long-Term Ecological Monitoring Programme the primary reason for measuring temperature is to determine whether the water column is thermally stratified and as an aid (if required) to the interpretation of dissolved oxygen concentration and saturation. Thermal stratification is the term used to describe the situation where temperature changes markedly through the water column, with the most significant change often occurring over a relatively narrow range of depth and where warm water overlays cool water. Thermal stratification occurs because, and is thus an indicator of, water column stability. In other words, stratification develops if there is relatively little mixing between the upper and lower portions of the water column. Because water masses of different temperature have a different density they tend not to mix. Persistent thermal (and salinity, see below) stratification leads to the ‘trapping’ of bottom water, which may become hypoxic or even anoxic if the oxygen demand exceeds the rate at which the water is re-ventilated. Although once-off measurements do not provide an understanding of the (seasonal) persistence of stratification, the corollary is that if stratification is persistent then it should be detected. Thermal stratification is more common in the summer months, since in winter storms usually ensure that the water column is well-mixed.

Temperature profiles in and near the Port of Mossel Bay are presented in Figure 3, while a comparison between surface and bottom waters is presented in Figure 4. Temperature varied minimally through the water column at each and between stations. Only at stations 3, Y3 and Y4 did the temperature near the bottom of the water column decrease somewhat, but this never amounted to more than a 1.5°C change compared to the remainder of the water column. Overall, therefore, the water column in and near the port was well-mixed at the time of monitoring, with no evidence for thermal stratification.

Water Quality Assessment: The South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) state that the “maximum acceptable variation in ambient temperature is ±1°C”. It is presumed that temperature changes of concern in this context are those induced by anthropogenic discharges (e.g. heated or cooled effluent), since no detailed explanation pertinent to application of the guideline is provided. Considering that the ambient temperature range for water in the Port of Mossel Bay has not, as far as the scientists that compiled this report could establish, been adequately quantified. Also, as evidenced by the data generated in this survey water column temperature is often highly variable at and between any particular location in the port at any particular time. Therefore, it will be virtually impossible to determine whether water quality has been anthropogenically altered by a change of as little as 1°C through ‘once-off’ surveys. No water quality classification criteria for temperature were defined

---

[2] Raw data are presented as appendices to this report.

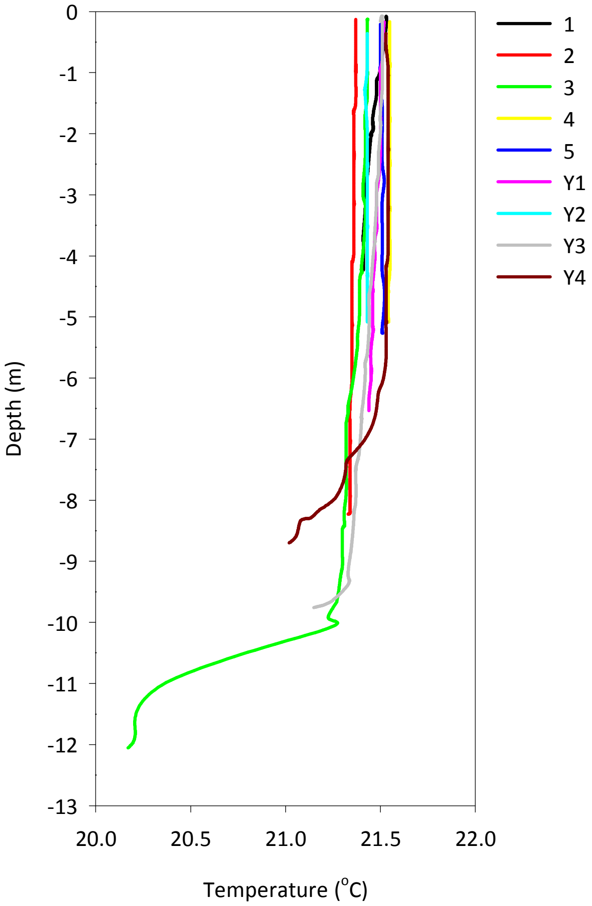

Figure 3. Temperature profiles for the water column in and near the Port of Mossel Bay on the 19th of February 2013.

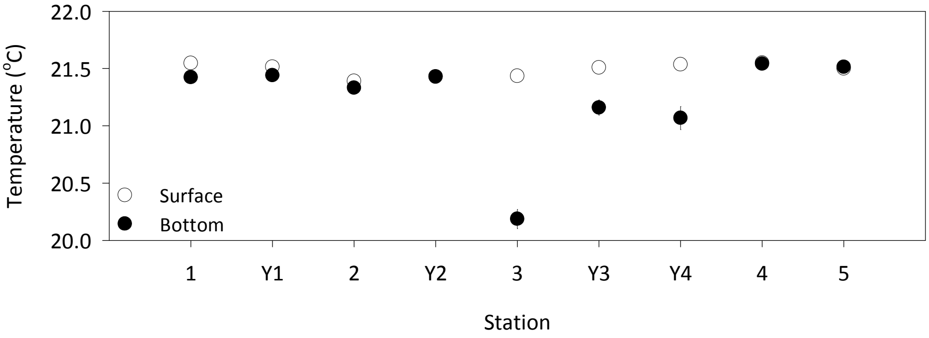

Figure 4. Comparison of the average (± standard deviation) temperature of surface and bottom waters in and near the Port of Mossel Bay on the 19th of February 2013.

by scientists from the Coastal Systems research group of the CSIR and no assessment of water quality according to its temperature was thus made. This said, during surveys performed in 2011 (CSIR 2011) a temperature variation in surface waters in the vicinity of stations 1/Y2 was evident and was tentatively linked to the discharge from a factory into the port.

4.2. Salinity

Salinity is a measure of the concentration of all salts that are dissolved in water[3]. Salinity is an important determinant of the distribution of estuarine organisms, which display differing salinity tolerances (e.g. Summers and Engle 1993, Melwani and Thompson 2007). Marine organisms, in contrast, usually display a narrow salinity tolerance.

The measurement of salinity provides information on the extent and influence of freshwater inflows (e.g. stormwater) into the Port of Mossel Bay and is

---

[3] Although numerous workers express salinity in parts per thousand (ppt), based on the fact that salinity is determined by taking the ratio between two electrical conductivities it is more correctly expressed in Practical Salinity Units (PSU), a unitless scale. The average salinity of oceanic waters is usually given as 35, but can vary over a fairly wide range from one ocean to another.

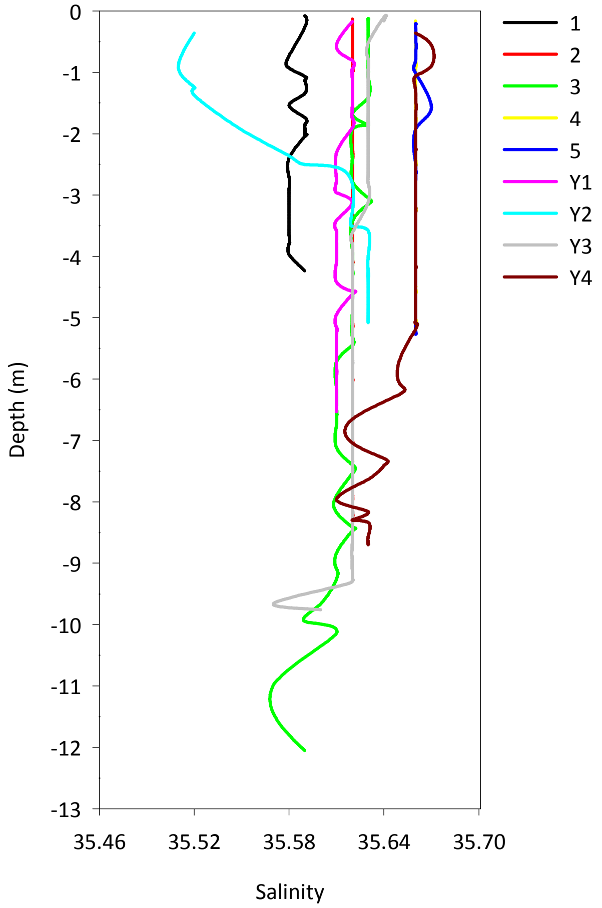

Figure 5. Salinity profiles for the water column in and near the Port of Mossel Bay on the 19th of February 2013.

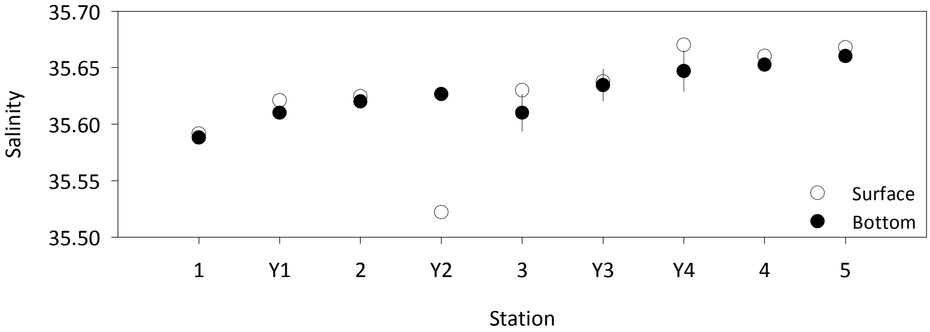

Figure 6. Comparison of the average (± standard deviation) salinity of surface and bottom waters in and near the Port of Mossel Bay on the 19th of February 2013.

useful for determining whether anomalous measurements for certain physical and chemical parameters can be attributed to these inflows. This is because salinity behaves conservatively and can be used as an index of mixing (see section 4.7 for a further discussion in this context).

Salinity stratification of the water column can occur in sheltered waters under suitable conditions, because of density differences between fresh and saline waters. Salinity stratification has a similar effect as thermal stratification, that is, 'trapping' bottom water that may become hypoxic or even anoxic if there is a high oxygen demand because of a lack of ventilation by oxygen rich surface waters.

Salinity profiles for the water column in and near the Port of Mossel Bay are presented in Figure 5, while a comparison between surface and bottom waters is presented in Figure 6. Salinity varied minimally through the water column at each station and between stations with the exception of station Y2, where the salinity in the upper part of the water column was lower compared to the bottom part. The salinity depression was, however, minimal (0.11 units). A salinity depression in the vicinity of station Y2 was also evident in summer and winter surveys performed in 2011 (CSIR 2011). In 2011, fieldworkers observed an ‘icy’ water discharge through an outfall in the vicinity of stations 1/Y2 (see Figure 1) and it was presumed this discharge accounted for the low salinity in the upper part of the water column. A similar conclusion is reached for the summer 2013 survey, although fieldworkers did not observe water discharging through the outfall at the time of monitoring.

There was a progressive, albeit small, increase in the salinity of surface and bottom water from the inner part of the port to the marine stations, with the obvious exception of surface water at station Y2 (Figure 6). A similar trend was evident for summer and winter surveys performed in 2011 (CSIR 2011) and implies that the discharge mentioned above (or some other discharge) has a persistent (but small) influence on surface water salinity across the port.

Water Quality Assessment: The South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) provide a target range for salinity of 33 - 36. The target range is defined to take into account the significant and persistent reduction or increase in salinity due to anthropogenic discharges of low salinity or hypersaline effluent respectively in marine waters, where the salinity is stable (around 35). As stated above there is a known discharge into the port in the vicinity of stations 1/Y2, but this did not significantly influence water column salinity and the salinity through the water column at all stations exceeded 33 and was below 36 (Figures 5 and 6).

4.3. pH

pH is the negative logarithm (base 10) of the chemical activity of the hydrogen ion in solution. The pH scale indicates a neutral solution at 7, an acidic solution below 7, and an alkaline (basic) solution above 7. Because the scale is logarithmic, a unit change in pH corresponds to a tenfold change in the hydrogen ion concentration. Thus, small changes in pH can significantly alter the chemistry of marine and estuarine waters.

The pH of marine waters is fairly stable (range between about 7.5 - 8.5 worldwide) because of the buffering capacity provided by the abundance of strong basic cations (such as sodium, potassium and calcium) and weak acid anions (such as carbonates and borates; Wetzel 1983). The pH of surface waters is usually higher than that of bottom waters because of the effect of solar radiation. This effect is twofold: it promotes photosynthesis and increases surface water temperature, both of which decrease the amount of free carbonic acid and consequently raise the pH (Skirrow 1965, Wetzel 1983). Even in estuaries and embayments where considerable dilution of seawater by freshwater inflow may occur, buffering is sufficient to maintain a fairly stable pH, usually in the slightly alkaline range (i.e. usually higher than about 7.3).

pH is often measured in coastal water quality monitoring programmes since it provides an indirect measure of the presence of pollutants. This is typically evidenced by unusually low or high pH values (often taken as ≤7 and ≥9 respectively), which may, for example, come about due to the release of acids or caustic materials. However, excursions of pH to as high as 9 can be caused by high rates of photosynthesis (e.g. Hansen 2002). pH is an important factor affecting chemical and biological reactions. The degree of dissociation of weak acids or bases is affected by changes in pH. This effect is important because the toxicity of many compounds is affected by the degree of dissociation. One such example is for ammonia, which is usually present in the un-ionised, more toxic form at higher pH. The solubility of metal compounds in bottom sediments is also affected by pH, with direct toxicity implications.

Profiles of pH for the water column in and near the Port of Mossel Bay are presented in Figure 7, while a comparison between surface and bottom waters is presented in Figure 8. There was little variation in pH through the water column at most stations. The most pronounced change was in the lower few meters of the water column at stations 3 and Y4 (Figure 7). These decreases were closely linked to the decrease in temperature. Although differences in pH between stations were small, there was a generally progressive increase in the pH of surface and bottom water from the inner part of the port to the marine stations (Figures 8). This broadly

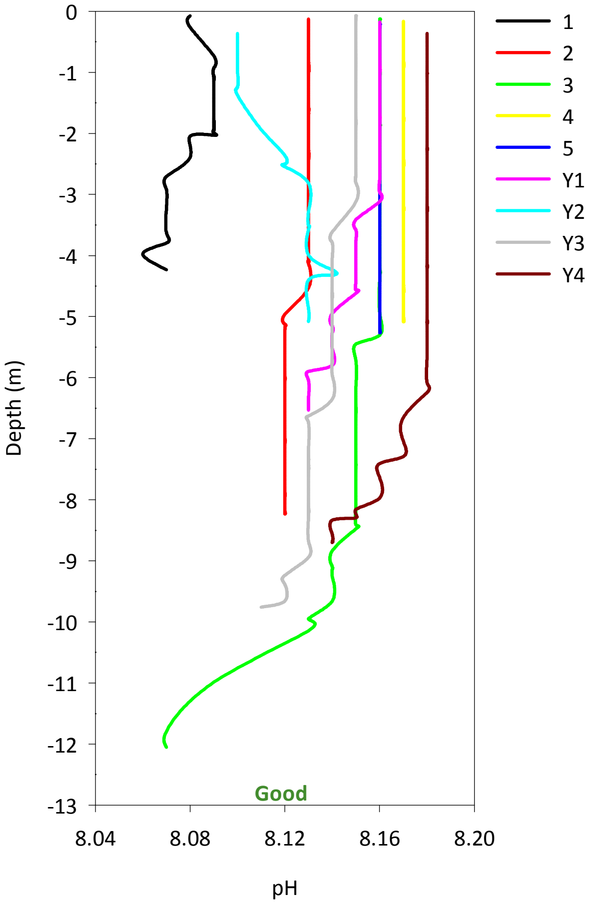

Figure 7. pH profiles for the water column in and near the Port of Mossel Bay on the 19th of February 2013.

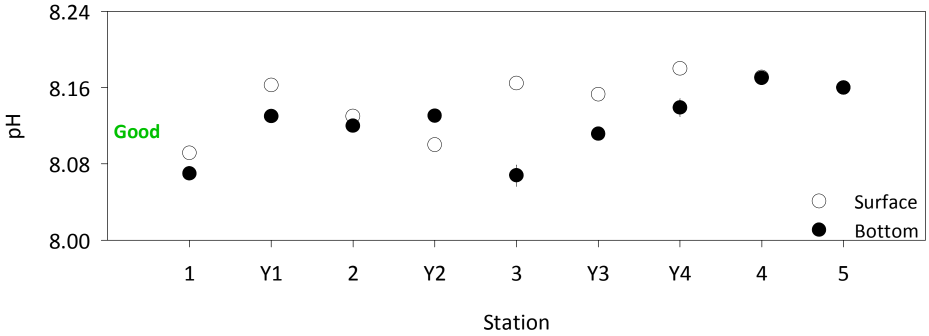

Figure 8. Comparison of the average (± standard deviation) pH of surface and bottom waters in and near the Port of Mossel Bay on the 19th of February 2013.

mirrors the progressive increase in salinity from the inner part of the port to the marine stations discussed above. A comparable pH trend was also evident for summer and winter surveys performed in 2011 (CSIR 2011). Freshwater has a lower pH than seawater and it is presumed that the discharge mentioned previously accounts in part for the progressive increase in pH, through its influence on water column salinity in the port. Support for this conclusion is provided by the strong positive correlation between salinity and pH (r = 0.831, p = 0.005).

Water Quality Assessment: The pH through the water column at all stations fell within the target range prescribed by the South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment), of 7.3 - 8.2.

Scientists from the Coastal Systems research group of the CSIR consider the lower limit of this target range to be underprotective and the upper limit overprotective. Analysis of estuarine and marine water quality guidelines from many regions of the world shows that the upper limit for pH is usually in the order of 8.5 - 8.7 (e.g. Canada: CCME 1999). This takes into account that the pH of estuarine and marine waters in many regions is in the order of 8.1

- 8.3, but makes allowance for excursions above about 8.3 due to natural processes (e.g. high primary productivity). Therefore, for the purposes of the survey described in this report scientists from the Coastal Systems research group of the CSIR defined water quality classification criteria for pH as:

Good: ≥7.80 - ≤8.40
Fair: ≥7.4 - <7.80, >8.4 - ≤8.8
Poor: <7.4, >8.8

Based on these criteria water quality was classified good at all stations (Figures 7 and 8; see report card in section 5).

4.4. Dissolved oxygen

Dissolved oxygen is a fundamental requirement for the maintenance of balanced populations of fish, shellfish and other aquatic fauna and flora, and as such comprises one of the most important parameters that define water quality. Oxygen deficiency (hypoxia (<2 $mg.l^{-1}$) and anoxia (0 $mg.l^{-1}$)) is widely considered the most widespread anthropogenically induced deleterious effect in estuarine and marine environments around the world.

Dissolved oxygen concentrations are usually highest in surface waters, due to ventilation from the atmosphere (this is aided by wind induced turbulence of surface waters). The concentration of dissolved oxygen is also influenced by temperature and salinity. Cold water can hold more dissolved oxygen than warm water, and freshwater holds more than salt water.

The dissolved oxygen concentration can also be enhanced by photosynthetic oxygen production by macro- and microalgae in daylight hours. Under certain conditions, oxygen super-saturation may manifest, that is, oxygen saturation exceeding 100%. In deeper waters, as the light regime becomes limiting and photosynthetic activity is reduced or inhibited, oxygen is consumed by bacteria that decompose organic matter that sinks to the bottom. In poorly ventilated bottom waters and under conditions of high organic matter loading of the sediment, the respiratory requirements of the bacteria may exceed oxygen resupply and lead to the development of hypoxia and anoxia. Areas with the greatest dissolved oxygen depletion are usually those with restricted circulation and an abundant supply of organic matter from natural (e.g. high microalgal productivity) or anthropogenic sources (e.g. sewage). Anthropogenic discharges, such as effluent and stormwater, tend to exert a high oxygen demand due to the presence of high organic matter loads and of contaminants that are easily oxidised in estuarine and marine waters. Thermal and salinity stratification exacerbate the development of low dissolved oxygen concentration in bottom waters by limiting mixing between oxygen rich surface and oxygen poor bottom waters.

The saturation concentration of dissolved oxygen in estuarine and marine waters under natural conditions is typically in the region of 6 - 8 $mg.l^{-1}$. Dissolved oxygen concentrations ≥5 $mg.l^{-1}$ are generally considered to be protective of aquatic life (USEPA 2003). As concentrations fall below 5 $mg.l^{-1}$, mobile organisms (such as fish) begin to leave the affected area (e.g. Wannamaker and Rice 2000, Breitburg 2002), while less mobile organisms become stressed and may die. At concentrations of about 3 - 4 $mg.l^{-1}$ effects become severe, especially if the low dissolved oxygen concentrations persist (Pearson and Rosenberg 1978, Diaz and Rosenberg 1995, Nixon 1995, USEPA 2001, 2003). Virtually all organisms die when the dissolved oxygen concentration falls below 1.5 $mg.l^{-1}$ for a few days or more. Some benthic invertebrates are, however, tolerant of low dissolved oxygen concentration. Prolonged periods of low dissolved oxygen concentration can lead to major changes in the composition of benthic invertebrate communities. This has ripple-like impacts on higher levels of food webs and ecosystem functioning (Pearson and Rosenberg 1978, Diaz and Rosenberg 1995, Taylor and Eggleston 2000, Breitburg 2002).

The measurement of dissolved oxygen in water quality monitoring programmes is not only relevant to an understanding of direct impacts to fauna and flora, but also because many toxic compounds become increasingly toxic at low dissolved oxygen concentrations (e.g. Davis 1975).

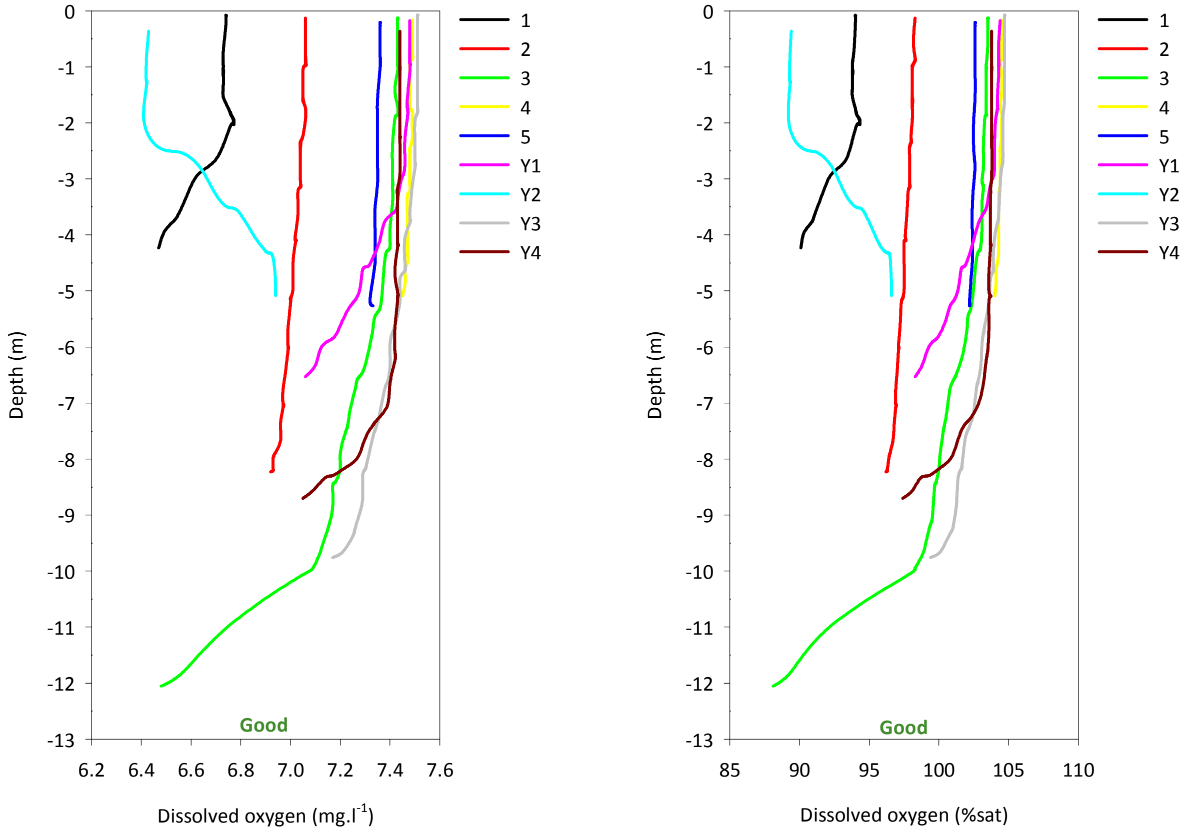

Figure 9. Dissolved oxygen concentration and saturation profiles for the water column in and near the Port of Mossel Bay on the 19th of February 2013.

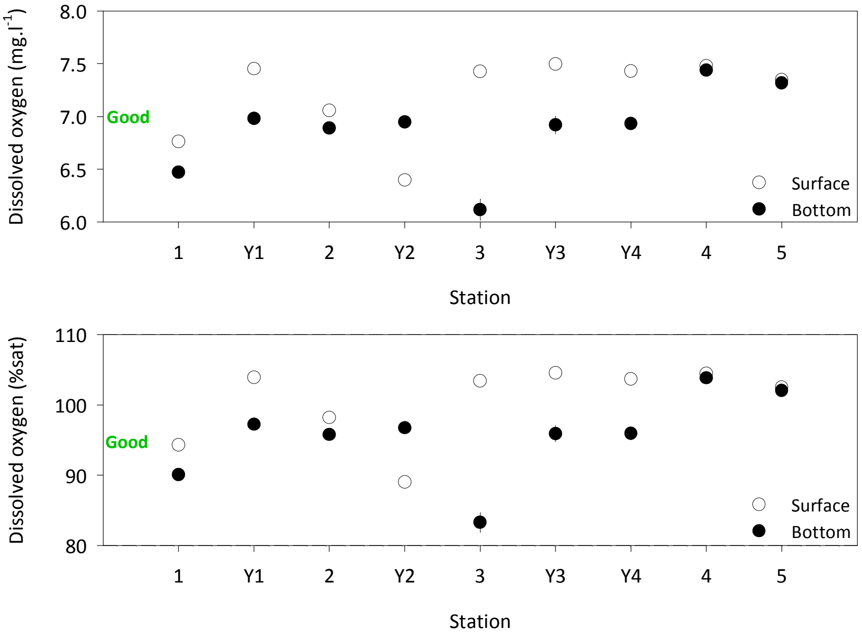

Figure 10. Comparison of the average (± standard deviation) dissolved oxygen concentration and saturation in surface and bottom waters in and near the Port of Mossel Bay on the 19th of February 2013.

Dissolved oxygen concentration and saturation[4] profiles for the water column in and near the Port of Mossel Bay are presented in Figure 9, while a comparison between surface and bottom waters is presented in Figure 10. There was typically minimal variation in dissolved oxygen concentration through the water column. Although the dissolved oxygen concentration at some stations decreased in near-bottom waters, the decrease was minimal. The

---

[4] Percent saturation is the ratio between the actual amount of dissolved oxygen measured and the potential that the water has for holding oxygen (in coastal areas usually determined by temperature and salinity). If the percentage saturation is <100%, then the demand for oxygen (e.g. through respiration or chemical reactions) is exceeding that rate at which it is being generated by photosynthesis or replaced by diffusion.

exception was station 3, where there was an approximately 1 mg.l^{-1} decrease in concentration between 4 - 12 m depth. The decreases at some stations were closely linked to decreases in temperature and pH, implying that the variation in these parameters is linked. The dissolved oxygen concentration in surface water at stations 1 and Y2 was somewhat lower compared to most other stations and it is presumed the discharge causing the lower salinity and pH in surface water at station Y2 was also the cause of the 'low' dissolved oxygen concentration at these stations.

Water Quality Assessment: Dissolved oxygen concentration through the water column at all stations exceeded the South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) target of 6 mg.l^{-1} that should be achieved 95% of the time and 5 mg.l^{-1} that should be achieved 99% of the time.

For the purposes of the survey described in this report scientists from the Coastal Systems research group of the CSIR defined water quality classification criteria for dissolved oxygen concentration as:

Good:	≥5.0 mg.l^{-1} - ≤9.0 mg.l^{-1}
Fair:	≥2.0 - <5.0 mg.l^{-1}, >9.0 mg.l^{-1}
Poor:	<2.0 mg.l^{-1}

Water quality in terms of dissolved oxygen concentration was classified good at all stations (Figures 9 and 10, see report card in section 5).

The South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) do not specify a target range for dissolved oxygen saturation. For the purposes of the survey described in this report scientists from the Coastal Systems research group of the CSIR defined water quality classification criteria for dissolved oxygen saturation as:

Good:	≥80 - ≤110%
Fair:	≥40 - <80, >110 - ≤140%
Poor:	<40%, >140%

Water quality in terms of dissolved oxygen saturation was classified good at all stations (Figures 9 and 10; see report card in section 5).

4.5. Turbidity and total suspended solids

Turbidity and total suspended solids provide generally complimentary information on water quality and are consequently discussed concurrently.

Turbidity is a measure of water clarity or transparency. More specifically, turbidity relates to the amount of scattering of light by particulate and dissolved matter in water (Wetzel 1983). This matter includes inorganic solids, such as silt and clay, organic solids, such as (micro)algae and detritus, and dissolved salts. The higher the concentration of this matter the more turbid the water. Natural turbidity in coastal ecosystems is caused by colloidal suspension, such as silt and clay introduced by river runoff or through re-suspension of debris in the water column by strong wind and wave action, and in ports also by vessel movements (propeller wash) and dredging. Other anthropogenic sources of suspended solids to aquatic ecosystems include stormwater runoff, sewage discharges and industrial wastes.

Total suspended solids is a measure of the dry weight of suspended particulate matter per unit volume of water, and includes the inorganic and organic solids mentioned above but not the dissolved salts. This is because suspended solids are operationally defined as matter retained by a filter of 45 µm pore size. The type and concentration of suspended particulate matter controls the turbidity of water (along with dissolved salts). Anthropogenic sources of suspended solids include stormwater runoff, sewage discharges and industrial wastes.

Although turbidity generally increases when the amount of suspended particulate matter increases, and there is consequently an often strong relationship between these parameters, this is not always the case. Poor relationships may come about because the total weight of particles in suspension is a direct function of their number, size and specific gravity, but turbidity is a direct function of the number, surface area and refractive index of the particles but an inverse function of their size. Dissolved substances, which are not part of the suspended solids load, affect turbidity but not the suspended solids concentration as they pass through a 45 µm pore size filter. This may

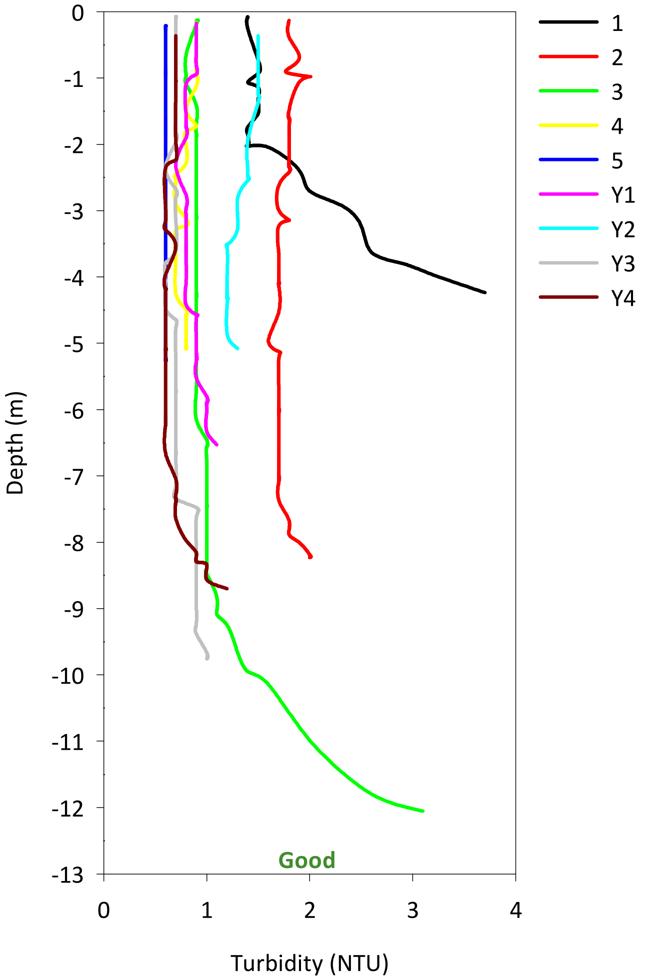

Figure 11. Turbidity profiles for the water column in and near the Port of Mossel Bay on the 19th of February 2013.

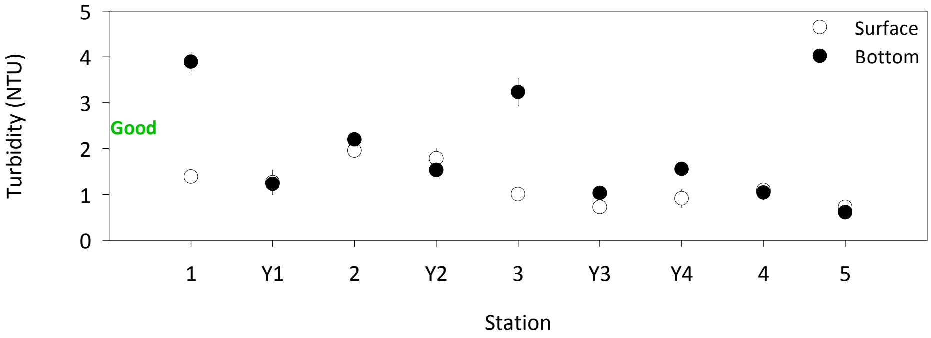

Figure 12. Comparison of the average (± standard deviation) turbidity of surface and bottom waters in and near the Port of Mossel Bay on the 19th of February 2013.

contribute to a poor relationship between turbidity and total suspended solids concentrations.

Turbidity and total suspended solids have several adverse ecological effects. Turbidity reduces the distance that light penetrates into the water column. Since aquatic plants are reliant on light for photosynthesis, this reduces the depth of the euphotic zone, that is, the depth of the water column in which photosynthesis is possible. The deposition of suspended material from the water column can alter the composition of sediment, increasing the proportion of fine particles and clogging interstitial spaces. This can lead to shifts in the composition of benthic invertebrate communities that show a dependence on sediment of a specific grain size composition. The fine particles can also smother these communities and lead to the clogging of the feeding apparatus of filter feeders. Line-of-sight predators, such as piscivorous fish and birds, are also vulnerable to high suspended solids loads.

Profiles of turbidity for the water column in and near the Port of Mossel Bay are presented in Figure 11, while a comparison between surface and bottom waters is presented in Figure 12. The turbidity through the water column at all stations was very low, usually <2 NTU, and generally varied little between stations. A turbidity <2 NTU is indicative of very clear water. There were small increases in turbidity in the bottom part of the water column at stations 1 and 3, but it is not possible to speculate on the possible causes of these increases.

Total suspended solids concentrations in surface waters at each station are presented in Figure 13. The total suspended solids concentration at all stations was low, consistent with the low turbidity.

Water Quality Assessment: The South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) state that turbidity should not reduce the depth of the euphotic zone by more than 10% of the background level measured at a comparable control station. It is difficult to identify control stations within ports because of the inherent potential for anthropogenic impacts and disturbances within these environments. It is also not suitable to use a control station in the marine environment since this environment can be expected to naturally differ in terms of the physical and chemical characteristics of the water column and sediment compared to port environments. Apart from these complexities, scientists from the Coastal Systems research group of the CSIR consider the turbidity guideline of the South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) to be overly restrictive in situations where turbidity is low. For example, a 10% change to a background turbidity of 10 NTU amounts to 1 NTU. Whether such a small change is ecologically meaningful is debatable. Furthermore, it would be extremely difficult to attribute a change of as little as 1 NTU to an anthropogenic activity when it is considered the turbidity of the water column in ports frequently varies naturally through the water column at ranges greater than 1 NTU, and in an often unpredictable manner. Consequently, scientists from the Coastal Systems research group of the CSIR defined water quality classification criteria for turbidity as:

Good: ≤10 NTU
Fair: >10 - ≤20 NTU
Poor: >20 NTU

Based on these criteria surface and bottom water quality at all stations was classified good (Figures 10 and 11; see report card in section 5).

The South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) state that the concentration of suspended solids should not be increased by more than 10% of the background level. This guideline and its application in sheltered estuarine embayments and ports present the same problems as those discussed for turbidity. Consequently, scientists from the Coastal Systems research group of the CSIR defined water quality classification criteria for total suspended solids as:

Good: ≤20 $mg.l^{-1}$
Fair: >20 - ≤40 $mg.l^{-1}$
Poor: >40 $mg.l^{-1}$

Based on these criteria surface and bottom water quality at all stations was classified good (Figure 13; see report card in section 5).

4.6. Faecal indicator bacteria

There are two significant microbial groups in marine waters: microbes from animal and human wastes and environmental microorganisms. Environmental microorganisms are ubiquitous and occur in high numbers in coastal waterbodies. They fulfil essential roles in aquatic systems, such as the cycling of nutrients, energy and carbon, and are thus a fundamental component of a healthy aquatic environment. In contrast, there are undesirable pathogenic microorganisms. The primary reasons for measuring for pathogenic microorganisms in water quality monitoring programmes are twofold, namely to determine whether there are sources of recent faecal contamination (including from effluent discharge) and to determine potential health hazards posed by these organisms to human users of the waterbody.

Due to the fact that it is difficult and expensive to isolate, culture and identify many pathogens, indicator microbes are used to define microbiological water quality. The indicator

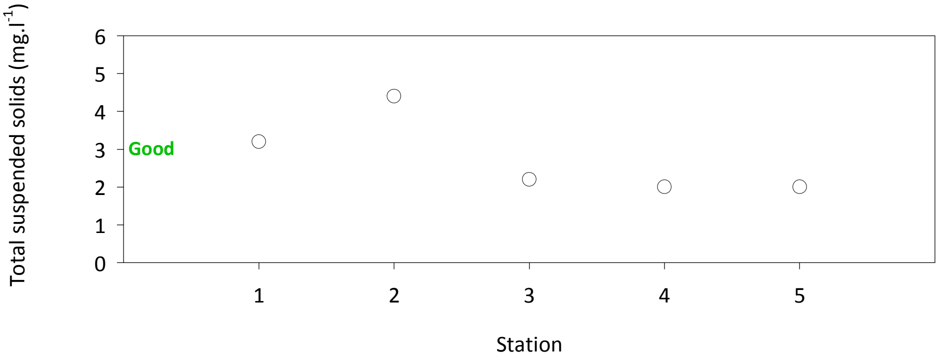

Figure 13. Total suspended solids concentrations in surface waters in and near the Port of Mossel Bay on the 19th of February 2013.

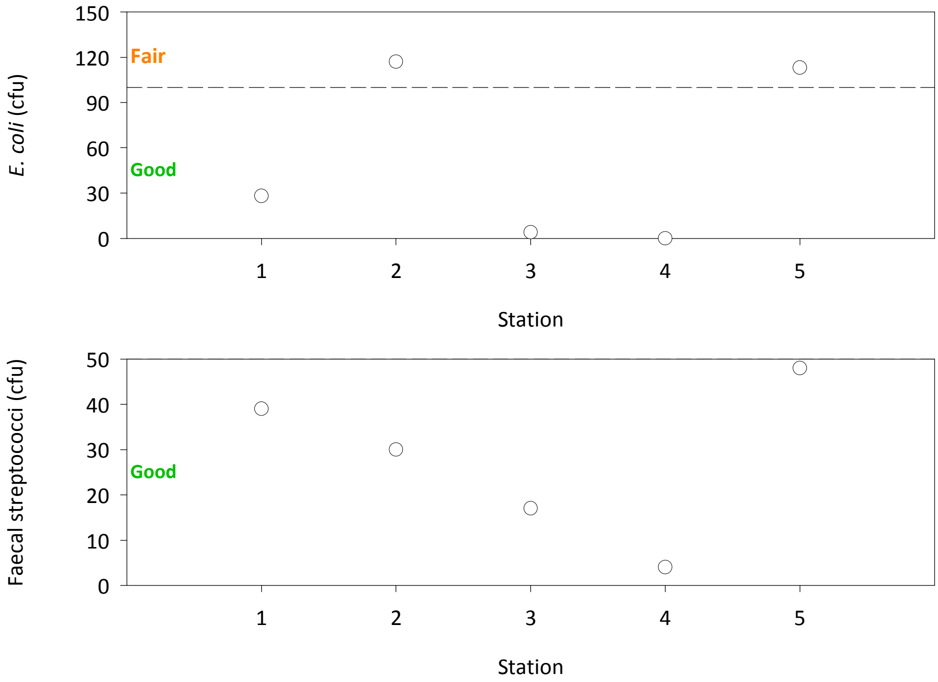

Figure 14. Faecal indicator bacteria colony forming unit counts for surface waters in and near the Port of Mossel Bay on the 19th of February 2013. The horizontal dashed line denotes the delineation between good and fair water quality as defined by scientists from the Coastal Systems research group of the CSIR (see text for further information).

microbes are indicators of the risk of more dangerous pathogens that commonly cause gastrointestinal, eye, ear, nose and throat infections. Examples include viruses, bacteria including *Salmonella* and hepatitis, and protozoa such as *Cryptosporidium* and *Giardia*. These pathogens can be taken up through ingestion, inhalation or breaks in the skin.

The indicator microbes analysed for in the survey described in this report were *Escherichia coli* (*E. coli*) and faecal streptococci. *E. coli* is a major subset of faecal coliforms, comprising about 97% of all coliform bacteria in the intestinal tract of humans and other warm blooded animals (i.e. mammals and birds). Although some faecal coliforms may be of environmental origin, they are widely used as an indicator of recent faecal contamination. However, they die off more rapidly in marine waters than some other microorganisms, such as viruses and protozoa, and it is for this reason that longer lived faecal streptococci were measured. Faecal streptococci also occur in the faeces of humans and other animals. They are less abundant than faecal coliforms in humans, but in other animals this may be reversed. In an epidemiological study performed by the USEPA (1983), enterococci exhibited the strongest correlation to swimming associated gastroenteritis in marine waters. The stronger correlation may be due to enterococci's ability to survive longer than coliforms, similar to the pathogens of concern. In addition, faecal coliforms are sometimes detected where other faecal contamination is absent, possibly resulting in inaccurate assessments of recreational safety.

E. coli and faecal streptococci bacteria were present in surface water at all stations with the exception of station 4, where *E. coli* bacteria were not detected (Figure 14). Colony forming unit counts of *E. coli* bacteria at stations 2 and 5 were high. Faecal streptococci bacteria colony forming unit counts were moderately high in the inner part of the port, and then decreased toward the marine environment. This said, the count at station 5 in the marine environment was the highest for any station (Figure 14).

High bacteria colony forming unit counts at station 2 were also evident in the summer survey performed in 2011 (CSIR 2011) and suggest there is a persistent source of faecal indicator bacteria to this area of the port. High colony forming unit counts were detected at station 1 in the winter survey of 2011, which was different to the summer surveys in 2011 and obviously also to 2013. There is some uncertainty whether the source of the bacteria in the port is anthropogenic or natural, because seals frequent the port and are a potential source of bacteria. The high bacteria colony forming unit counts at station 5 are clearly not related to sources in the port.

Water Quality Assessment: For the purposes of the survey described in this report, scientists from the Coastal Systems research group of the CSIR defined water quality classification criteria for *E. coli* bacteria as:

Good: ≤100 cfu per 100 ml
Fair: >100 - ≤200 cfu per 100 ml
Poor: >200 cfu per 100 ml

and for faecal streptococci bacteria as:

Good: ≤50 cfu per 100 ml
Fair: >50 - ≤100 cfu per 100 ml
Poor: >100 cfu per 100 ml

Water quality in terms of *E. coli* bacteria colony forming unit counts at stations 2 and 5 was classified fair, but good at other stations (Figure 14; see report card in section 5). Water quality in terms of faecal streptococci bacteria colony forming unit counts was classified good at all stations, although the count at start 5 was only marginally lower than the delineation between a good and fair water quality classification (Figure 14; see report card in section 5).

4.7. Nutrients

Nutrients are essential to the productivity of coastal waters since they regulate the growth of aquatic plants, including submerged aquatic macrophytes (e.g. seagrasses), macroalgae (e.g. seaweeds) and microalgae (or phytoplankton). However, when excessive concentrations of nutrients are introduced to a waterbody this can lead to eutrophication. Eutrophication is widely regarded as one of the most significant threats facing coastal systems throughout the world. Eutrophication is a complex process, with no single cause or outcome, but in its simplest form it involves the excessive stimulation of macro- and microalgal growth by elevated nutrient concentrations. This can include the formation of harmful microalgal blooms (e.g. red tide), which excrete toxins that pose a health risk to humans and/or biota. When the nutrients stimulating excessive macro- and microalgal growth have been depleted the macro- and microalgae die and sink to the bottom, where they are decomposed by oxygen consuming bacteria. The bacteria may consume all of the oxygen in the water column, leading to the development of hypoxia and anoxia and attendant adverse effects (see below). Similarly, high macro- and microalgal production can deplete oxygen in the water column at night, when macro- and microalgae consume rather than produce oxygen.

The most prominent primary symptoms of eutrophication are increased primary production, increased biomass of macro- and microalgae, shifts in the species composition of microalgae, and shifts from long-lived macroalgae to short-lived nuisance species (i.e. harmful microalgae). The most prominent secondary symptoms are oxygen depletion in bottom waters, harmful microalgal blooms, and changes in the species composition and biomass of the benthic invertebrates (Richardson and Jorgensen 1996, Bricker et al. 1999). Eutrophication in coastal areas can have far-reaching consequences, including fish-kills, loss or degradation of seagrass beds, nuisance odours, and

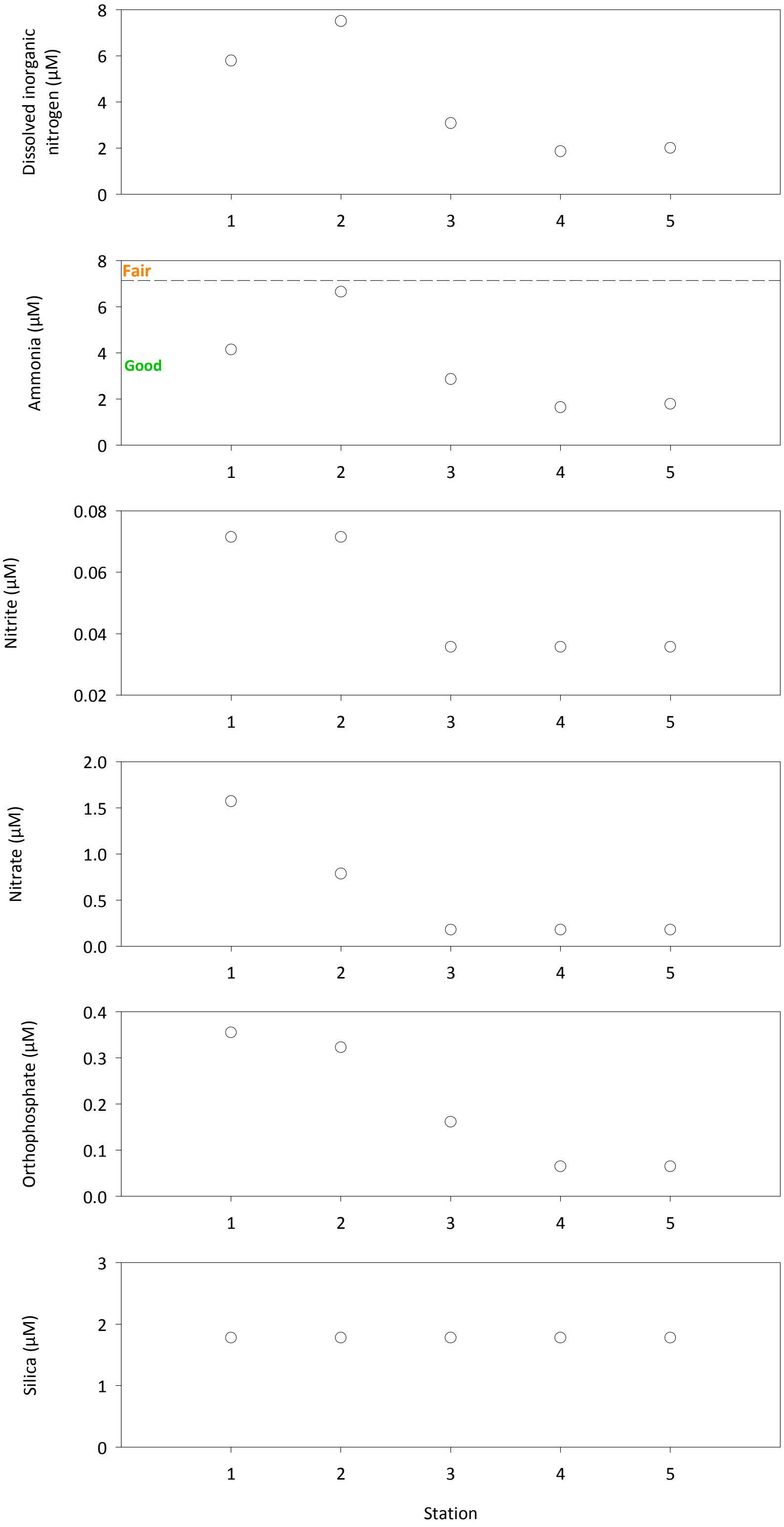

Figure 15. Nutrient concentrations in surface waters in and near the Port of Mossel Bay on the 19th of February 2013. The horizontal dashed line in the ammonia plot denotes the delineation between good and fair water quality as defined by scientists from the Coastal Systems research group of the CSIR (see text for further information).

impacts on human and marine mammal health though exposure to harmful microalgal blooms and poor water quality.

Although an assessment of (the potential for) eutrophication is an important reason for measuring nutrient concentrations in water quality monitoring programmes, there are other reasons. Ammonia is toxic and is measured, in part, to determine whether concentrations are so high that these may be directly toxic to biota. Sewage is typically rich in nitrogen and phosphorous and elevated concentrations of these nutrients provide a line of evidence for effluent discharge impacts,

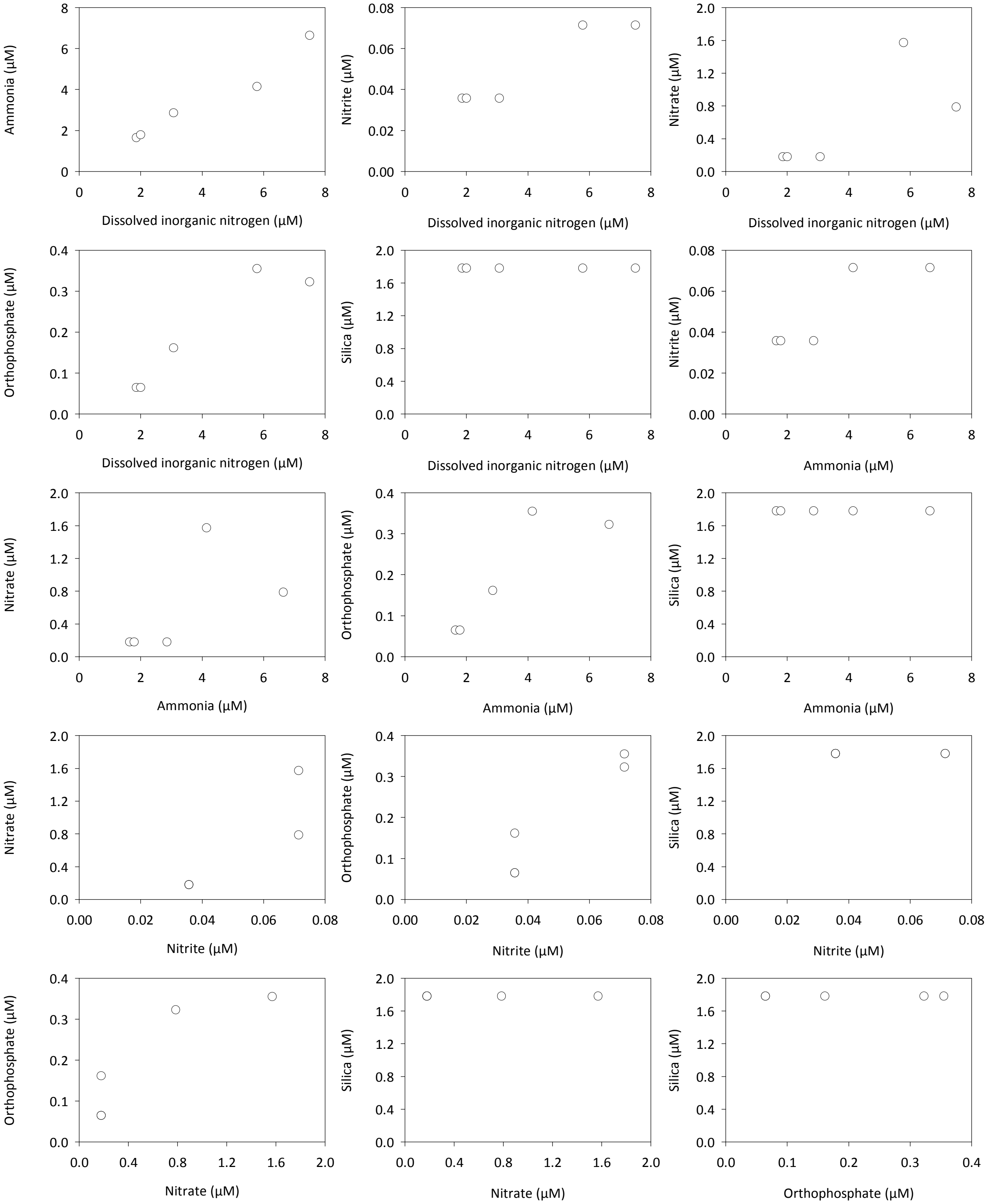

Figure 16. Relationship between nutrient concentrations in surface waters in and near the Port of Mossel Bay on the 19th of February 2013.

especially when high nutrient concentrations coincide with high colony forming unit counts of faecal indicator bacteria. Runoff from fertiliser-rich agricultural land and septic tank seepage are additional anthropogenic sources of nitrogen. Silica is measured because, apart from its importance as a nutrient source for macro- and microalgal growth, it provides an indicator of freshwater input since silica concentrations in freshwater are far higher than in estuarine and marine waters.

Concentrations of nutrients in surface waters in and near the Port of Mossel Bay are presented in Figure 15. With the exception of ammonia, nutrient concentrations were very low. In fact, the concentrations of most nutrients at most stations

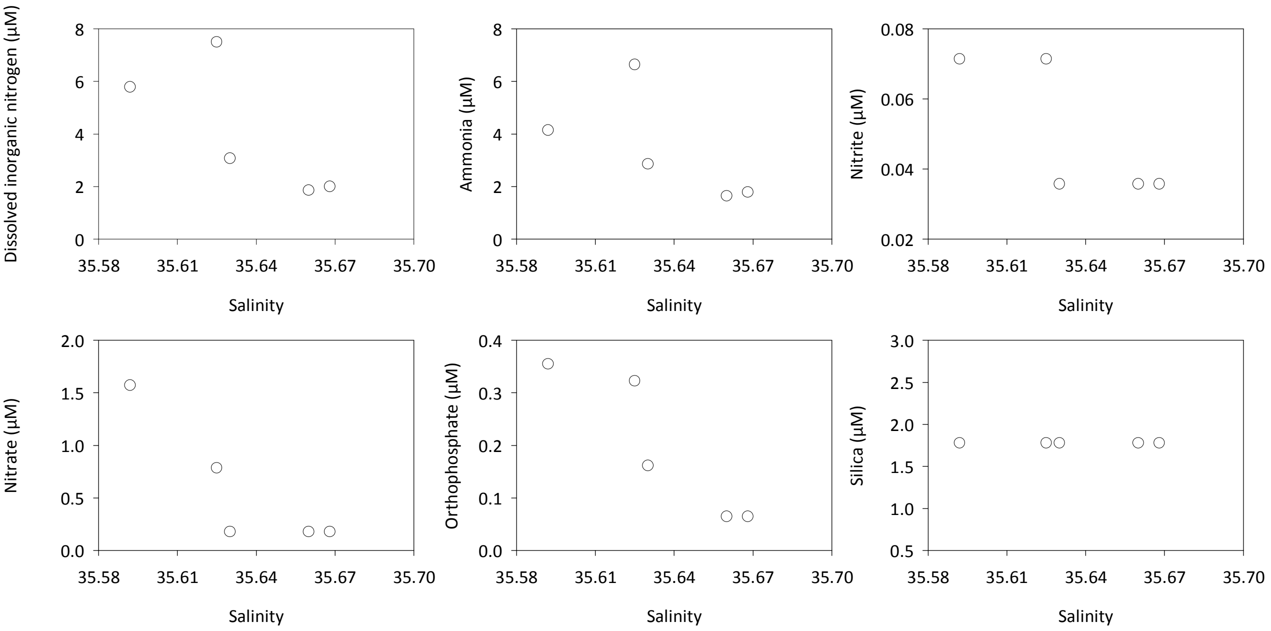

Figure 17. Relationship between salinity and nutrient concentrations in surface waters in and near the Port of Mossel Bay on the 19th of February 2013.

were below the method detection limit. Nevertheless, nutrient concentrations generally progressively decreased from the inner part of the port to the marine stations. This suggests there was a source of nutrients to the inner part of the port and that the input was being progressively diluted by mixing with nutrient poor marine water. This was also the trend for surveys performed in 2011 (CSIR 2011), implying that there is a persistent nutrient source to the port. This trend for nutrients is thus opposite to the generally progressive increase in salinity and pH from the inner part of the port to the marine stations and suggests a common link between the factor/s causing spatial variation in these parameters.

Useful approaches for interpreting nutrient concentrations in coastal waters are to examine the nature of relationships between concentrations of different nutrients on the one hand and between nutrient concentrations and salinity on the other.

If the concentrations of different nutrients are strongly positively correlated then this suggests they had the same source and were being proportionately consumed or diluted within the waterbody. Concentrations of most nutrients in surface waters were not especially strongly positively correlated. This was at least partly due to the concentrations of most nutrients at most stations being below the method detection limit (Figure 16). Ammonia concentrations were strongly positively correlated to the dissolved inorganic nitrogen concentration due to the fact that ammonia was by far the dominant form of inorganic nitrogen present. Orthophosphate and ammonia concentrations were also relatively strongly positively correlated. This suggests that ammonia and orthophosphate had the same source/s. The trend in concentrations suggests the source was near station 1.

Ammonia was also the dominant form of dissolved inorganic nitrogen at all stations in surveys performed in 2011 (CSIR 2011). This is usually not the case for nearshore marine waters that have minimal anthropogenic influence, where nitrate is usually the dominant form. In fact, even in port waters nitrate is usually the dominant form of nitrogen - this was, with few exceptions, the case in other ports for the summer survey. It is difficult to explain why ammonia was the dominant form of nitrogen in the Port of Mossel Bay, but a source of ammonia to the port is implied by the result. A possible source is refrigeration systems used to produce ice for the storage of fish and products – as mentioned previously, in 2011 fieldworkers observed an ‘icy’ water discharge into the port.

Salinity-nutrient concentration plots, or mixing diagrams, provide an understanding of whether nutrients are behaving conservatively, that is, whether physical mixing and dilution between nutrient rich freshwaters and nutrient poor marine waters is the predominant factor controlling their concentration. If so, then there is usually a strong inverse relationship between salinity and nutrient concentrations. If the relationship has a convex shape, however, then this is indicative that nutrients are being generated within the system through, for example, the decomposition of organic matter, or that nutrients are being introduced from an anthropogenic source, such as effluent or stormwater discharge. If the relationship has a concave shape, then this is indicative that nutrients are being consumed within the system (e.g. through uptake by primary producers) at a rate faster than the supply. Salinity-nutrient concentration plots for surface waters in and near the Port of Mossel Bay are presented in Figure 17. With the exception of orthophosphate the concentrations of nutrients were only reasonably inversely correlated to salinity. The highest nutrient concentrations were, nevertheless, consistently measured in the lowest salinity water. This suggests that nutrients were introduced to the port in the vicinity of station 1 (and possibly also station 2) by the same source that influenced water column salinity, and were being proportionally diluted with tidally entrained nutrient poor marine water. It also implies that there were no significant sources or consumption of nutrients in the 'middle' reach of the port.

Water Quality Assessment: The South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) provide a guideline for ammonia of 42.86 µM (0.6 mg.l^{-1}), but not for other nutrients. Scientists from Coastal Systems research group of the CSIR are of the opinion that this guideline is too high (i.e. under-protective), and consequently defined classification criteria for ammonia as:

Good:	≤7.14 µM
Fair:	>7.14 - ≤42.86 µM
Poor:	>42.86 µM

Ammonia concentrations in surface water at all stations were below 7.14 µM and water quality was consequently classified good (Figure 15; see report card in section 5). This said, the ammonia concentration in surface water at station 2 was only marginally below the delineation between a good and fair classification.

Since nitrogen and phosphorous present risks in terms of eutrophication, many jurisdictions have defined guidelines for these nutrients in coastal waters. It is, however, difficult to simply adopt guidelines derived for other regions of the world to South African conditions because the manner in which the systems function may be fundamentally different. A review of nutrient guidelines shows that they differ significantly from one jurisdiction to another. For a National Coastal Condition assessment, the United States Environmental Protection Agency considered that for coastal waters along the east coast of the conterminous United States of America, dissolved inorganic nitrogen concentrations <7.14 µM, between 7.14 - 35.71 µM and >35.71 µM were indicative of good, fair and poor water quality respectively. For dissolved inorganic phosphorous, concentrations <0.32 µM, between 0.32 - 1.61 µM and >1.61 µM were considered indicative of good, fair and poor water quality respectively. If these criteria are used to classify water quality in the Port of Mossel Bay then water quality at all stations would be classified good. Water quality according the inorganic phosphorous concentration would also be classified good at all but station 1, where it would be classified fair (and then only because the orthophosphate concentration marginally exceeded the delineation between a good and fair classification).

4.8. Chlorophyll-*a*

Chlorophyll-*a* is the molecule that mediates photosynthesis in most primary producers. Chlorophyll-*a* is used as a surrogate for microalgal biomass and abundance and is measured in water quality monitoring programmes for two inter-related reasons.

First, when the biomass of microalgae in the water column is high this can elevate dissolved oxygen concentrations during the daytime, due to the photosynthetic production of oxygen. High dissolved oxygen concentration and saturation is thus usually a reliable direct indicator of high microalgal biomass and usually an indirect indicator

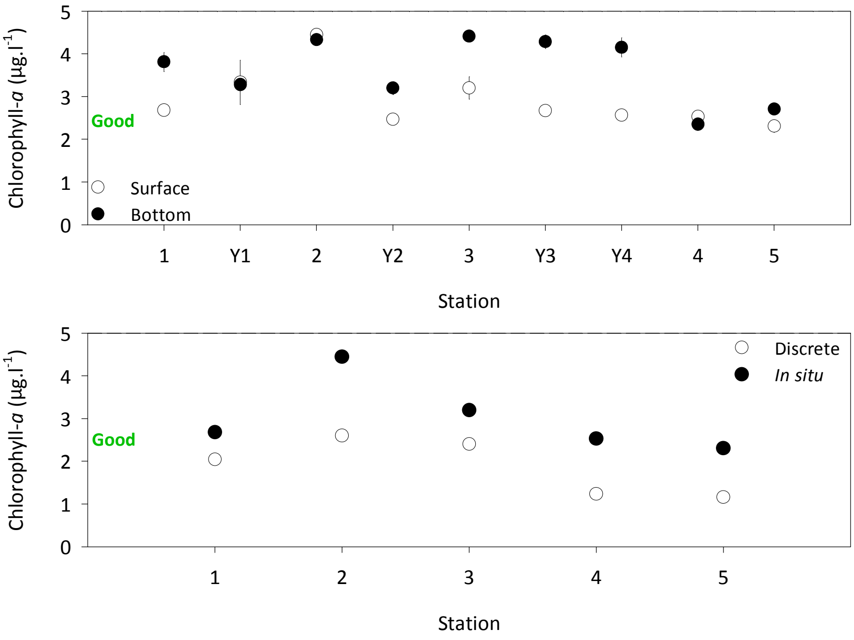

Figure 18. Average (± standard deviation) chlorophyll-*a* concentrations *in situ* in surface and bottom waters (top) in and near the Port of Mossel Bay on the 19th of February 2013, and a comparison of concentrations in discrete surface water samples and at the surface *in situ* (bottom).

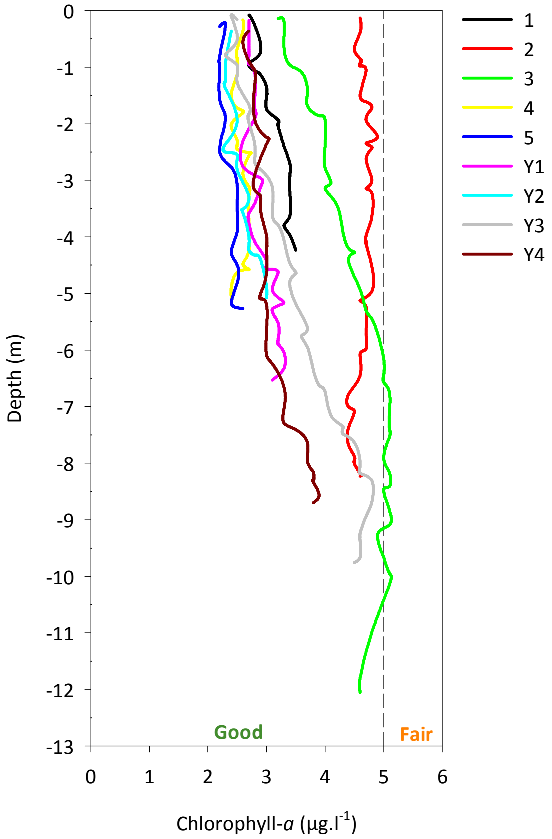

Figure 19. Chlorophyll-*a* concentration profiles for the water column in and near the Port of Mossel Bay on the 19th of February 2013. The vertical dashed line denotes the delineation between good and fair water quality as defined by scientists from the Coastal Systems research group of the CSIR (see text for further information).

of high nutrient inputs. The significance of high chlorophyll-*a* and dissolved oxygen concentration in the daytime is that they highlight the potential for low dissolved oxygen concentrations at night, when the microalgae cease to photosynthesise and consume rather than produce oxygen. In most waterbodies dissolved oxygen concentration is lowest just before dawn, since microalgae (and all other biota) have been consuming oxygen throughout the night.

Second, while high nutrient concentrations are an important driver of eutrophication in coastal waters, high nutrient concentrations are not an obligatory indicator of eutrophication. Low nutrient concentrations also do not necessarily indicate the absence of eutrophication. The reason is that macro- and microalgae are able to rapidly take up dissolved inorganic nitrogen and phosphorous that, within timescales of hours to days, can reduce surface water nutrient concentrations to near detection limits yet the system may still be degraded. Thus, depending on the time scale of nutrient delivery to a waterbody versus biological response, ambient nutrient concentrations often reflect the inventory of nutrients left over or that which has been recycled into organic forms. For this reason ambient nutrient concentrations are often not significantly correlated to biological response indicators (e.g. Kennison et al. 2003). Identifying whether a waterbody is eutrophic is more reliably assessed by the measurement of microalgal biomass (i.e. chlorophyll-*a* concentration).

It is important to note that high chlorophyll-*a* concentration is not necessarily 'bad' - it is the persistence of elevated concentrations that is cause for concern. Excessive macro- and microalgal growth often leads to poor water quality, noxious odours, oxygen depletion, human health problems and fish kills. It may also be linked to harmful (toxic) microalgal blooms.

Chlorophyll-*a* concentrations in surface and bottom waters in and near the Port of Mossel Bay were not especially low or high (Figure 18 and 19). The highest concentrations were evident at stations 2 and 3. Thus concentrations in the port were generally slightly higher than at the marine stations.

Water Quality Assessment: The South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) do not provide a guideline for chlorophyll-*a* concentration. For the purposes of the survey described in this report scientists from the Coastal Systems research group of the CSIR defined water quality classification criteria for chlorophyll-*a* as:

Good: <5 $\mu g.l^{-1}$
Fair: 5 - 20 $\mu g.l^{-1}$
Poor: >20 $\mu g.l^{-1}$

Water quality from a chlorophyll-*a* concentration perspective was classified good at all stations (Figures 18 and 19; see report card in section 5). This said, based on *in situ* measurements the concentration though part of the water column at station 3 slightly exceeded the delineation between a good and fair water quality classification. However, as mentioned previously *in situ* measurements provided a slight overestimate of chlorophyll-*a* concentration and nothing should be read into this exceedance.

4.9. Metals

Many metals, including iron, copper and zinc, are essential to the efficient physiological functioning of living tissue, and regulate biochemical processes. These metals are, however, only required in trace amounts and are toxic at elevated concentrations. Other metals, including mercury, have no known biological function and can be toxic at low concentrations. The toxic and carcinogenic effects of some metals, and the potential for mercury to biomagnify, provide the main reason for monitoring metal concentrations in environmental quality monitoring programmes.

As stated previously, metals can be acutely or chronically toxic to biota. They can also cause reproductive problems. Mercury (in its methylated, or organic form) can biomagnify and thus becomes increasingly concentrated in higher trophic level organisms (such as piscivorous fish). This can make some biota, such as fish and shellfish, collected from polluted areas unsafe for human consumption.

As stated previously, metals can be acutely or chronically toxic to biota. They can also cause reproductive problems, while mercury (in its methylated, or organic form) can biomagnify and thus becomes increasingly concentrated in higher trophic level organisms (such as piscivorous fish). This can make some biota, such as fish and shellfish, collected from polluted areas unsafe for human consumption.

Concentrations of most metals were present at

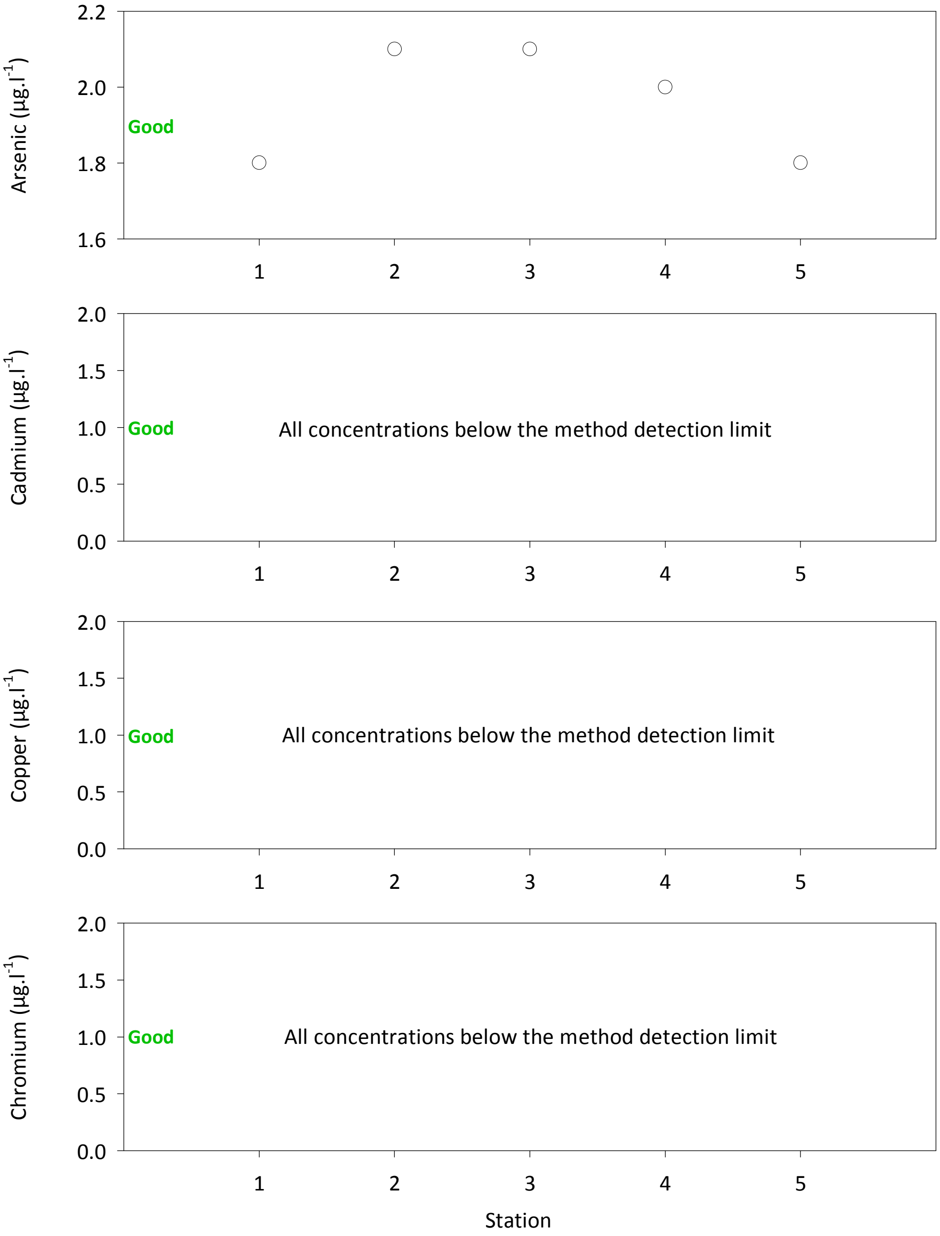

Figure 20. Metal concentrations in surface waters in the in and near the Port of Mossel Bay on the 19th of February 2013. Absent data points reflect that the concentration was below the method detection limit.

concentrations below the method detection limit. Where not, concentrations were very low (Figure 20).

Water Quality Assessment: For the purposes of the survey described in this report scientists from the Coastal Systems research group of the CSIR defined classification criteria for metals based on the South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) as:

Good: ≤relevant guideline
Fair: ≤2 x relevant guideline
Poor: >2 x relevant guideline

The concentrations of all metals were below relevant guidelines and water quality was consequently classified good at all stations (Figure 20; see report card in section 5).

4.10. Hydrocarbons

Hydrocarbons are compounds that contain only carbon and hydrogen. The term total petroleum hydrocarbons is used to describe a broad range of compounds originally derived from crude oil, ranging from harmless n-alkanes to toxic and carcinogenic aromatic compounds (e.g. benzo(a)pyrene). Since there are so many hydrocarbon compounds in use it is not practical to measure all. Total petroleum hydrocarbons provide a useful measure of the presence of hydrocarbons

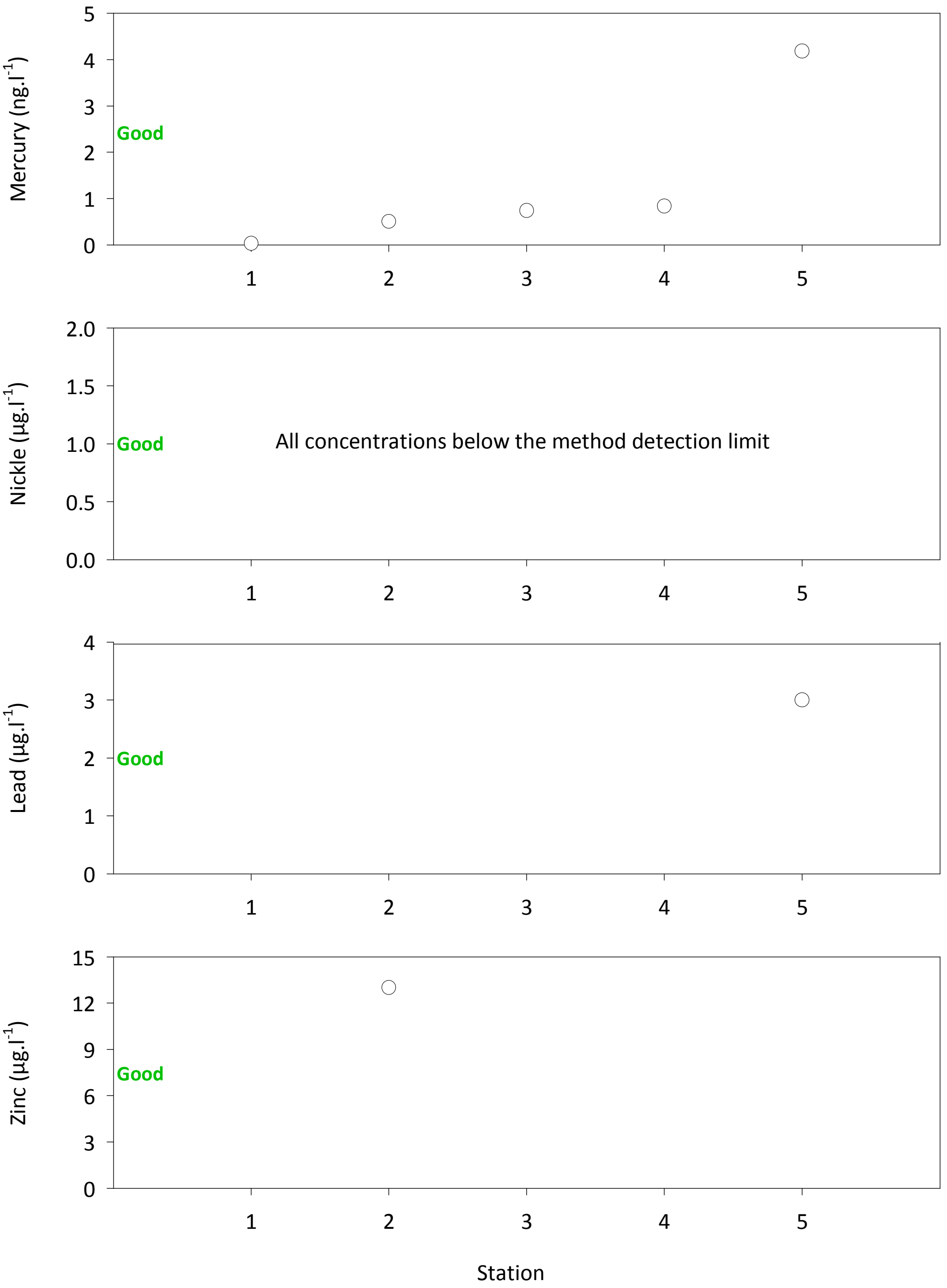

Figure 20 continued. Metal concentrations in surface waters in and near the Port of Mossel Bay on the 19th of February 2013. Absent data points reflect that the concentration was below the method detection limit.

in the natural environment. Total petroleum hydrocarbon concentrations cannot, however, be used to estimate ecological and human health risk since identical concentrations may have a very different compositions and hence pose a very different risks. The measurement of total petroleum hydrocarbons is thus used as an indicator of gross hydrocarbon contamination. If gross contamination is identified, then a more detailed (and more expensive) assessment of the actual types of hydrocarbons present is usually undertaken.

Polycyclic aromatic hydrocarbons, a subset of total petroleum hydrocarbons, are cause for concern because of their persistence and the potential carcinogenicity, mutagenicity and teratogenicity of higher molecular weight isomers and toxicity of the lower molecular weight isomers (Haynes and Johnson 2000). In particular, benzo(a)pyrene has been identified as being highly carcinogenic (Kuo et al. 1998, Wang et al. 2002). Polycyclic aromatic hydrocarbons have very low solubility (i.e. high hydrophobicity) and this generally results in low concentrations in the water column and higher concentrations in sediment. Most isomers also have a high bioaccumulation potential. However, polycyclic aromatic hydrocarbons are less prone to bioaccumulation or biomagnification than chlorinated compounds (e.g. polychlorinated biphenyls), partly because of metabolic degradation of in top predators and their prey (MacDonald and Bewers 1996).

BTEX is the term used for benzene, toluene, ethylbenzene and xylene, which are volatile aromatic compounds typically found in petroleum products (e.g. petrol, diesel).

BTEX concentrations in surface waters at all stations were below the method detection limit (Appendix 4). Only a single petroleum hydrocarbon carbon range equivalent was detected at a concentration exceeding the method detection limit, and then at a very low concentration (Appendix 4). Only a single polycyclic aromatic hydrocarbon isomer was present at a concentration exceeding the method detection limit, and here too at a very low concentration (Appendix 4).

Water Quality Assessment: Because there are no local water quality guidelines, and the few international guidelines for BTEX, total petroleum hydrocarbons and polycyclic aromatic hydrocarbons are considered unreliable, professional judgment must be used to classify water quality based on the presence of these chemicals. Based on the complete or almost complete absence of BTEX, total petroleum and polycyclic aromatic hydrocarbons in surface waters, and when present the low concentrations, water quality at all stations was classified good (see report card in section 5).

5. Environmental Quality Report Card

The water quality report card is presented in Table 2. Attention should be given to the limitations presented in section 3.4 regarding a report card approach to assessing environmental quality.

6. Conclusions

Water quality in and near the Port of Mossel Bay during the 2013 summer survey was good, and was by some way the best for any port surveyed in the summer of 2013. The most significant impairment was due to elevated faecal indicator bacteria counts at one station in the port. If not for these high bacteria counts then water quality at this station would have been considered excellent. Anomalies for pH and dissolved oxygen at two stations, and ammonia concentrations that were high relative to other nutrients imply some anthropogenic impairment of water quality in the port. However, the magnitude of impairment was minimal and does not change the conclusion regarding the water quality classification.

7. Recommendations

There was evidence that a discharge was influencing water quality in the port. The source and quality of the discharge should be identified and monitored.

From a programmatic perspective the monitoring of BTEX, total petroleum hydrocarbon and polycyclic aromatic hydrocarbon concentrations in surface water samples should be discontinued if the concentrations of these chemicals are also low in the winter survey. Most organic contaminants, for various reasons, tend not to remain in solution but rather settle from the water column and accumulate in sediment. The findings of the survey discussed in this report and surveys performed in 2011 (CSIR 2011) show that hydrocarbon concentrations in the water column were invariably low, and usually below the method detection limit. The effort and finances expended on monitoring these chemicals in water samples could be used to increase the suite of chemicals monitored (e.g. by adding polychlorinated biphenyls) in sediment and biological tissue. These so-called ‘fate compartments’ are where organic chemicals are more likely to accumulate if they are frequent but low level contaminants of the water column, and where these chemicals are more likely to exert adverse ecological effects.

8. References

BREITBURG DL (2002) Effects of hypoxia, and the balance between hypoxia and enrichment, on coastal fishes and fisheries. *Estuaries* 25: 767-781.

BRICKER SB, CLEMENT CG, PIRHALLA DE, ORLANDO SP and FARROW DRG (1999) *National estuarine eutrophication assessment effects of* *nutrient enrichment in the nation's estuaries*. NOAA, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science. Silver Spring, MD.

CCME (1999) *Canadian environmental quality guidelines*. Canadian Council of Ministers of the Environment. Winnipeg, Canada.

CSIR (2011) Long-Term Ecological Monitoring for the Port of Mossel Bay: Surveys made in 2011. CSIR Report CSIR/NRE/ECOS/ER/2011/ 0119/C+.

DAVIS JC (1975) Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. *Journal of Fisheries Research Board Canada* 32: 2295-2332.

DIAZ RJ and ROSENBERG R (1995) Marine benthic hypoxia: A review of its ecological effects and the behavioral responses of benthic macrofauna. *Oceanography and Marine Biology Annual Review 33*: 245-303.

DWAF (Department of Water Affairs and Forestry) (1995a) *South African Water Quality Guidelines for Coastal Marine Waters. Volume 1: Natural Environment.* Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry) (1995b) *South African Water Quality Guidelines for Coastal Marine Waters. Volume 2: Recreational Use.* Pretoria, South Africa.

HALLOCK D (2002) *A water quality index for Ecology's stream monitoring program*. Environmental Assessment Program, Washington State Department of Ecology.

HAYNES D and JOHNSON JE (2000) Organochlorine, heavy metal and polyaromatic hydrocarbon pollutant concentrations in the Great Barrier Reef (Australia) environment: a review. *Marine Pollution Bulletin* 41: 267-278.

KENNISON R, KAMER K and FONG P (2003) *Nutrient dynamics and macroalgal blooms: A comparison of five southern California estuaries*. Southern California Coastal Water Research Project, Westminster, CA.

KOROLEFF F (1983) *Determination of nutrients*. In: Grasshoff K, Ehrhardt M and Kremling K (Eds), *Methods of seawater analysis*. Verlag,.

KUO CY, CHENG YW, CHEN CY and LEE H (1998) Correlation between the amounts of polycyclic aromatic hydrocarbons and mutagenicity of airborne particulates samples from Taichung City, Taiwan. *Environmental Research* **78**: 43-49.

MACDONALD RW and BEWERS JM (1996) Contaminants in the Arctic marine environment: priorities for protection. *ICES Journal of Marine Science* 53: 537-563.

MELWANI A and THOMPSON B (2007) *The influence of chemical and physical factors on macrobenthos in the San Francisco Estuary*. San Francisco Estuary Institute Contribution No. 543.

NIXON SW (1995) Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia* 41: 199-219.

PEARSON TH and ROSENBERG R (1978) Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Revue* 163: 229-311.

RICHARDSON K and JORGENSEN BB (1996) Eutrophication: Definition, history, and effects. In: Jorgensen BB and Richardson K (Eds), *Eutrophication in coastal marine ecosystems*. American Geophysical Union.

SKIRROW G (1965) The dissolved gases-carbon dioxide. In: Riley JP and Skirrow G (Eds), *Chemical oceanography*. Academic Press, London.

SUMMERS JK and ENGLE VD (1993) Evaluation of sampling strategies to characterize dissolved oxygen conditions in northern Gulf of Mexico estuaries. *Environmental Monitoring and Assessment* 24: 219-229.

TAYLOR DL and EGGLESTON DB (2000) Effects of hypoxia on an estuarine predator-prey interaction: foraging behavior and mutual interference in the blue crab *Callinectes sapidus* and the infaunal clam prey *Mya arenaria*. *Marine Ecology Progress Series* 196: 221-237.

USEPA (2001) *Nutrient criteria technical guidance manual: estuarine and coastal marine waters.* EPA-822-B-01-003. Office of Water, Office of Science and Technology, Washington, D.C.

USEPA (2003) *Ambient water quality criteria for dissolved oxygen, water clarity and chlorophyll a for the Chesapeake Bay and its tidal tributaries*. EPA 903-R-03-002. US EPA Region III, Annapolis, MD, Region III Water Protection Division, Philadelphia, PA, and Office of Water, Office of Science and Technology, Washington, DC.

WANG L, YANG Z, NIU J and WANG J (2009) Characterization, ecological risk assessment and source diagnostic of polycyclic aromatic hydrocarbons in water column of the Yellow River Delta, one of the most plenty biodiversity zones in the world. *Journal of Hazardous Materials* 169: 460-465.

WANNAMAKER CM and RICE J (2000) Effects of hypoxia on movements and behavior of selected estuarine organisms from the southeastern United States. *Journal of Experimental Marine Biology and Ecology* 249: 145-163.

WETZEL RG (1983) *Limnology*. CBS College Publishing, Philadelphia.

ZHANG J-Z and BERBERIAN GA (1997) *Determination of dissolved silicate in estuarine and coastal waters by gas segmented flow colorimetric analysis*. United States Environmental Protection Agency Method 366.0.

Table 2. Report card for water quality in and near the Port of Mossel Bay for a summer survey performed on the 19th of February 2013.

		Station								
Category	**Parameter**	**1**	**2**	**3**	**4**	**5**	**Y1**	**Y2**	**Y3**	**Y4**
Conventional	pH	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢
	Turbidity	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢
	Dissolved oxygen concentration	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢
	Dissolved oxygen saturation	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢	🟢/🟢
	Total suspended solids	🟢	🟢	🟢	🟢	🟢				
Microbiological	*E. coli*	🟢	🟠	🟢	🟢	🟠				
	Faecal streptococci	🟢	🟢	🟢	🟢	🟢				
Nutrients	Ammonia	🟢	🟢	🟢	🟢	🟢				
Microalgal biomass	Chlorophyll-*a*	🟢	🟢	🟢	🟢	🟢				
Trace metals	Arsenic	🟢	🟢	🟢	🟢	🟢				
	Cadmium	🟢	🟢	🟢	🟢	🟢				
	Copper	🟢	🟢	🟢	🟢	🟢				
	Chromium	🟢	🟢	🟢	🟢	🟢				
	Mercury	🟢	🟢	🟢	🟢	🟢				
	Nickel	🟢	🟢	🟢	🟢	🟢				
	Lead	🟢	🟢	🟢	🟢	🟢				
	Zinc	🟢	🟢	🟢	🟢	🟢				
Organic chemicals	BTEX	🟢	🟢	🟢	🟢	🟢				
	Polycyclic aromatic hydrocarbons	🟢	🟢	🟢	🟢	🟢				
	Total petroleum hydrocarbons	🟢	🟢	🟢	🟢	🟢				

Legend

Symbol	Classification
🟢	Good
🟠	Fair
🔴	Poor
🟢/🟠	Symbol on left denotes classification for surface water and on right for bottom water.

9. Appendices

Appendix 1. Physical, chemical and biological parameter values/concentrations measured *in situ* for surface and bottom waters in and near the Port of Mossel Bay on the 19th of February 2013.

Station	Temperature (°C)	Salinity	pH	Turbidity (NTU)	Chlorophyll-*a* (µg.l^{-1})	Dissolved Oxygen Saturation (%)	Dissolved Oxygen (mg.l^{-1})
Surface							
1	21.55	35.59	8.09	1.39	2.68	94.32	6.76
2	21.39	35.62	8.13	1.95	4.45	98.20	7.06
3	21.43	35.63	8.16	1.01	3.20	103.42	7.43
4	21.55	35.66	8.17	1.09	2.53	104.47	7.48
5	21.50	35.67	8.16	0.72	2.31	102.47	7.35
Y1	21.52	35.62	8.16	1.26	3.34	103.91	7.45
Y2	21.43	35.52	8.10	1.79	2.47	89.02	6.40
Y3	21.51	35.64	8.15	0.72	2.67	104.55	7.50
Y4	21.54	35.67	8.18	0.91	2.57	103.68	7.43
Bottom							
1	21.42	35.59	8.07	3.89	3.81	90.07	6.47
2	21.33	35.62	8.12	2.20	4.33	95.78	6.89
3	20.19	35.61	8.07	4.18	4.41	83.29	6.12
4	21.54	35.65	8.17	1.04	2.35	103.82	7.44
5	21.52	35.66	8.16	0.61	2.71	102.05	7.32
Y1	21.44	35.61	8.13	1.23	3.28	97.23	6.98
Y2	21.43	35.63	8.13	1.53	3.20	96.72	6.95
Y3	21.16	35.63	8.11	1.03	4.29	95.90	6.92
Y4	21.07	35.65	8.14	1.55	4.15	95.92	6.93

Appendix 2. Nutrient, chlorophyll-*a* and total suspended solids concentrations, and faecal indicator bacteria colony forming unit counts in discrete surface water samples collected in and near the Port of Mossel Bay on the 19th of February 2013. NO_3+NO_2 = nitrate, NO_2 = nitrite, NH_3 = ammonia, PO_4 = orthophosphate, Si = silica, Chl-*a* = chlorophyll-*a*, TSS = total suspended solids, cfu = colony forming unit.

Station	NH_3 (mg.l^{-1})	NO_2 (mg.l^{-1})	NO_3+NO_2 (mg.l^{-1})	PO_4 (mg.l^{-1})	Si (mg.l^{-1})	Chl-*a* (µg.l^{-1})	TSS (mg.l^{-1})	Faecal coliforms (cfu/100 ml)	*E. coli* (cfu/100 ml)
1	0.058	0.001	0.022	0.011	<0.01	2.04	3.2	62	28
2	0.093	0.001	0.011	0.010	<0.01	2.60	4.4	255	117
3	0.040	<0.001	<0.005	0.005	<0.01	2.40	2.2	47	4
4	0.023	<0.001	<0.005	<0.004	<0.01	1.23	<2	26	0
5	0.025	<0.001	<0.005	<0.004	<0.01	1.15	<2	236	113

Appendix 3. Metal concentrations in discrete surface water samples collected in and near the Port of Mossel Bay on the 19th of February 2013. As = arsenic, Cd = cadmium, Cu = copper, Cr = chromium, Mn = manganese, Hg = mercury, Ni = nickel, Pb = lead, Zn = zinc.

Station	As (µg.l^{-1})	Cd (µg.l^{-1})	Cu (µg.l^{-1})	Cr (µg.l^{-1})	Hg (µg.l^{-1})	Mn (ng.l^{-1})	Ni (µg.l^{-1})	Pb (µg.l^{-1})	Zn (µg.l^{-1})
1	1.8	<0.5	<1	<1	<1	0.03	<1	<1	<2.5
2	2.1	<0.5	<1	<1	<1	0.51	<1	<1	13
3	2.1	<0.5	<1	<1	<1	0.74	<1	<1	<2.5
4	2	<0.5	<1	<1	<1	0.84	<1	<1	<2.5
5	1.8	<0.5	<1	<1	<1	4.18	<1	3	<2.5

Appendix 4. BTEX, polycyclic aromatic hydrocarbon and total petroleum hydrocarbon concentrations (µg.l^{-1}) in discrete surface water samples collected in and near the Port of Mossel Bay on the 19th of February 2013.

Isomer	Station				
	1	2	3	4	5
Benzene	<0.20	<0.20	<0.20	<0.20	<0.20
Toluene	<0.20	<0.20	<0.20	<0.20	<0.20
Ethylbenzene	<0.20	<0.20	<0.20	<0.20	<0.20
o-Xylene	<0.20	<0.20	<0.20	<0.20	<0.20
m p-Xylene	<0.20	<0.20	<0.20	<0.20	<0.20
Xylenes(sum)	<0.40	<0.40	<0.40	<0.40	<0.40
BTEX(sum)	<1.0	<1.0	<1.0	<1.0	<1.0
TPH (C10-C12)	6.7	<4.0	<4.0	<4.0	<4.0
TPH (C12-C16)	<5.0	<5.0	<5.0	<5.0	<5.0
TPH (C16-C21)	<6.0	<6.0	<6.0	<6.0	<6.0
TPH (C21-C30)	<10	<10	<10	<10	<10
TPH (C30-C35)	<5.0	<5.0	<5.0	<5.0	<5.0
TPH (C35-C40)	<8.0	<8.0	<8.0	<8.0	<8.0
TPH (C10-C40)	<38	<38	<38	<38	<38
Naphtalene	<0.020	<0.020	<0.020	<0.020	0.022
Phenanthrene	<0.010	<0.010	<0.010	<0.010	<0.010
Anthracene	<0.010	<0.010	<0.010	<0.010	<0.010
Fluoranthene	<0.020	<0.020	<0.020	<0.020	<0.020
Benzo(a)anthracene	<0.010	<0.010	<0.010	<0.010	<0.010
Chrysene	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo(k)fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo(a)pyrene	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo(ghi)perylene	<0.010	<0.010	<0.010	<0.010	<0.010
Indeno(123cd)pyrene	<0.010	<0.010	<0.010	<0.010	<0.010

10. Glossary of Terms[5]

Adsorption	Bonding of metals and nutrients onto the surfaces of suspended particles by way of physical, chemical and biological processes.
Aliquot	A sub-sample of the original sample.
Analyte	That which is analysed.
Anoxic (anoxia)	A condition where very little to no oxygen (typically <0.5 $mg.l^{-1}$) is present in the water body.
Anthropogenic	Made and/or introduced into the environment by humans, especially pertaining to contaminants/pollutants.
Bacteria	Single-celled organisms that generally reproduce by fission. Some are pathogenic (cause disease) but most are free-living, with some being saprophytic (feed on dead or decaying organic matter).
Benthic	Pertaining to the environment inhabited by organisms living on or in the ocean bottom.
Benthos	Living organisms (e.g. algae and animals) associated with the sea bottom.
Bioaccumulate	The process by which chemical substances are taken up by living things and retained.
Bioavailable	A substance in a chemical and physical form that allows it to affect organisms or be accumulated by them.
Biochemical (or biological) oxygen demand	The decrease in oxygen content in $mg.l^{-1}$ of a sample of water in the dark at a certain temperature over a certain of period of time which is brought about by the bacterial breakdown of organic matter.
Biological community	An assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another.
Biomass	Total weight of organisms per unit area or volume of water.
Biota	All living things, including microorganisms, plants and animals.
Bloom	An unusually large number of organisms per unit of water, usually algae, made up of one or a few species.
BTEX	BTEX is the term used for benzene, toluene, ethylbenzene, and xylene-volatile aromatic compounds typically found in petroleum products, such as gasoline and diesel fuel.
Buffering capacity	A measure of the relative sensitivity of a solution to pH changes on addition of acids or base.
Catchment	The total area draining into a river, reservoir, or other body of water.
Chlorophyll-a	Chlorophyll-*a* is the green pigment found in all plants and in nearly all algae. Chlorophyll-*a* allows plants and algae to use sunlight in the process of photosynthesis for growth. The concentration of chlorophyll-*a* in estuarine, coastal or marine waters is used as an indicator of photosynthetic plankton biomass.
Colony forming unit (CFU)	A unit (measurement) of density used to estimate bacteria concentrations in ocean water. The number of bacterial cells that grow to form entire colonies, which can then be quantified visually.
Coliform bacteria	A group of bacteria primarily found in human and animal intestines and wastes. These bacteria are widely used as indicator organisms to show the presence of such wastes in water and the possible presence of pathogenic

---

[5] This glossary of terms and acronyms was compiled from numerous sources, which are available from the CSIR on request.

	(disease-producing) bacteria. *Escherichia coli* (*E. coli*) is one of the faecal coliform bacteria widely used for this purpose.
Community	Any group of organisms belonging to a number of different species that co-occur in the same habitat or area. An association of interacting assemblages in a given water body.
Community composition	All the types of taxa present in a community.
Community structure	All the types of taxa present in a community and their relative abundances.
Concentration	The quantifiable amount of a substance in water, food or sediment.
Contaminants	Biological or chemical substances or entities, not normally present in a system, capable of producing an adverse effect in a biological system, seriously injuring structure or function.
Cumulative effects/impact	Effects on the environment resulting from actions that are individually minor but that add up to a greater total effect as they take place over a period of time.
CSIR	Council for Scientific and Industrial Research
Grab	A mechanical device designed to collect bottom sediment samples. The device consists of a pair of hinged jaws and a release mechanism that allows the opened jaws to close and entrap a sediment sample once they touch bottom.
Detection limit	The smallest concentration or amount of a substance that can be reported as present with a specified degree of certainty by definite complete analytical procedures.
Detritus	Unconsolidated sediments composed of both inorganic and dead and decaying organic material.
Dissolved oxygen	Oxygen that is dissolved in water and therefore available for plants (phytoplankton), shellfish, fish, and other animals to use.
Diversity	A measurement of community structure that describes the abundances of different species within a community, taking into account their relative rarity or commonness.
Ecosystem	Any system in which living organisms and their immediate physical, chemical and biological environment are interactive and interdependent.
Escherichia (*E.*) *coli*	A type of faecal coliform bacteria which is found in large numbers in the faeces of humans and other mammals, and birds. It serves as a reliable indicator of recent faecal contamination of water.
Enterococci	Any streptococcal bacteria normally found in the human intestinal tract. Usually non-pathogenic.
Euphotic	Of surface waters to a depth of approximately 80 - 100 m, the lit region that extends virtually from the water surface to the level at which photosynthesis fails to occur because of reduced light penetration.
Eutrophication	A condition in an aquatic ecosystem where high nutrient concentrations stimulate blooms of algae (e.g. phytoplankton). Algal decomposition may lower dissolved oxygen concentrations. Although eutrophication is a natural process in the aging of lakes and some estuaries, it can be accelerated by both point and non-point sources of nutrients.
Fate	Disposition of a material in various environmental compartments (e.g. soil or sediment, water, air, biota) as a result of transport, transformation and degradation.
Faecal coliform	A type of bacteria found in faecal material of humans and other mammals. It serves as a reliable indicator of recent faecal contamination of water.
Guideline	A numerical concentration limit or narrative statement recommended to

	support and maintain a designated water use.
Habitat	A place where the physical and biological elements of ecosystems provide an environment and elements of the food, cover and space resources needed for plant and animal survival.
Hydrocarbons	Organic compounds consisting exclusively of the elements carbon and hydrogen and including such substances as paraffin, benzene and fuel oil. Some are obtained by cracking larger molecules (e.g. petrol).
Hydrophobic	Having little or no affinity for water, repels or does not absorb water.
Hypoxia	The condition of low dissolved oxygen in aquatic systems (typically with a concentration <2 $mg.l^{-1}$ but >0.5 $mg.l^{-1}$).
Impact	A change in the chemical, physical or biological quality or condition of a waterbody caused by external sources.
Impairment	A detrimental effect on the biological integrity of a water body caused by an impact.
Indicator	Characteristics for the environment, both abiotic and biotic, that can provide quantitative information on condition or state of en ecosystem. They include biological indicators (e.g. species composition, species abundance) and physical or chemical indicators (e.g. dissolved oxygen concentration, temperature). These often represent the targets, or water quality objectives, that need to be met in order to actually achieve the desired level of ecosystem protection.
Infauna	Those animals that live within bottom sediment.
Inorganic	Any compound lacking carbon.
In situ	In the natural habitat as opposed to in a laboratory or controlled situation.
Median	The median is the middle value in a data set ranked from lowest to highest.
Normalise	Perform a data calculation in order to express results in terms of a reference parameter or characteristic.
Nutrients	Essential chemicals (e.g. nitrogen and phosphorus) needed by plants for growth.
Parameter	A measurable or quantifiable characteristic or feature.
Pathogen	An agent such as a virus, bacterium or fungus that can cause diseases in humans. Pathogens can be present in municipal, industrial, and non-point-source discharges.
Photosynthesis	The conversion of carbon dioxide to carbohydrates in the presence of chlorophyll using light energy.
pH	pH is a measure of acidity or alkalinity of water on a log scale from 1 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline).
Physico-chemical	Measurement of both physical properties (e.g. temperature, salinity) and chemical determinants (e.g. metals and nutrients) to characterise the state of an environment.
Population	An aggregate of interbreeding individuals of a biological species within a specified location.
Pollution	The Paris Convention defines pollution as the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as hazards to human health, harm to living resources and to marine ecosystems, damage to amenities or interference with other legitimate uses of the sea.
Polycyclic aromatic hydrocarbon	A class of chemical compounds composed of fused six-carbon rings. Polycyclic aromatic hydrocarbons are commonly found in petroleum oils

	(e.g., gasoline and fuel oils) and are emitted from various combustion processes (e.g., automobile exhausts, electric companies).
Primary production	The first stage in the production of organic matter, mainly as a result of phytoplankton and algal growth.
Producers	Organisms that are able to build up their body substance from inorganic materials.
Redox potential	An expression of the oxidising or reducing power of a solution relative to a reference potential.
Salinity	A measurement of the amount of salt in water.
Sediment	Mud, sand, silt, clay, shell debris, and other particles that settle on the bottom of rivers, lakes, estuaries, and oceans.
Sorting	The range of grain sizes that comprise marine sediments. Also refers to the process by which sediments of similar size are naturally segregated during transport and deposition according to the velocity and transporting medium. Well sorted sediments are of similar size (such as desert sand) while poorly sorted sediments have a wide range of grain sizes (as in a glacial till).
Species	A category of biological classification ranking immediately below the genus, comprising related organisms potentially capable of interbreeding. A species is identified by a two part name; the name of the genus followed by a Latin or Latinised un-capitalised noun agreeing grammatically with the genus name.
Species richness	The number of species per unit area.
Station	A sampling location within a study area or site, where physical, chemical, or biological sampling and/or testing occurs.
Supersaturation	Refers to a solution containing more solute than equilibrium conditions will allow.
Trace Metal	A metal found in low concentration, in mass fractions of micrograms or less, in some specified source (e.g. sediment, tissue).
Taxon (taxa)	Any group of organisms considered to be sufficiently distinct from other such groups to be treated as a separate unit (e.g. species, genera, families).
Total Suspended Solids (TSS)	A measure of the total weight of particles in the water column, and is analysed in the laboratory from field samples.
Toxic	Poisonous, carcinogenic, or otherwise directly harmful to life.
Toxicity	A measure of the impact on a chosen biological process or condition.
Turbidity	Turbidity is a measure of water clarity or murkiness. It is an optical property that expresses the degree to which light is scattered and absorbed by molecules and particles.
Water Quality	A value, not to be exceeded, set for a specific water quality constituent in a defined water body portion or a water body, to ensure with a given measure of reliability, its agreed fitness for use. This is an achievable value determined by considering the water quality requirements of recognised water users as well as relevant physical, technological, economic and socio-political issues.
Water Quality Guideline	A parameter concentration (e.g. nitrate) or narrative statement (e.g. no algal blooms) used to assess whether a declared water value is being sustained. If the guideline is not being met, the water maybe under threat and investigation is warranted to ascertain whether the cause is anthropogenic or due to natural phenomena.