Species composition, abundance and biomass of microphytoplankton in the KwaZulu-Natal Bight on the east coast of South Africa

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Nearshore marine environments are influenced by an array of variables that can either be land-derived or of marine origin, and nearshore phytoplankton communities may differ in their taxonomic composition and biomass in response to such variables. The KwaZulu-Natal Bight (hereafter referred to as ‘the bight’) is an oligo-mesotrophic, nearshore oceanic environment, that is influenced by both terrestrial run-off and upwelling. A microphytoplankton survey of the bight conducted over several stations and depths and two seasons was conducted in order to ascertain species composition, abundance and biomass. Microphytoplankton abundance was generally low (a maximum of 180 000 cells l⁻¹ was recorded) but differed considerably between sites and seasons. A total of 99 taxa of mainly Bacillariophyceae and some Dinophyceae, Prymnesiophyceae and Cyanophyceae were identified in the present study. In the central bight, higher abundance and biomass were measured in February (wet season), which may be a possible consequence of terrestrial nutrient inputs. In the northern and southern bight we measured higher abundance and biomass in August (dry season). Upwelling was not detected during the study, but an influence of terrestrial nutrient sources was detected at the coastal stations. Turbid conditions were specific to the site near the Thukela River mouth and possibly influenced abundance, biomass and species composition at this site. Historic data on microphytoplankton composition are scarce, but comparisons with surveys from the 1960s reveal that around 60% of the common diatoms recorded then also occurred in the present study. Small taxa [20–200 µm] dominated the microphytoplankton community. Community composition was fairly uniform throughout the bight in both seasons, dominated in general by Chaetoceros species, and on occasion co-dominated by Thalassionema nitzschioides and Dactyliosolen fragilissimus.

Keywords: Agulhas current, diatoms, phytoplankton, primary productivity, run-off, upwelling

Online supplementary material: Supplementary material detailing the relative abundance of microphytoplankton taxa in the KwaZulu-Natal Bight in February and August 2010 can be found online at http://dx.doi.org/10.2989/1814232X.2016.1145597.

Introduction

Phytoplankton, as a major global primary producer and carbon sink (Falkowski 1998), exhibits complex response patterns to the abiotic and biotic environment. Phytoplankton taxa prefer various abiotic niches that are characterised by particular combinations of light, temperature, salinity, nutrients, abundance of grazers and other factors. As such, the species composition of phytoplankton communities changes in different environments, giving rise to variability in community properties including species richness, diversity, abundance and biomass. As these properties are important characteristics of the phototrophic base of a food web, the characterisation of phytoplankton communities is of interest from both a diversity and an ecological point of view.

In nearshore environments, land-derived nutrients and fresh water can influence the structuring of phytoplankton communities, and this is especially evident in coastal areas where large rivers discharge (e.g. Humborg et al. 1997; Carreto et al. 2003; van Beusekom et al. 2009; Goes et al. 2014). Whereas delivery of extreme amounts of nutrients causes hypertrophy in coastal areas and consequent spread of large hypoxic areas (e.g. Diaz and Rosenberg 2008), oligotrophic and mesotrophic nearshore marine ecosystems may be dependent on riverine nutrient delivery for part of their productivity. Such terrestrial influence on the nearshore may be as seasonal as the rainfall patterns it is caused by and has indeed been documented for various bays, bights and other shelf regions across the world. However, examples of these in the literature are few, even though the nearshore regions are one of the most productive regions on Earth and provide numerous ecosystem services to humans. However, all such studies illustrate a marked terrestrial influence on coastal phytoplankton populations and seasonal community succession, as well as the importance of such nutrient delivery to coastal oceanic systems. Examples include riverine influence on the northern Adriatic Sea (Aubry et al. 2012) and the northern Wadden Sea (van Beusekom et al. 2009); rainfall influencing nearshore regions...
in the eastern part of the Mediterranean off Israel (Azov 1986); agricultural run-off from a Japanese island (Blanco et al. 2008); the western tropical North Atlantic influenced by the Amazon River (Goes et al. 2014) and the influence of the monsoon rainfalls in the eastern Arabian Sea off India (Parab et al. 2006).

In addition to riverine nutrient input, the influence of upwelled nutrients on phytoplankton biomass, productivity and selected species is well documented (e.g. Prego et al. 1999; Meyer et al. 2002; Wasmund et al. 2005; Thiel et al. 2007; Ryan et al. 2009). The taxonomic composition and biomass of nearshore phytoplankton communities may thus differ with short- and long-term changes in delivery of terrestrial and upwelled nutrients and in the resulting abiotic environment. Phytoplankton prefer different environmental conditions according to species, and responses of phytoplankton communities to these conditions have been documented for certain nearshore oceanic regions and through experiments. In general, either diatoms (Sawant and Madhupratap 1998; Bajarias 2000; Li and Harrison 2001; Blanco et al. 2008; Li 2009; Schaeffer et al. 2010), or dinoflagellates (Azov 1986; Koening et al. 2009) tend to dominate marine phytoplankton communities in mesotrophic environments such as coastal and upwelling areas. In oligotrophic regions, however, picoeukaryotes (Li 2009) or cyanobacteria are often found to be the most abundant groups (Bajarias 2000; Li and Harrison 2001; Li 2009, 2002, 2009; Blanco et al. 2008; Čalić et al. 2013). This patterning is due to complex top-down and bottom-up advantages enjoyed by picoplanktonic cells under oligotrophic conditions: they have a better size:volume ratio for uptake of scarce nutrients, are less subject to filtration by predators (Li 2009) and, in addition, pico-cyanobacteria such as Prochlorococcus and Synechococcus are diazotrophic and are less constrained by low ambient fixed nitrogen levels; they can dominate, for example in tropical oligotrophic waters such as the central Pacific (Zehr et al. 2001) and central North Atlantic (Li and Harrison 2001).

The ecological importance of knowing how phytoplankton communities are influenced by their abiotic environment is that consumers of phytoplankton are influenced by the availability of suitable cell size, nutritional quality and generation time to satisfy energy demand and element requirements (Cloern and Dufford 2005). Thus, differences in dominance patterns of the various trophic groups have consequences for other trophic levels.

Similar to other coasts, the east coast of South Africa includes a mesotrophic nearshore oceanic environment, the KwaZulu-Natal (KZN) Bight (referred to hereafter as ‘the bight’), that is influenced by terrestrial runoff and upwelling (Meyer et al. 2002; Lambeth et al. 2009). The bight is the only part of the South African east coast with a sizeable shelf area, whereas the coast north and south of the bight are characterised by steep drop-offs and a narrow shelf (Lutjeharms et al. 2000a). The shelf area of the bight stretches for about 160 km between Durban and Cape St Lucia and measures about 45 km at its widest point off the Thukela River mouth (Lutjeharms et al. 2000a). From the landward side, the Thukela River discharges into the central bight, and many more small estuaries also discharge into the bight, especially during the spring and summer rainfall periods. This constitutes a nutrient source for the bight (Lambeth et al. 2009; Ayers et al. 2013), whereas on its seaward side the bight is bordered by the oligotrophic Agulhas Current (Meyer et al. 2002). Shelf water in the bight has a relatively short residence time (Roberts et al. 2016), and is characterised by sporadic upwelling in the north off Richards Bay, a lee eddy in the south near Durban, and wind-driven currents along the coast (Lutjeharms et al. 2000a, 2000b; Lutjeharms 2006).

The phytoplankton community of the KZN Bight has been studied in the past by analysing primary production (Burchall 1968), pigments (Barlow et al. 2008, 2013, 2015), and remote sensing data (Smith et al. 2013). Early studies on primary production suggested that the area south-east of the Thukela Mouth region was highly productive (Burchall 1968). The most comprehensive study of microphytoplankton composition from cell counts in the KZN Bight was conducted in 1965 (Thorrington-Smith 1969). Only three out of the 17 stations sampled were located within the 200 m isobath, and occurred in the southern part of the bight around Durban (Thorrington-Smith 1969). Nonetheless, tow-net samples from 50 m depth to surface showed a dominance of Bacillariophyceae diatoms and Dinophyceae dinoflagellates, and also that the highest species richness and highest productivity were apparent off the Thukela Mouth (station depth 281 m). The study also showed a lower diversity at the coastal stations and the eastern fringe of the Agulhas Current as compared to stations in the Agulhas Current (Thorrington-Smith 1969).

From pigment data it was apparent that small flagellates were dominant in general, and that diatoms dominated cooler patches (<22 °C) (Barlow et al. 2008). In 1966 a study was published that reported phytoplankton taxa from the wider South-West Indian Ocean (Taylor 1966), based on data collected between April 1962 and January 1963, during which time four surveys were conducted along four lines of stations off the eastern and southern coast of South Africa. Only some stations from that study occurred in the region of the bight and it was found that diatoms (especially species of Chaetoceros) dominated the samples. Surveys by the National Research Institute for Oceanology (NRIO) in 1979/1980 reported a dominance of diatoms in the vicinity of the Durban Eddy (unpublished data summarised in Carter and Schleyer 1988).

Based on the rather scarce information on phytoplankton of the KZN Bight from previous studies, the current study aimed to examine the diversity, abundance and biomass of microphytoplankton at sites in the vicinity of various nutrient sources, spread across the entire bight. These included sites that are influenced by upwelling (northern bight), the Thukela River (central bight), the Agulhas Current (midshelf) and the Durban Eddy in the southern bight, that was previously studied in June 1965 (Thorrington-Smith 1969) and in September 1979 (NRIO unpublished data as summarised in Carter and Schleyer 1988). The current study is therefore not only the first study for several decades to examine microphytoplankton species composition by microscopy in the area, but also includes the entire bight, and records both abundance and biomass from cell counts. Information arising from this study contributes to the biodiversity knowledge regarding phytoplankton of
South African east coast marine waters. Information on abundance and biomass of microphytoplankton, on the other hand, gives an indication of the trophic state of the bight, and of the energy available from this size class to higher trophic levels. The influences of the Thukela River and the St Lucia upwelling cell are discussed.

Material and methods

Samples were collected from the KZN Bight on two surveys from 2 to 20 February and 3 to 25 August 2010, on board the RS Algoa. Overall, four stations across the bight were sampled, which were Durban Eddy (DE) in the south (chosen because it was in the often-observed Durban lee eddy [Pearce et al. 1978; Anderson et al. 1988]), Thukela Mouth (TM) (selected for its proximity to the outflow of the Thukela River), Midshelf (MS) (located in the middle of the shelf of the bight area), and Richards Bay North (RN), at the northernmost boundary of the area that is part of the northern upwelling zone in close proximity to the shelf edge and Agulhas Current (Figure 1). All four stations were sampled for phytoplankton on three consecutive days between 10:00 and 11:00 local time. Hydrographic profiling was achieved through CTD deployments at each station, measuring temperature, salinity and fluorescence. Seawater samples were collected using a Rosette Niskin with 5-litre capacity bottles at three depths (surface, mid-depth and near-bottom) for nutrient, chlorophyll a (Chl a) and phytoplankton analysis. Mid-depth was chosen during each downcast based on streaming fluorescence data, and the samples were collected at the maximum ($F_{\text{max}}$). Subsamples were taken from the Niskin bottles and preserved with Lugol’s iodine for phytoplankton analyses. Nutrient samples were frozen and analysed ashore by standard auto-analyser techniques (Mostert 1983). Total Chl a concentrations were analysed by liquid chromatography as described in Barlow et al. (2010).

For phytoplankton identification and numeration, sample volumes of 1 litre were settled for 48 h to a volume of 100 ml. This in turn was settled for another 48 h in Utermöhl chambers. Microphytoplankton species were identified using a Nikon Eclipse Ti-S inverted microscope using differential interference contrast (DIC) and ×200, ×400 and ×1 000 (oil) magnifications. Samples were identified to...
species level where possible, except for the small, fragile cells, for which the genus and algal group were recorded. Identification guides included the following: Hoppenrath et al. (2009), Tomas (1997) and Hallegraeff et al. (2010). Due to the nature of the microscope techniques chosen, it was not possible to confidently identify phytoplankton cells below 10 μm in size. The focus of the paper is therefore on microphytoplankton, classified as taxa that are generally larger than 20 μm (Dussart 1965; Omori and Ikeda 1984). Microphytoplankton were counted from a minimum of 20 fields of view (×400 magnification) or 300 cells, whichever came first. Cell measurements were converted into biovolumes and carbon following the methods and values in Olenina et al. (2006).

The four focus sites (stations) were analysed for their differences in taxon abundance and biomass, at three depths and in two seasons (February [summer/wet] and August [winter/dry]), using analysis of variance (ANOVA) in R (R Development Core Team 2014). Cluster analyses to identify associations of species were based on Bray–Curtis similarities and included taxa with frequencies of occurrence >5%. Based on the taxonomic composition at each station, a matrix of pairwise Bray–Curtis distances between species and stations was generated. Agglomerative clusters were derived from each distance matrix (Maechler et al. 2014). Only data from two depths, Surface and $F_{max}$, were used for this analysis, as these were comparable in terms of sampling depths across all sampled stations.

Results

**Physico-chemical environment**

Detailed descriptions of the physico-chemical parameters of the bight during the sampling surveys in terms of
temperature, nutrients and Chl a concentrations are given in Barlow et al. (2013) and Muir et al. (2016). The findings particularly important to this study are detailed here (Figures 2–5). Surface temperatures in February ranged between 22 and 24 °C at stations TM and MS in the central bight, between 24 and 26 °C at DE in the southern bight and between 25 and 27 °C at RN in the northern bight (Figure 2). The vertical temperature distribution showed

Figure 3: Vertical profiles of nitrite, nitrate, silicate and phosphate (mmol m⁻³) measured on successive days at the four stations in the KZN Bight during the February 2010 survey. For station names see Figure 1 legend. No near-bottom samples were collected at RN
that temperatures declined to 17–19 °C at 35 m and below. During the winter survey (August), most stations (except DE) did not show a vertical temperature gradient, with both surface and deeper layers measuring between 20 and 22 °C (Figure 4). DE, on the other hand, showed a similar vertical gradient in winter and summer albeit with lower surface temperatures (around 22 °C) in winter compared to summer (Figures 2, 4). Surface salinity was generally lower than that of deeper layers in summer at all stations, with values of 35.2–35.3 at the surface and around 35.45 in deeper layers (Figure 2). In winter, vertical mixing was evident at all stations, with salinity around 35.3–35.4 throughout the water column (Figure 4). A notable exception was DE on 3 August, when a gradient was apparent (Figure 4). Concentrations of nitrate, silicate and phosphate showed vertical gradients in summer with lower concentrations at the surface than in deeper layers (Figure 3). This vertical gradient was also present at station DE in winter, where all other stations were mixed (Figure 5; also see Barlow et al. 2013). A notable exception was nitrite-N that was higher in deeper layers at TM and MS in both summer and winter. Silicate was typically in the range of 3–5 mmol Si m$^{-3}$ at DE and 1–3 mmol Si m$^{-3}$ at TM, MS and RN. Nitrate-N concentrations between 0 and 7 mmol N m$^{-3}$ were recorded at DE. Nitrate-N ranged between 0–4 mmol N m$^{-3}$ at TM, MS and RN in summer and around 1 mmol N m$^{-3}$ in winter. Nitrite-N was mostly below the detection limit at the surface, but around 0.4 mmol N m$^{-3}$ in deeper layers. Phosphate ranged between 0 and 0.4 mmol P m$^{-3}$ in summer and around 0.3 mmol P m$^{-3}$ in winter at TM, MS and RN, at all depths. The vertical gradient at DE in winter was between 0.2 (surface) and 0.4 mmol P m$^{-3}$ (50 m).

Figure 4: Vertical profiles of temperature (°C), salinity and chlorophyll a (mg m$^{-3}$) measured on successive days at the four stations in the KZN Bight during the August 2010 survey. For station names see Figure 1 legend.
Chlorophyll $a$ concentrations, indicative of the biomass of primary producers, were generally low throughout the area (Figures 2, 4). In summer, concentrations at most stations were around 1 mg m$^{-3}$, with notable exceptions at MS (2.6 and 4.1 mg m$^{-3}$ on 10 and 11 February) and DE (2.4 mg m$^{-3}$). Winter Chl $a$ concentrations were again low at TM and also at MS (<1 mg m$^{-3}$). Surface Chl $a$ at DE and RN in winter was higher than in summer.

Figure 5: Vertical profiles of nitrite, nitrate, silicate and phosphate (mmol m$^{-3}$) measured on successive days at the four stations in the KZN Bight during the August 2010 survey. For station names see Figure 1 legend
**Microphytoplankton composition**

A total of 99 infrageneric taxa were identified as belonging to the divisions Bacillariophyceae (66 taxa), Dinophyceae (24 taxa), Pyrnesiosphyceae (4 taxa), Cyanophyceae (2 taxa), Cryptophyceae (1 taxon), Euglenophyceae (1 taxon) and Dictyochophyceae (1 taxon) (see Appendix S1, available online). The Bacillariophyta were mainly represented by Biddulphiales (centric diatoms) of which the family Chaetocerotaceae (16 taxa) was the most prominent. In the group of dinoflagellates, small athecate taxa were common. Unfortunately these could not be resolved to a lower taxonomic level using the inverted microscope due to their generally small size and/or lack of adequate preservation. Other common dinoflagellate genera were Ceratium spp. (3 taxa), Gyrodinium spp. (3 taxa), Prorocentrum spp. (3 taxa) and Oxytoum spp. (3 taxa).

A few species were numerically dominant in the area. The diatom Thalassionema frauenfeldi was present in most samples, with higher abundances in February compared to August at all stations (Appendix S1). At MS and TM, abundances were high in both seasons (1 069 to 3 270 cells l\(^{-1}\)). Other abundant species were Chaetoceros compressus (especially at RN in August, with 95 953 cells l\(^{-1}\)), and Leptocylindrus danicus (RN, February). In August Brockmanniella brockmannii was found at TM at all three depths. Taxa that occurred frequently throughout the study were the diatom species Chaetoceros compressus, Leptocylindrus danicus, Pseudonitzschiella delicatissima species complex, Thalassionema frauenfeldi and T. nitzschioides, and the dinoflagellates Gyrodinium sp., Protoperoiridium sp. and Torodinium robustum (Figure 6 and Appendix S1).

The relatively high concentrations of microphytoplankton cells observed in February at MS, and in August at DE and RN, mainly consisted of diatoms (at least 50% relative abundance). At other sites, with lower total cell concentrations, dinoflagellates were equally abundant (Figure 7). The cyanobacterium Trichodesmium sp. was observed frequently in surface samples from sites DE and RN in February but these were not quantified due to the variations in strain size. This group will have been undersampled because clusters tend to float on the surface, and samples were collected with Niskin bottles just below the surface.

In general, microphytoplankton cell concentrations were low in the bight (see Discussion for comparisons with other coastal areas) and differed considerably between sites and seasons. Results of a 3-way ANOVA indicate that there were significant differences in cell abundance between Sites (\(F = 13.0, p < 0.01\)), Months (\(F = 37.3, p < 0.01\)) and Depth (\(F = 10.3, p < 0.01\)). A post hoc test revealed that RN was different from all other sites (\(p < 0.05\)), and the only other significant difference was found between DE and TM. In terms of Depth, there was no difference in abundance between surface and \(F_{\text{max}}\), however, there was a significant difference between each of the two depths and near-bottom samples (\(p < 0.05\)). There was a significant interactive effect between Site and Month, indicating an influence of seasonality at the sites. Higher abundance was measured in February (wet season) at Midshelf (MS), whereas higher abundance was measured in August (dry season) at Durban Eddy (DE) and Richards Bay North (RN). Average abundance ranged from 3 400 cells l\(^{-1}\) (SD 1 800, DE-Feb, near-bottom) to 180 000 cells l\(^{-1}\) (SD 16 180, RN-Aug, \(F_{\text{max}}\)) (Figure 7). The biggest differences between seasons were apparent from the MS and RN sites, although with opposite effects: MS showed higher abundance in February, whereas abundance at RN was low during that month and much higher in August (Figure 7).

**Microphytoplankton biomass**

Biomass ranged from 1 247 ng C l\(^{-1}\) (SD 312; TM, \(F_{\text{max}}\), August) to 44 017 ng C l\(^{-1}\) (SD 8 651; RN, \(F_{\text{max}}\), August). Significant differences in terms of biomass were found between February and August (\(F = 4.2, p < 0.05\)), and TM was different from all other sites (\(F = 13.1, p < 0.01\)). An interactive effect between Site and Month was apparent for biomass (as was observed for the abundance data). Higher biomass values were observed in February at all sites except at RN, but including DE, where the comparatively low abundance showed higher biomass compared to August (Figure 7). There was no significant difference between depths (\(p > 0.05\)).

The high biomass at DE in February was mainly caused by the presence of relatively large diatom species with high carbon content such as Odontella spp., Neocalyptra robusta and Rhizosolenia setigera. In February the biomass of the surface samples at DE, TM and MS were to a large extent composed of small thecate and athecate dinoflagellates that could not be identified during this study, mainly due to their small size. The proportional biomass of diatoms increased on average with depth at all four sites and was lowest at TM and MS in August.

Overall, abundance and biomass showed slightly different trends. Whereas cell abundance at MS was clearly highest compared to all other stations in February, MS featured only slightly higher biomass relative to TM and DE. Lowest abundance and biomass were apparent from the northern bight (RN) in February. In August, however, both abundance and biomass were highest in the northern bight (RN), followed by the southern bight (DE) and lowest in the central bight (TM and MS).

**Association of species**

The analysis of the associations of taxa revealed three broad groups (Figure 8). The first group consisted of five diatom taxa: Chaetoceros compressus, C. costatus, C. affinis, Dactyliosolen fragilissimus and Guinardia striata. This was also the least diverse group. Chaetoceros compressus is characteristic of warm to temperate regions whereas D. fragilissimus is cosmopolitan (Tomas 1997). These taxa were particularly abundant and were dominant at RN, DE or MS at times, but not at TM. The second group included the diatoms Bacteriastrium elongatum, B. furcatum, Chaetoceros didymus, C. lorencizanus, C. messanensis, Climacodium sp., Pseudonitzschia delicatissima complex and Rhizosolenia setigera. These taxa were common at all sites in similar but comparatively low abundances, and can be considered to be characteristic of the KZN Bight (Figure 8). The third group consisted of 25 taxa characteristic of general coastal phytoplankton populations. The combined abundance of this group was of the same order of magnitude as the dominant taxa of the first group (note...
Figure 6: Some of the common species of microphytoplankton observed in the KZN Bight: (a) Chaetoceros compressus, (b) Leptocylindrus danicus, (c) Pseudonitzschia delicatissima, (d) Thalassionema frauenfeldii, (e) Thalassionema nitzschioides, (f) Torodinium robustum, (g) Protoperidinium sp. and (h) Gyrodinium sp.
the different scales of the y-axis in Figure 8), but the group was much more diverse. The most abundant taxa in this group were the unidentified dinoflagellate spp. (athecate and thecate).

Discussion

The microphytoplankton survey of the KZN Bight was conducted over four stations, three depths and two seasons in order to ascertain their species composition, abundance and biomass. The survey encompassed areas of the bight with hydrographic features which may influence all three variables investigated. In the past, it was thought that the St Lucia upwelling cell in the north of the bight controlled the nutrient supply to the entire shelf, and that the upwelled water would dominate the north of the bight (Lutjeharms et al. 2000b; Meyer et al. 2002). Previously measured Chl a concentrations (Meyer et al. 2002) coarsely matched the then-identified three nutrient-source regions of the bight, with the northern bight showing higher Chl a values, thought to be caused by the comparatively higher nutrient concentrations from the upwelling. Lowest Chl a values were measured in the southern part and intermediate values in the central part.

Figure 7: Mean (a) cell concentrations and (b) biomass of the three main phytoplankton groups Bacillariophyceae, Dinophyceae and Cyanophyceae at three depths (surface, $F_{\text{max}}$ and near-bottom) at four stations (DE, TM, MS and RN) in the KZN Bight during two surveys in February and August 2010. For station names see Figure 1 legend. No samples were collected at near-bottom from RN in February.
Figure 8: Cluster diagram of taxa from surface and $F_{\text{max}}$ samples collected at sites DE, TM, MS and RN in February and August 2010. Clustering is based on the relative abundance of phytoplankton taxa in cells l$^{-1}$. 
of the bight, where the Thukela River has been shown to contribute nutrients through subsurface outflow (Meyer et al. 2002). Chl a values from the present study conducted about 20 years later were comparable at the RN site in the northern bight. However, at the central bight stations, TM and MS, situated about 9 km and 30 km, respectively, offshore from the Thukela River, and especially at the southern bight station DE, Chl a values were up to 25-fold higher during the present study. Here, the southern part of the bight showed higher values compared to the northern or central part. Nutrient data presented in Muir et al. (2016) furthermore showed higher nutrient concentrations near the coast, which may represent an influence from terrestrial run-off. The surface salinity was on average lower in February (35.31) than in August (35.42, Figure 2) and this indicates that freshwater input had an effect on surface water. At one of the stations (DE), the surface water salinity in February gradually increased from 35.28 on the first day of the survey to 35.35 on the fifth day. The samples collected over those days showed an increase of flagellates (dinoflagellates and others) from 7 251 cells l–1 to 12 817 cells l–1 over the five days. The abundance of other groups of microphytoplankton remained similar during this period. Also, the increase of flagellates was not reflected in the total Chl a measurements, which remained stable on all sampling days (around 0.35 mg m–3, Figure 2). This result suggests that a response was observed to freshwater input, either from precipitation or through riverine run-off. Such a gradual change in salinity over consecutive sampling days was not detected at the other stations. It has been widely reported that nutrients from riverine run-off stimulate coastal phytoplankton communities (e.g. Blanco et al. 2008; Goes et al. 2014); however, the influence on species composition does not seem to be predictable (Oviatt et al. 1989).

The microphytoplankton community was dominated by diatoms in terms of number of taxa, abundance and biomass. Exceptions to this were the biomasses at the surface and Fmax depths at the central bight stations, TM and MS, in August, where dinoflagellates were dominant. As most oceanographic phytoplankton studies concentrate on Chl a and other pigment analysis, few studies are available to compare taxon richness, abundance, and biomass derived from cell counts in nearshore regions. However, compared to studies conducted in the northern Adriatic Sea, where 372 taxa were identified from samples taken over eight years (Aubry et al. 2012), the KZN Bight seems comparatively low in diversity. In offshore Brazilian waters, for example, 173 taxa were identified from two sampling occasions, including both neritic and oceanic stations (Koening et al. 2009) and, off the Lebanon coast, a two-year sampling programme in the mid-seventies produced 263 taxa (Lakkis and Novel-Lakkis 1981), whereas a study on the Abrolhos Bank, Brazil, counted 326 microphytoplankton taxa from two sampling occasions (Susini-Ribeiro et al. 2013). Samples for our study were collected with Niskin bottles as opposed to a plankton net that is often used in other phytoplankton studies. The use of Niskin bottles allowed for the quantitative assessment of the microphytoplankton but, as a consequence, the sampling effort was much smaller compared to the use of a plankton net, which typically samples much larger volumes of water. Using a plankton net, Thorrington-Smith (1969) counted about 160 taxa at coastal and offshore (in the Agulhas Current) stations in the region. However, there are certainly areas which have fewer taxa: for example, the surface layers (to 60 m) in the South China Sea, Western Philippines, had 56 phytoplankton taxa (Bajarias 2000). There are also several difficulties in comparing the number of taxa across regions, since besides the differing sampling effort and the environmental differences in salinity, temperature and nutrient regimes, the number of taxa found is further dependent on sampling depth, seasonality and overall duration of the sampling programme.

Of the 29 diatom taxa that occurred commonly in net phytoplankton hauls in the 1960s (based on three separate studies – South African Division of Sea Fisheries 1961, Taylor 1966 and Thorrington-Smith 1969, as discussed in Carter and Schleyer 1988), 17 were regularly found in this study (Appendix S1). Some cosmopolitan species that were reported in these previous studies from the Agulhas Current were not observed in the present study, which was confined to the bight only. In the 1960s, species diversity was lower at coastal sites on the shelf than in the Agulhas Current (Torrington-Smith 1969). The earlier studies found 12 species of the genus Chaetoceros, whereas the present study found 11 species in that genus, of which only 6 coincided with the previous studies. Five of the six species that were not observed in the previous study were of the subgenus Phaeoceros, which is characterised by larger cells with strong setae that are often very long, striated and armed with conspicuous spines. These spines may increase the probability of capture by net, which may have accounted for these taxa occurring more frequently in net hauls (the collection method used in the studies in the 1960s), than in the present study where Niskin bottles were used.

There are no abundance data available for the region for comparison. Cell counts ranged over three orders of magnitude between stations and depths, from several hundred cells l–1 to 175 000 cells l–1 (Figure 7). Despite the high variability, a few patterns emerged. Firstly, the station nearest the Thukela River (TM) showed on average the lowest cell counts for both the wet and dry seasons. In the current study, the turbidity was high in this area (Muir et al. 2016), which we suggest resulted in unfavourable light conditions for phytoplankton growth. The presence of Brockmanniella brockmannii and Navicula sp. in the August samples at TM also indicates the possible importance of a riverine plume. B. brockmannii is associated with sediments and spring plankton, whereas Navicula is a strictly benthic genus that often indicates riverine and estuarine influence (Sullivan 1999). Other factors such as rapid dilution of the nutrient concentrations delivered, or possibly high grazing pressure, may prevent further build-up of phytoplankton. Phytoplankton blooms can often be observed at the interface of riverine plumes (Lalli and Parsons 1997). The TM station was situated in, rather than on the fringe of, the plume. However, the Midshelf station in the central bight (MS), showed high overall cell counts in February. This station was deliberately but serendipitously chosen during the February survey as satellite data suggested the
presence of elevated chlorophyll levels in that area at that time (Barlow et al. 2013). These eutrophic conditions at MS were dominated by Chaetoceros spp., combined with high abundances of Leptocylindrus spp. and Thalassionema spp. Concentrations of N, P and Si were lower in February than in August at MS, suggesting that these taxa may have used up most of the available nutrients, especially since nutrient concentrations near the bottom were an order of magnitude higher compared to the surface. As this was the wet season, when river outflow was stronger, the subsurface flow mentioned in Meyer et al. (2002) may have influenced this region. Thorrington-Smith (1969) also showed high biomass associated with a station in this area of the bight, with dominant diatoms Thalassionema frauenfeldi and Chaetoceros lorenzensis. In August (dry season), the southern (DE) and northern (RN) stations showed considerably higher cell concentrations compared to the central bight stations. The above patterns correspond to Chl a and nutrient levels in the respective months at these stations. The average biomass at these stations and depths showed a similar pattern to the abundance data in August.

The high biomass at DE in February was largely the result of the presence of relatively large species with high carbon content such as Neocalyptrella robusta and Rhizosolenia setigera. Larger taxa are known to become more abundant towards late summer (Aubry et al. 2012). Thorrington-Smith (1969) reported 29 taxa contributing at least 1% to relative abundance from a station that was in close proximity to DE. The dominant taxa were Chaetoceros lorenzensis, C. messanensis and Thalassionema frauenfeldi. In the present study these taxa also formed important parts of the community but, in contrast, other taxa such as C. compressus and C. costatus were dominant.

The phytoplankton community composition (in terms of abundance and biomass) was fairly similar across the bight, with a few exceptions. This suggests that most of the bight has a fairly uniform microphytoplankton community. Whereas Chaetoceros species were abundant in all samples, co-dominance of other diatoms such as Thalassionema nitzschioides and Dactyliosolen fragilissimus was the main difference between the relatively high microphytoplankton counts at MS in February and RN in August. Equally, the abundant (but not dominant) athecate dinoflagellates at DE in August made this site distinct from others in the bight. These differences may have been caused by different nutrient regimes, e.g. the high dinoflagellate abundance at DE off Durban in winter may have been influenced by undetected terrestrial run-off. Muir et al. (2016) show that while bacterial numbers and biomass at DE were extremely low in summer, these rose during the dry season, and suggest that there is a correlation between Chl a abundance and bacterial activity, but find that this cannot be correlated with nutrient status, which remained extremely oligotrophic throughout.

In summary, the KZN Bight featured a fairly low taxon count, with low cell abundance and biomass. Little influence of upwelling could be detected except at Richards Bay in August and instead the strongest influence of nutrients was seen at the other three stations in both summer and winter that appeared to be influenced by terrestrial run-off. This was apparent especially from the DE site in the central bight off Durban, as well as the Midshelf site in the shelf ecosystem of the KwaZulu-Natal Bight, South Africa. African Journal of Marine Science 37: 467–484.

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