Interactions between seasonality and oceanic forcing drive the phytoplankton variability in the tropical-temperate transition zone (~30°S) of Eastern Australia

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A B S T R A C T
The East Australian Current (EAC) has been shown to be warming rapidly, which is expected to cause latitudinal shifts in phytoplankton abundance, distribution and composition along the east Australian coast. Yet a lack of phytoplankton information exists northward of 34°S. Here, we provide the first detailed taxonomic time-series survey (monthly sampling for about one annual cycle, 2011–2012) in the east Australian tropical-temperate transition zone (~30°S, upstream of the EAC separation point at ~31–32°S). All phytoplankton (categorised depending on their association with specific water-types) show a seasonal signal with abundance maxima (minima) during summer (winter). This seasonal signal is most pronounced in the seasonal/bloom category and least expressed by deep-water taxa, which prefer cold, saline and dense bottom water independent of the season. Different extents of EAC encroachment onto the continental shelf drive the cross-shelf phytoplankton composition and distribution, such that a weak EAC is associated with phytoplankton community being organised along ‘distance’ and ‘depth’ gradients with high phytoplankton abundances inshore. A strong EAC favours the occurrence of warm-water taxa offshore and an increase in diatom abundance on the mid-shelf (53% shelf width). We conclude that the phytoplankton community in the tropical-temperate transition zone of Eastern Australia is driven by an interaction of intrinsic seasonal cycles and primarily EAC-driven oceanic forcing. Our findings benefit studies located in Western Boundary Current systems worldwide, in which warming and strengthening of these currents are predicted to severely impact phytoplankton dynamics.

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1. Introduction

Global Western Boundary Currents (WBCs) are being modified as a result of the present anthropogenically induced climate change (IPCC, 2013; Wu et al., 2012). Specific changes include the surface warming of these currents at a two to three times faster rate than the global mean ocean surface warming, as well as an intensification and/or poleward shifts of the extent of the WBCs (Wu et al., 2012). Such modifications in ocean circulation, and associated alterations of physical and chemical properties of the ocean itself, are expected to affect phytoplankton distribution and community structure worldwide (Hallegraeff, 2010). Predicted long-term changes include an earlier timing of annual phytoplankton blooms (peak production periods), changes in the marine food web structure, disruption of established seasonal succession patterns, poleward range expansions of tropical species, enhanced stratification impeding on nutrient accessibility and an increased frequency of harmful algal blooms (Hays et al., 2005; Hallegraeff, 2010; Winder et al., 2012). Recent investigations suggest that such alterations in the marine ecosystem have already started as evidenced in a decline of global net primary productivity (between 1996 and 2006; Behrenfeld et al., 2006) and phytoplankton biomass (over the last century; Boyce et al., 2010).

The East Australian Current (EAC) is the South Pacific WBC flanking the east Australian coast over the continental slope, transporting warm-water masses from tropical to temperate latitudes (Godfrey et al., 1980). Generally, the EAC flows southward with a speed of up to 2 m s−1 from its formation point at about 10–15°S until it bifurcates at about 32°S into an eastward and southward component (Tasman Front and Southern Extension, respectively; Godfrey et al., 1980; Ridgway and Dunn, 2003). In addition to the poleward residual flow, cyclonic and anti-cyclonic eddies are regularly shed at the separation zone (Suthers et al., 2011; Ridgway and Hill, 2012). During the past 60 years, the southward penetration of the EAC has extended, as evidenced by a warming trend of 2.28 °C century−1 and an increase in salinity of 0.34 psu century−1 recorded at 42°S (Ridgway, 2007). These modifications in the EAC characteristics

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have been attributed to changes in basin-scale wind forcing influencing the Subtropical Gyre (Hill et al., 2008).

Changes in the oceanographic environment seem to have already impacted on the phytoplankton community structure along the south-east Australian coast. For example, the warming and strengthening EAC has been associated with the recent poleward range expansions of the red-tide dinoflagellate Noctiluca scintillans (Hallegraeff et al., 2008; McLeod et al., 2012) and several species of the dinoflagellate genus Ceratium (Buchanan et al., 2014). Thompson et al. (2009) reported decreasing silicate concentrations off South-Eastern Australia (34°S) within the last 60 years. Considering the reduced silicate availability and the warming and strengthening of the EAC, diatoms were expected to decline and dinoflagellates to increase (Thompson et al., 2009). Although recent studies by Ajjani et al. (2014a,b) found no change in diatom abundance and a decline in dinoflagellates, this pattern was attributed to a short-term (decadal) decrease in water-column temperature as a result of periodical fluctuations in water properties (particularly related to El Niño Southern Oscillations, Holbrook et al., 2011). With diatoms playing a key role in primary production and the carbon cycle (Smetacek, 1999) and dinoflagellates being the most frequent cause for harmful algal blooms (Hallegraeff, 2010), changes in their relative abundance patterns could severely affect the local biogeochemical processes and economical values along the east Australian coast.

On an intra-annual time-scale, the strength of the EAC varies seasonally, reaching maximum velocities during the austral summer and being weakest in winter (Ridgway and Godfrey, 1997), although this seasonality is weakly expressed in shelf velocities (Wood, 2014). In particular, encroachments of the EAC onto the shelf (i.e. an onshore shift in axis of the EAC flow, intruding the continental shelf and dominating the circulation inshore of the 200 m isobath; Roughan and Middleton, 2002) are mostly driven by the EAC instabilities (Schaefeer et al., 2013, 2014a,b). In addition, Schaeffer et al. (2014b) showed a correlation between EAC encroachments and onshore transport of cold bottom water in the Coifs Harbour region occurring quasi-periodically between 90–100 days (a-seasonally). Nevertheless, it seems that a clear relationship between EAC dynamics and large scale variations in surface chlorophyll a (Chl a) concentrations (a proxy for phytoplankton biomass) exists (Everett et al., 2014). It has been shown that south of the separation zone (~34°S), the combination of wind-and current-driven upwelling, promotes nutrient input and phytoplankton growth and therefore controls the onset of the annual spring bloom (Hallegraeff and Jeffrey, 1993; Ajjani et al., 2001; Pritchard et al., 2003).

Very little is known about phytoplankton dynamics northward of the EAC separation zone. The Coifs Harbour region, at about 30°S, is characterised by a complex topography due to numerous small islands and reefs (NSW MPA, 2008). Frequent changes in the local oceanography (daily-weekly) including wind stress (Rossi et al., 2014), EAC intrusions and northward counter currents have been reported to cause temperature gradients of up to 11 °C (Malcom et al., 2011). Current-driven upwelling has been shown to be the dominant driver of cold water uplift in this EAC-dominated region (Schaefeer et al., 2013, 2014a). Intense EAC encroachments onto the shelf influence the cross-shelf dynamics and in particular the transport of potentially nutrient-rich bottom water (Schaefeer et al., 2013, 2014a,b).

Armbrecht et al. (2014) provided the first study of insights into the cross-shelf responses of phytoplankton to different oceanographic conditions north of the EAC separation zone. These authors showed that during an EAC-driven upwelling event, the major phytoplankton response was found on the mid-shelf (~53% shelf width) and was constituted of primarily oceanic diatom species. Simultaneously, an increase in species richness, mainly due to the appearance of tropical dinoflagellates, was found offshore, which is consistent with long-term predictions of EAC-driven dinoflagellate distribution (Thompson et al., 2009; Ajjani et al. 2014a,b). However, there is no longer-term (e.g. seasonal–annual) information on whether the distributional patterns of phytoplankton as shown by Armbrecht et al. (2014) are recurrent phenomena and directly related to periodical EAC strength. The latter information is urgently needed in the context of a strengthening of the EAC, as coastal phytoplankton dynamics may have impacts on the distribution of higher trophic organisms, ultimately impacting on fisheries and marine parks planning, as well as potentially being applicable to other WBC systems.

In this study we provide the first detailed taxonomic phytoplankton time-series survey in the east Australian tropical-temperate transition zone (~30°S), covering about one annual cycle between 2011 and 2012. The specific aims of our study are to: (i) determine seasonal patterns and the natural variation and in the phytoplankton abundance, composition and distribution in the course of nearly one year; (ii) identify the impact of EAC encroachment onto the shelf on the cross-shelf phytoplankton abundance, composition and distribution; and (iii) investigate the link between tropical input of phytoplankton species into the study area and the influence of the EAC. Our study is based on microscopy analyses of the monthly sampled phytoplankton community within the physical oceanographic background derived from moored instruments and vertical water property profiles. A statistical approach is applied to pursue our three main aims and the importance of the results is discussed within a regional and general context.

2. Materials and methods

2.1. Sampling design and instrumentation

Monthly sampling was undertaken at the 25, 50, 70 and 100 m isobaths along two cross-shelf transects (CH-Line and B-Line) and one intermediate station (SS) off the east coast of Australia between May 2011 and February 2012 with one extra sampling in September 2012 (Fig. 1, Supplementary Material Table 1). Stations CH3 and CH5 were also the site of long-term in-situ oceanographic moorings (CH070 and CH100, respectively; Roughan et al., 2010, 2013; Schaefeer et al., 2013, 2014a,b). These moorings recorded temperature in 8 m distance intervals from the bottom to about 15 m below the sea surface. Current measurements from the bottom-mounted Acoustic Doppler Current Profiler (ADCP) were provided at 4 m bins in the vertical. Daily depth-averaged along-shelf velocity was used as a proxy for the EAC encroachment onto the shelf during each sampling. For full details on the mooring deployments the reader is referred to Schaefeer et al. (2013, 2014a,b). Satellite observations were used to provide additional spatial context to the local dynamics (https://imos.aodn.org.au/). Geostrophic velocity was derived from altimetry (Deng et al., 2011) and sea surface temperature from IMOS GHRSST L3C products (6 day composite).

2.2. Hydrographic sampling

Sampling was either undertaken on the RV Bombora (NSW Office of Environment and Heritage, OEH, vessel; May and June 2011, September 2012) or on the RV Circe (provided by the National Marine Science Centre, NMSC, Coifs Harbour; July 2011–February 2012). On RV Bombora an automatic SBE32 carousel water sampler (Sea-Bird Electronics, Inc., USA) with 12 × 5 L Niskin-bottles (General Oceanics, USA) was deployed via an A-Frame. The CTD rosette was fitted with a SBE 911plus Conductivity–Temperature–Depth profiler (CTD) (Seabird Electronics, Inc., USA) and an ECO FLNTU fluorescence sensor (Wetlabs, Inc., USA). At each station, the CTD was allowed a surface soak of 3 min and then lowered to within 5 m of the seabed. Subsequently, water samples were taken at 20 m depth intervals during the upward cast and, as the CTD profiles were visualised in real time (during the downward cast), at the depth of the deep Chl a maximum (Supplementary Material Table 1). Surface samples were collected in a 10 L plastic bucket. Cast start and finish times and positions were recorded, however, as CTD casts lasted for a maximum of 20 min and boat drift with the mean current was negligible (~0.002 decimal degrees both
Accuracy in counting 400 cells of a single species infers a precision of ±10% (Lund et al., 1958) by counting a minimum of 400 cells per sample at 200× magnification. Plankton enumeration followed the Utermöhl method (Utermöhl, 1958) by dividing the filamentous cyanobacterium Triphysopseudo-nitzschia spp. at CH1 20 m, December 2011) per sample, the true number of cells was between 700% and 5%, respectively, of our estimate (Lund et al., 1958). Identification and enumeration were made at the lowest taxonomic level possible by an expert analyst based on taxonomic guides by Dakin and Colefax (1940), Crosby and Wood (1958, 1959), Wood (1954, 1961a,b), Wood et al. (1959), Tomas (1997), and Hallegraeff et al. (2010); and further studies by Hallegaard and Reid (1986), Ajani et al. (2001), Gómez et al. (2008), and Stidolph et al. (2012).

As the purpose of this study was to determine functional phytoplankton groups that are characteristic for distinct water-types, species belonging to the same genus were grouped. The morphologically similar diatom taxa Ceratoneis closterium/Nitzschia longissima, Gyrosigma/Pleurosigma spp., and their dinoflagellates Alexandrium/Gonyaulax/Heterocapsa spp., and Gephyrocapsa/Thalassiothrix spp. were grouped into a complex (Table 1). If the genus could not be determined (e.g. due to overlying particles in the sample or degradation of distinct morphological structures) diatoms were classified as “undefined centric” or “undefined pennate” and dinoflagellates as “undefined dinoflagellates”. A Calcofluor White Stain solution was added to each 3 mL sample 30 min prior to counting, at a total concentration of 20 μg mL⁻¹, to facilitate identification of thecate dinoflagellates (Fritz and Triemer, 1985), Distinct Gymnodinium spp. and Gyrodinium spp. >20 μm were included in the counts. Smaller individuals difficult to distinguish were excluded from the counts.

To quantify the abundance of the filamentous cyanobacterium Trichodesmium erythraeum, the average cell length of ten random filaments in a randomly picked sample was determined prior to counting (average = 7.5 μm; standard deviation = 1.9 μm). Subsequently (during counting), each filament was measured using an eyepiece micrometre and cell numbers of T. erythraeum were calculated by dividing the filament length by the average cell length.

Zooplankton (copepods and their larvae) including microzooplankton (ciliates, including tintinnids) were counted (following the Utermöhl
Table 1
List of taxa included in each water-type category and abbreviations used in Figs. 5b–8. Note that although some taxa may be considered as belonging to more than one category (e.g. warm-water and offshore), they were grouped under one category only based on their ordination (see Fig. 5b). Also given is the averaged (across all samples) proportional abundance including standard deviation of each taxon. Abundances of taxa that occurred on average >1% are indicated in italic font.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Abbreviation</th>
<th>Category</th>
<th>Average abundance (%)</th>
<th>Standard deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diatoms</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amphora spp.</td>
<td>Amp</td>
<td>Deep</td>
<td>0.05</td>
<td>0.16</td>
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<td>Deep</td>
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<td>0.045</td>
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<tr>
<td>Asterionellopsis glacialis</td>
<td>Ag</td>
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<td>7.84</td>
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<td>0.03</td>
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<td>1.50</td>
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<tr>
<td>Ceratoneis closterium/Nitzschia longissima</td>
<td>Cc/Nl</td>
<td>Cosmopolitan</td>
<td>4.62</td>
<td>4.91</td>
</tr>
<tr>
<td>Cerataulina pelagica</td>
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<td>Cosmopolitan</td>
<td>0.24</td>
<td>0.85</td>
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<td>Chaetoceros spp. (Hyalochoaete)</td>
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<td>6.49</td>
<td>9.79</td>
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<td>Offshore</td>
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<td>Deep</td>
<td>0.005</td>
<td>0.065</td>
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<td>Corethron spp.</td>
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<td>0.12</td>
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<td>Coccosidocus spp.</td>
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<td>0.14</td>
<td>0.41</td>
</tr>
<tr>
<td>Cyclotella spp.</td>
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<td>0.09</td>
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<td>2.72</td>
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<td>2.00</td>
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<td>0.07</td>
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<td>Deep</td>
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<td>3.81</td>
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<td>Gyrosigma/Pleurasygma spp.</td>
<td>G/Pleu</td>
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<td>0.34</td>
<td>0.83</td>
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<td>0.50</td>
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<td>5.18</td>
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<td>Warm</td>
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<td>0.69</td>
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<td>1.86</td>
<td>5.10</td>
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<td>0.07</td>
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<td>0.52</td>
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<td>0.0086</td>
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<td>0.32</td>
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<tr>
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<td>Dinoflagellates</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cf. Alexandrium/Gonyaulax/Heterocapsa spp.</td>
<td>Al/Gon/Het</td>
<td>Warm</td>
<td>0.62</td>
<td>0.99</td>
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<td>0.0069</td>
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<td>0.023</td>
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<td>Offshore</td>
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<td>0.07</td>
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<td>0.21</td>
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<td>3.94</td>
<td>6.30</td>
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<tr>
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Silicoflagellates

(continued on next page)
2.4. Multivariate analyses

In order to determine seasonal patterns in phytoplankton composition we conducted non-metric multidimensional scaling (MDS) on the log(X + 1) transformed phytoplankton abundance data (based on Bray–Curtis similarity and Kruskal-fit scheme 1) using PRIMER Version 6.1.12 (Clarke and Gorley, 2006).

To categorise phytoplankton taxa depending on their association with distinct water-types (where a water-type shall be defined as being characterised by one, or a combination of, abiotic environmental condition(s)/variable(s) within this study) we applied distance-based redundancy analysis following (Legendre and Anderson, 1999) via the distance-based linear modelling (distLM) procedure in PRIMER. Forward selection on the Akaike’s Information Criterion (AIC) was used to select the minimally adequate model. Environmental variables included in the distLM were month, temperature, salinity, density, distance from the coast, sample depth, mixed layer depth (MLD) and southward velocity. Months were integrated in the analyses by assigning each calendar month its respective number, e.g. January = 1, February = 2, etc. Temperature (°C), salinity (psu) and density (kg m⁻³) were recorded during CTD casts. Mixed layer depth (MLD, in m) was calculated for each station as the depth at which temperature < surface temperature−0.5 °C (Levitus, 1982). In the case that a station was too shallow and no MLD could be determined, the deepest sampled depth at that station was used instead. EAC velocities (m s⁻¹) on the shelf were derived from the moored ADCP measurements at the sampling depths of CH070 and CH100 on the respective sampling day. Measurements from CH070 and CH100 were extrapolated, assigning the velocities measured at CH070 to all inshore and midshelf stations (CH1–CH3, SS, B2–B6) and velocities measured at CH100 to the offshore stations (CH5 and B8). In the event that measurements were missing at a certain sampling depth, the measurement at the closest sampling depth of the same station was used. As velocity measurements were missing between July and August 2011 at CH3, and May and August 2011 at CH5 due to instrument failure, the average velocity measured over all other sampling days at the respective station was used during these two months in order to avoid any bias during the multivariate analysis. We compared the velocities from the sampling day (V-d0) to the preceding days (vd-1, vd-3) to account for the recent water mass history. None of the statistical comparisons showed a significant difference between velocities (data not shown), thus we consider our multivariate analysis as robust. Eleven samples had to be excluded from the distLM due to missing environmental information (Supplementary Material Table 1).

In order to determine seasonal phytoplankton abundance and composition patterns, and to define specific ranges of physical parameters associated with each category, we summarised the monthly- and depth-averaged abundances of each category and counted zooplankton position patterns, and to demonstrate Material Table 1).

We investigated the influence of the EAC encroachment on the cross-shelf phytoplankton community structure by choosing two months characterising weak and strong events of EAC influence (as determined by ADCP velocity data) and conducted an additional MDS and distLM for each of these months (using PRIMER Version 6.1.12).

3. Results

3.1. Oceanography

The mean (standard deviation) depth-averaged poleward alongshelf velocity over the 20 sampling days was 0.24 (0.15) m s⁻¹ and 0.37 (0.25) m s⁻¹ at CH070 and CH100, respectively (Fig. 2). The average temperature in the Coffs Harbour region across all sampling days, stations and depths was 20.6 °C ± 2 °C (Fig. 3a).

Weak current velocities occurred on 12 October 2011, when the EAC was flowing more offshore (Fig. 2) and the circulation on the shelf was less than half the mean, with poleward depth-averaged velocities of 0.06 m s⁻¹ at CH070 and 0.10 m s⁻¹ at CH100 (Fig. 2). We found weak cross-shelf gradients of temperature and density (Fig. 3c, d) with horizontal differences of 20–20.5 °C and 24.6–25.5 kg m⁻³ in the upper water column (0–20 m depth) while salinity remained at ~35.5 psu (Fig. 3d). This scenario was chosen to characterise the weak EAC influence on the phytoplankton community (Section 3.5). In contrast, strong current velocities occurred on 24 January 2012, with depth-averaged velocities of 0.34 m s⁻¹ at CH070 and 0.77 m s⁻¹ at CH100 (Fig. 2). This was a consequence of the EAC encroaching the shelf, as shown in Fig. 1 by the warm intense southward flow reaching shallow depths close to the coast, and in Fig. 2 by a similar current intensity measured at CH100 and through axiometry at the shelf break.

The intrusion of the EAC onto shelf was characterised by a warm surface layer, which resulted in an uplift of the isopycnals in response to the intense bottom stress when encroaching the shelf (Fig. 3e, f). A horizontal increase in temperature of about 2 °C was observed in the surface waters across the shelf, with a larger temperature gradient at depth (3–5 °C; Fig. 3e, f), in good agreement with findings by Schaeffer et al. (2013, 2014a) of composite values of cross-shelf temperature gradients in response to the EAC. This scenario represented the strong EAC influence on phytoplankton community composition (Section 3.5).

3.2. Phytoplankton abundance and composition

A total of 74 phytoplankton genera were determined throughout the complete study period, with 19 taxa (12 diatom taxa, six dinoflagellate taxa and Trichodesmium erythraeum) occurring (across all samples) on average >1% (Table 1). Most abundant were Leptocylindrus spp. (18%, mainly L. danicus and very rarely L. mediterraneus), Pseudo-nitzschia spp. (14%), T. erythraeum, Chaetoceros spp. (Hyalochaete) and undefined pennate diatoms (each about 6% Table 1). The 19 abundant taxa, except undefined pennate diatoms and undefined dinoflagellates, were selected as representatives of the water-type categories (Section 3.4). A complete list of all phytoplankton genera, their abbreviations and average

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**Table 1 (continued)**

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<th>Taxon</th>
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<th>Standard deviation (%)</th>
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method) in order to account for successional patterns in the plankton community. However, as the primary focus of this study is to provide a phytoplankton time-series survey, the total abundance of the zoo- and micro-zooplankton is used as a simple proxy of their potential predatory impact.
percent abundance across all samples including standard deviation is given in Table 1. The exact abundance per sample of each individual taxon (of a total of 137 taxa) within the 74 genera and of zooplankton is publicly available at: http://catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=f7502841-2c7-4437-b557-20ef89e754e0. Total abundances of the sum of diatoms, dinoflagellates and silicoflagellates ranged between $2.00 \times 10^2$ cells L$^{-1}$ (CH5, 90 m, July 2011) and $1.94 \times 10^6$ cells L$^{-1}$ (CH1, 20 m, December 2011; Fig. 4). T. erythraeum occurred in abundances of up to $4.33 \times 10^5$ cells L$^{-1}$ (SS, 0 m, October 2011; Fig. 4). Thus, low phytoplankton abundances were found in late autumn and winter and high abundances in spring and summer (Fig. 4). Phytoplankton abundances generally decreased with increasing distance from the coast and sample depth. Diatoms dominated the phytoplankton community throughout all samplings. Zooplankton abundance reached $1.75 \times 10^4$ specimens L$^{-1}$ (CH1, 0 m, October 2011) but remained below $1 \times 10^3$ specimens L$^{-1}$ in most instances (and were frequently 0; Fig. 4). High zooplankton abundances were found in surface samples during spring and summer (http://catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=f7502841a2c7-4437-b557-20ef89e754e0).

### 3.3. Characterisation of the phytoplankton community through environmental variables

Multivariate analyses on the complete phytoplankton abundance dataset enabled to identify a seasonal pattern in phytoplankton composition in the Coffs Harbour region (Fig. 5a). Species composition differed slightly in each month as reflected by the relatively close clustering of the same symbols in Fig. 5a. A gradual transition in species composition is indicated from May (austral autumn) through to August 2011 (winter; as indicated by black and purple to blue filled symbols, which are arranged from right to left in Fig. 5a), September to November 2011 (spring; ordination of light to dark green symbols from the right to the left in Fig. 5a) and December to February (summer; ordination of light to dark orange/red open symbols from the left to the right in Fig. 5a). The phytoplankton population found in September 2012 (grey open triangles) seemed to differ from the population in September 2011 (light green crosses, Fig. 5a).

DistLM determined seven of the eight environmental variables measured as being important drivers of the phytoplankton community structure. In descending order these variables were: MLD, temperature, distance from the coast, sample depth, month, velocity and density; in total explaining 18.7% of the variability in phytoplankton composition (Table 2). Fitted vectors represented the strength (length of a vector) and correlation (Spearman correlation, where a strong (weak) correlation is indicated by acute (obtuse) angles between vectors) of the environmental variables (Fig. 5b). Thus, velocity and month, and velocity and temperature, were correlated, as were density, sample depth, MLD and salinity (Fig. 5b). Distance from the coast was correlated with temperature, increased sample depth, MLD and salinity (Fig. 5b). The correlation of velocity with temperature as well as month indicated
that seasonal and EAC-driven patterns in phytoplankton composition are partially related.

Superimposed ordination of individual phytoplankton taxa suggested groups of phytoplankton taxa that specifically responded to different environmental variables (i.e. ordination along vectors representing those variables, Fig. 5b, Table 1). Consequently, we determined five phytoplankton categories associated with different water-types, with the latter being defined based on the ordination of vectors:

1. Seasonal/bloom taxa: Taxa associated with the variable month and, to a lesser degree, southward velocity.
2. Cosmopolitan taxa: Taxa not particularly responding to any environmental variable, i.e. tolerant towards a relatively wide range of environmental conditions.
3. Deep-water taxa: Taxa associated with increased sample depth, salinity and density.
4. Warm-water taxa: Taxa strongly associated with increased temperature and, to a lesser degree, southward velocity.
5. Offshore taxa: Taxa responding to increased distance from the coast and increased MLD.

While diatoms were the major phytoplankton class in categories one to three, dinoflagellates dominated categories four and five (Table 1). Silicoflagellates only occurred in category five and *T. erythraeum* was assigned to the warm-water group (Table 1). All taxa and their assigned category are listed in Table 1. It should be noted that although some taxa may be considered as belonging to more than one category (e.g. warm-water and offshore), they were grouped under one category only based on their ordination (Fig. 5b). Furthermore, the grouping was qualitative, i.e. no individual tolerance windows of taxa for environmental variables were determined but a general association with such variables. However, detailed information on the temperature ranges of individual taxa assigned to the warm-water category can be found in Supplementary Material Table 2.

### 3.4. Seasonal variation of the phytoplankton community in relation to the physical environment

Monthly averaged abundance of all phytoplankton taxa assigned to each of the five water-type categories (and their most abundant representative taxa), total phytoplankton and zooplankton was summarised in T-S plots (Figs. 6, 7). The exact values of averaged abundances including standard deviations are given in Supplementary Material Table 3.

T-S plots visualised the seasonal change in total phytoplankton abundance and the seasonal contribution of each category (and representative species) with respect to the physical oceanographic environment (Figs. 6, 7). Generally, we found the abundance of total phytoplankton and within each phytoplankton category to be higher in summer (characterised by warm, low-salinity/density water) than late autumn and winter (characterised by cold, saline/dense water) (Fig. 6a–d, f, g). This seasonal signal was most pronounced in the seasonal/bloom category (Fig. 6c) and least expressed in the deep-water category (Fig. 6e). The seasonal/bloom, cosmopolitan, deep and warm water categories were sporadically abundant in individual months during spring (September–November 2011 and September 2012), which was characterised by relatively cold, saline/dense water, especially during September 2012 (Fig. 6c, d, e, f).

Highest abundances were found within the seasonal/bloom category during December 2011 (4.71 × 10^5 cells L^{-1}) and September 2012 (2.19 × 10^5 cells L^{-1}) (Fig. 6c) and could be assigned to blooms of the diatoms *Leptocylindrus danicus* (September 2012) and *Pseudo-nitzschia* spp. (December 2011) (Fig. 7a,b). Despite the identical appearance of individual *Pseudo-nitzschia* cells counted in the September 2012 samples we cannot exclude that more than one species of this diatom genus were present (due to the relatively low resolution of light microscopy) and therefore refer to *Pseudo-nitzschia* spp. in the following. Average temperature, salinity and density during the *Pseudo-nitzschia* spp. bloom were 21 °C, 35.5 psu and 24.74 kg m^{-3}, respectively while during the *L. danicus* bloom 18 °C, 35.5 psu and 25.75 kg m^{-3}, respectively (Figs. 6a, 7a,b). The depth-averaged southward velocity was 0.24 m s^{-1} and 0.42 m s^{-1} at CH070 and CH100, respectively, during the blooms in December 2011 (averaged between the two sampling days) and 0.04 m s^{-1} and 0.02 m s^{-1} at CH070 and CH100, respectively, during the September 2012 bloom (Fig. 2). Dinoflagellates of the genus *Gyrodinium* were also representative of the seasonal/bloom group (Fig. 7c). Although occurring in much lower abundances than *L. danicus* and *Pseudo-nitzschia* spp., a peak of *Gyrodinium* spp. was determined during December 2011 (the month of the *Pseudo-nitzschia* spp. bloom, Fig. 7b, c).

Relatively high abundance of the cosmopolitan category was found throughout all months (compared to warm-, deep-water and offshore
taxa) and over a wide range of temperature, salinity and density (17–24 °C, 35.2–35.5 psu and 24–25.75 kg m$^{-3}$, respectively, Fig. 6a, d). The seasonal abundance of this category followed the general pattern, with slightly higher abundances during summer than in late autumn and winter (Fig. 6d). Most (i.e. eight) of the 19 taxa that contributed >1% to the total phytoplankton community were assigned to the cosmopolitan category, with *Asterionellopsis glacialis* and *Chaetoceros* spp. (Hyalochaetes) being the most abundant (1.77 × 10$^4$ and 2.05 × 10$^4$ cells L$^{-1}$, respectively, Fig. 7d–k).

Chaetoceros spp. deviated from the seasonal pattern, being relatively abundant in June and August (Fig. 7f). The deep-water category was present in low abundance and did not follow the general seasonal signal as abundance within this group was elevated during winter and spring (especially August 2011, Fig. 6e). The most abundant representative of the deep-water category was the diatom genus *Navicula*, which peaked during August 2011, and, to a lesser degree, during September 2012 (Fig. 7m). We added the diatom genus *Diploneis* as a second representative of the deep-water category (*Diploneis* spp. contributed on average 0.9% to the total phytoplankton community, Table 1). However, *Diploneis* was most abundant during December 2011 and showed its second highest abundance during August 2011 (Fig. 7l).

Warm-water taxa were most prominent during summer (December 2011–February 2012, Fig. 6f). Within this category, *T. erythraeum* was the most abundant phytoplankton taxon (Fig. 7o). Despite exhibiting high abundances during summer (up to 2.42 × 10$^4$ cells L$^{-1}$), *T. erythraeum* also showed relatively high abundances during October 2011 (1.85 × 10$^4$ cells L$^{-1}$, Fig. 7o). Warm-water dinoflagellates of the genera *Oxytoxum*, *Karlodinium* and *Prorocentrum* and the species *Scrippsiella trochoidea* showed highest abundances during summer (Fig. 7n, p, q, r). All genera revealed high abundance during December 2011, however, elevated abundance of *Karlodinium* (6.95 × 10$^3$ cells L$^{-1}$), *Prorocentrum* (2.43 × 10$^3$ cells L$^{-1}$) and *S. trochoidea* (2.78 × 10$^3$ cells L$^{-1}$) was also determined during November 2011, October 2011 and September 2012, respectively (Fig. 7p, q, r, respectively).
Lowest abundances were found within the offshore category (compared to all other categories), reaching small maxima during summer (Fig. 6g). As no taxon assigned to this group contributed N1% to the total phytoplankton community, we selected the two most abundant offshore taxa, namely the silicoflagellate genus *Dictyocha* and the diatom *Climacodium frauenfeldianum* as representative taxa for this group (contributing on average 0.65% and 0.52% to the total phytoplankton community, Table 1).

*C. frauenfeldianum* had highest abundances during January 2012, and *Dictyocha* spp. during December 2011 (4 × 10^2 and 4.23 × 10^2 cells L^-1, respectively, Fig. 7s, t).

Zooplankton occurred in abundances between 88 and 2.67 × 10^3 specimens L^-1 (Fig. 6h). Maximum abundances within this group occurred during December 2011 and September 2012 (Fig. 6h), i.e. coinciding with bloom periods of the diatoms *Pseudo-nitzschia* and *Leptocylindrus* spp. (Fig. 7a, b).

### 3.5. Influence of EAC encroachments on phytoplankton composition

During October 2011, the weak EAC scenario, distLM revealed sample depth, distance from the coast and southward velocity as being the most important variables in explaining the variability in phytoplankton composition (in descending order; Table 2). In total, these variables explained 45% of the variability in the phytoplankton composition (Table 2). Sample depth was strongly correlated with density, distance

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<th>Temperature (°C)</th>
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<th>Density (kg m^-3)</th>
<th>Depth (m)</th>
<th>Month</th>
<th>Salinity (psu)</th>
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</table>

Fig. 6. Temperature–salinity plots showing average temperature and salinity including standard deviation (a), abundance of total phytoplankton (b), phytoplankton taxa belonging to the five water-type categories (c–g) and zooplankton (h) per month (averaged across all samples collected during each month; for complete species list and exact monthly averaged abundances including standard deviations see Table 1 and Supplementary Material Table 3, respectively). Phytoplankton abundances are given in cells L^-1 and zooplankton abundances in specimens L^-1. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)
from the coast with MLD and temperature with southward velocity (Fig. 8a). Unexpectedly, salinity was not correlated with depth/density, which we account to slightly lower salinity values measured at the bottom depths of the offshore stations (data not shown). However, the vector pair distance from the coast/MLD was ordinated in between the vector pair temperature/velocity and the vector pair depth/density, indicating a weak correlation with both these vector pairs (Fig. 8a). This ordination pattern suggested a cross-shelf gradient of increasing temperature/velocity and depth/density with distance from the coast (although this gradient was relatively small for temperature, salinity and density in the upper water column, see Section 3.1). We determined a cross-shelf transition in phytoplankton composition, indicated by the ordination of inshore to offshore stations following the direction of the distance from coast vector (blue to red symbols from the right to the left, Fig. 8a). The majority of diatoms were found to be associated with increased distances from the coast, including taxa from the cosmopolitan, offshore and seasonal/bloom categories (Fig. 8a). Dinoflagellates, including warm-water and seasonal/bloom taxa, seemed to mainly respond to warm temperature (Fig. 8a). Taxa associated with depth included taxa that had been predominantly assigned to the deep-water category (e.g. Navicula...
The cyanobacterium *T. erythraeum* was only correlated with temperature and velocity (although relatively weakly; Fig. 8a). Highest total phytoplankton abundances, in particular of *T. erythraeum*, were found in inshore surface waters ([http://catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=f7502841-a2c7-4437-b557-20ef89e754e0](http://catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=f7502841-a2c7-4437-b557-20ef89e754e0)).

During January 2012, when the EAC influence was strong, distLM determined southward velocity as being most important in explaining the variability of the phytoplankton composition, followed by distance from the coast and MLD (in descending order; Table 2). In total, these three variables explained 53% of the variability in the phytoplankton composition (Table 2). Velocity, MLD, temperature and distance from the coast were strongly positively correlated, as were sample depth, salinity and density (Fig. 8b). The first combination of vectors confirmed the strong influence of the warm EAC and its impact on the phytoplankton composition offshore, the latter being indicated by the ordination of the offshore stations close to the velocity vector (Fig. 8b). The second combination of vectors confirmed the intrusion of cold bottom water onto the shelf, which was observed to impact on the inshore phytoplankton community (Fig. 8b). The phytoplankton community composition on the mid-shelf seemed to be relatively mixed (as indicated by the wide-spread distribution of mid-shelf station symbols) and influenced by both the warm and strong EAC and the intrusion of cold, saline and dense bottom water (Fig. 8b). On average (across all samples) total phytoplankton abundance was eight times higher during January 2012 than during October 2011 (Fig. 6b, Supplementary Material Table 3) with highest abundances, in particular of diatoms, found at the mid-shelf station CH3 ([http://catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=f7502841-a2c7-4437-b557-20ef89e754e0](http://catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=f7502841-a2c7-4437-b557-20ef89e754e0)). Warm-water and offshore taxa, including...
several dinoflagellates and *T. erythraeum*, were clearly associated with elevated temperature and velocities in this strong EAC scenario (Fig. 8b). Deep-water taxa, such as *Navicula* spp. and *Diploneis* spp. were associated with the cold, saline and dense bottom water encroaching onto the shelf (Fig. 8b).

4. Discussion

4.1. Achievements and limitations of our phytoplankton survey

Our study provides the first detailed taxonomic phytoplankton time-series survey in the tropical-temperate transition zone (~30°S) of Eastern Australia. Within a nearly complete annual cycle we were able to determine 74 phytoplankton genera that occurred in the Coffs Harbour region between 2011 and 2012. Our analysis was based on phytoplankton counts conducted via microscopy, and infers two major restrictions. Firstly, microscopy suffers from inherently poor counting statistics (Lund et al., 1958; Sournia, 1978; Armbrrecht et al., a, under review) and counting errors cannot be excluded. Due to the limited resolution of light microscopy, cells <5 μm were excluded from the analyses. Such small-sized phytoplankton, however, dominate the phytoplankton community during winter months and non-bloom periods in the Coffs Harbour region (up to 80% in total; Armbrrecht, 2014). Therefore, future studies should employ measures to enable the inclusion of small-sized phytoplankton taxa when investigating interactions between physical parameters and primary production, especially in the context of SST warming and EAC strengthening.

We were able to link seasonal phytoplankton abundance and composition patterns (water-type categories and most abundant taxa) as well as cross-shelf distribution patterns to the strength of the EAC (discussed below in detail). However, it should be noted that a maximum variability of 53% was explained in our multivariate analyses (Section 3.5), i.e. other factors, such as nutrient concentrations, light regime and turbulence, most likely influenced the phytoplankton community during our samplings. These factors are acknowledged here, however, this paper is focussed on interactions between phytoplankton and the physical oceanographic environment.

4.2. Seasonal patterns in the phytoplankton composition off Coffs Harbour

The average velocity encountered on the continental shelf at 30°S between May 2011 and September 2012 is in agreement with the two-year averaged values presented in Schaeffer et al. (2013, 2014a). It is known that the EAC exhibits a seasonal cycle strengthening during the austral summer (Godfrey et al., 1980; Ridgway and Godfrey, 1997), although this seasonal cycle is not as clear in the circulation on the continental shelf (Schaeffer et al., 2013, 2014a; Wood, 2014). We found the seasonal phytoplankton abundance and composition to strongly depend on the strength of the current along the Coffs Harbour coast. This dependence was particularly supported by the strong correlation between environmental variables serving as proxies for temporal evolution in phytoplankton composition (month) and EAC influence (southward velocity and temperature). All phytoplankton categories defined in this study, particularly the seasonal/bloom category, exhibited their highest abundances during summer. The exception was deep-water taxa, which seemed to generally prefer relatively cold, saline and dense water independently of the season. Maximum phytoplankton abundance was reached during December 2011, when southward velocities were relatively high. During this month we observed a bloom of the diatom *Pseudo-nitzschia* spp., a ubiquitous taxon previously reported as one of the most abundant genera in the temperate region of Eastern Australia (Hallegraeff and Reid, 1986; Ajani et al., 2013). Although we are unable to make any statements regarding the longevity of this *Pseudo-nitzschia* bloom, the morphology and appearance of the diatom during our counts under the microscope suggested that it was in its stationary growth phase. A second prominent diatom bloom, this time attributed to *L. danicus*, was noted in September 2012, unexpectedly when southward velocities were relatively weak. The *L. danicus* bloom was most likely induced by a wind-driven upwelling event occurring four to five days prior to our sampling and already in its senescent phase as suggested by microscopy and pigment analyses (discussed in detail in Armbrrecht et al., a, b, under review). Assuming that the diatom blooms were already approaching or in their end-phases, the increased abundance of predatory zooplankton in December 2011 and September 2012 is also consistent with our bloom observations and suggests that grazing might have had an impact on bloom termination in both months. The latter assumption is plausible, considering that successive patterns in phytoplankton can cover short periods (a few weeks) until a physical disturbance "resets" the oceanographic and nutrient resource conditions (Hallegraeff and Reid, 1986; Wyatt, 2014).

4.3. Cross-shelf phytoplankton distribution during weak and strong EAC influence

Our study showed that the strength of the EAC has an influence on the cross-shelf phytoplankton community structure. When the EAC was weak (October 2011), the relatively homogeneous temperature, salinity and density of the upper water column across the whole shelf created a similar habitat (with regard to temperature and vertical mixing) for all taxa. The homogeneous condition of the upper water column might explain the overlapping cross-shelf distribution of, in particular, cosmopolitan, seasonal/bloom and offshore taxa (i.e. mainly diatoms) and also the relatively weak correlation of very few warm-water (*e.g. T. erythraeum*) taxa with temperature (as there was no major difference in temperature). However, highest total phytoplankton abundances were found inshore (25 m isobath), a feature common of the Coffs Harbour region (Armbrcht et al., 2014).

When a strong EAC prevailed during January 2012, and southward velocity drove the cross-shelf phytoplankton composition and distribution (alongside temperature, distance from the coast and MLD), warm-water and offshore taxa were highly associated with both warm temperature and increased distances from the coast. This association verified our selection of taxa into the warm-water and offshore categories. Our finding of highly elevated phytoplankton abundances, with an increase in the warm-water category at the expense of seasonal/bloom taxa (relative to December 2011 and February 2012), is consistent with previous results from Coffs Harbour, where the appearance of tropical dinoflagellates at the offshore station CH5 had been associated with pronounced EAC intensification (Armbrcht et al., 2014). In addition, the localisation of a maximum phytoplankton response, in particular diatoms, at the mid-shelf (~75 m isobath), equals previous findings from a current-driven upwelling period during June 2011 (Armbrcht et al., 2014). Such a repeated occurrence of a maximum phytoplankton response on the mid-shelf (~53% shelf-width) off Coffs Harbour during times when the EAC is strong indicates that this response is a recurrent phenomenon and should be investigated further.

The cyanobacterium *T. erythraeum* was the main contributor to the high phytoplankton abundance determined within the warm-water category during January 2012. *T. erythraeum* is a warm-water species commonly found in oligotrophic tropical regions (Capone et al., 1997); hence its appearance in the Coffs Harbour region during January 2012 may be indicative of its increased transport with the EAC. Nevertheless, we found a high density of *T. erythraeum* under both strong and weak EAC conditions. We hypothesise that *T. erythraeum* may have established itself permanently in the east Australian tropical-temperate transition zone and speculate that the species is undergoing a seasonal cycle with pronounced growth during spring and summer. This hypothesis is supported by our observation of a *T. erythraeum* bloom exactly one year later, around the 30th October 2012, in which cell numbers of $1.87 \times 10^6$ were reached at the surface at CH3 (data
not shown). Alternatively, the elevated abundance of *T. erythraeum* during our sampling in October 2011 might have been caused by EAC intrusions prior to our sampling (as exemplified by the *L. danicus* bloom in September 2012).

4.4. Coffs Harbour phytoplankton variability in the regional context

This study is the first to show that seasonal phytoplankton abundance patterns exist in the Coffs Harbour region, upstream of the EAC separation zone and thus highly exposed to the influence of the EAC. Our results exhibit similarities as well as differences to previous investigations from the more southerly Port Hacking station in the importance of the EAC as a driver phytoplankton dynamics. For example, phytoplankton taxa that have been defined as most abundant taxa in our study were also listed as highly abundant at the Port Hacking station. These taxa include the diatoms *Pseudo-nitzschia* spp., *L. danicus*, *Chaetoceros* spp., and *C. closterium/N. longissima*, as well as dinoflagellates such as *Gyrodinium*, *Prorocentrum* spp. and *S. trochoidea* (Hallegraeff and Reid, 1986; Ajani et al., 2001). In addition, taxa that were classified as warm-water or seasonal/bloom taxa through our analyses have been summarised in comparable groups in the Port Hacking studies (e.g. *L. danicus* as a bloom-species and *Pseudo-nitzschia* sp. (in particular *P. fraudulenta*) as consistently present, Hallegraeff and Reid, 1986). Consistent with our study, *T. erythraeum* has been described as frequently abundant warm-water species in investigations from Port Hacking before (Ajani et al., 2011).

However, there are differences in the composition of less abundant taxa with a higher proportion (−2x) of tropical species occurring at Coffs Harbour compared to Port Hacking (species distributions taken from Hallegraeff and Reid, 1986; Tomás, 1997; Ajani et al., 2001; Hallegraeff et al., 2010). Additionally, studies from Port Hacking have suggested that *T. erythraeum* is transported to temperate regions of Eastern Australia with the EAC, EAC-derived warm core eddies and occurs in higher abundances during anomalously warm conditions after El-Niño events (Hallegraeff and Reid, 1986; Ajani et al., 2001). Here we found *T. erythraeum* being highly abundant regardless of EAC strength. In addition, all or some samples fall within two consecutive La Niña periods between 2010 and 2012, in which record and near-record values of the Southern Oscillation Index (SOI) were reached (SOI’s of up to 27.3; BOM, 2012). La Niña events are expressed in enhanced trade winds over the tropical Pacific, resulting in a strong flow of the South Equatorial Current and EAC, above-average SST’s along the east Australian coast (Feng, 2004; Holbrook et al., 2011). Although the occurrence of the warm-water species *T. erythraeum* in the Coffs Harbour region may be associated with enhanced SST’s during La Niña conditions, its presence during strong and weak EAC events supports our hypothesis that this cyanobacterium has established itself permanently in the east Australian tropical-temperate transition zone and is undergoing an intrinsic seasonal cycle (see Section 4.3).

4.5. General relevance of the Coffs Harbour phytoplankton survey

It has been proposed that the phytoplankton communities along the Australian east coast will proportionally increase in dinoflagellates and decrease in diatoms due to climate change-derived modifications in physical and chemical parameters (e.g. strengthening EAC, warmer temperatures, lower silicate concentrations; Thompson et al., 2009; Ajani et al., 2014a, b). Our short-term study supports this theory as we found warm-water and offshore species to be dominated by dinoflagellates, including tropical taxa that were most likely transported to Coffs Harbour with the EAC. Our results furthermore suggest that increased abundances of dinoflagellates may be found particularly offshore, where the main flow of the EAC prevails.

It is speculated that the observed long-term strengthening of the EAC may increase the occurrence of current-driven upwelling events along the east Australian coast as a higher bottom stress leads to stronger bottom uplift (Schaef er et al., 2013, 2014a), in which case we would expect diatoms to be favoured by their competitiveness during sporadic nutrient pulses (e.g. Margalef 1978; Ajani et al., 2001). Our study demonstrated that diatoms, especially bloom-forming and cosmopolitan species, dominate the microphytoplankton community in the tropical-temperate transition zone. Species such as *L. danicus*, *Pseudo-nitzschia* spp. and *A. glacialis* can exhibit high division rates under nutrient-replete and high light conditions (−2.2, 1.5, 1.5 day−1, respectively; unpublished data, not shown) and are thus highly competitive. On the contrary, the predicted decline of diatoms due to reduced silicate availability (Thompson et al., 2009) might have severe consequences for succession patterns and biogeochemical processes, especially in an area that is as exposed to the EAC influence as the Coffs Harbour region. While abundances of diatoms seem stable, a change towards the less silicific species *Thalassiosira partheneia* (Brzezinski, 1985) has already been shown at the Port Hacking station (Ajani et al., 2014a,b). Similarly, Thompson et al. (2008) reported a shift from a *Pseudo-nitzschia* sp. to a *Skeletonema* sp. (low half-saturation constants for silicate uptake $K_s$; Paasche, 1973) dominated phytoplankton community in coastal waters at ~43°S, Tasmania.

With the predicted strengthening and warming of the EAC, tropical phytoplankton species might become more prominent in the east Australian tropical-temperate transition zone (this study and Armbrecht et al., 2014). Clearly, the Coffs Harbour region, exposed to the main flow EAC, and with the oceanographic infrastructure in place, provides an excellent study location for future changes on the primary producer level caused by long-term changes in the local oceanography. Such studies will also be of interest to fisheries and marine protected area authorities, especially at Coffs Harbour, which is part of a marine park.

5. Conclusion

Our study provides the first detailed taxonomic time-series survey in the east Australian tropical-temperate transition zone (−30°S) upstream of the EAC separation point. Within this study we determined 74 phytoplankton taxa, of which the majority were diatoms, followed by dinoflagellates, silicoflagellates and the cyanobacterium *T. erythraeum*. Five phytoplankton categories associated with different water-types were determined and confirmed via temperature–salinity plots. Four of the categories (seasonal/bloom, cosmopolitan, warm-water and offshore taxa), and representative taxa therein, revealed a seasonal signal (with increased/decreased abundance during summer/winter) while one category (deep-water taxa) occurred relatively independent of the season in cold, saline dense bottom water. The most extensive blooms were caused by diatoms (*Pseudo-nitzschia* spp., December 2011, and *L. danicus*, September 2012) and most likely initiated by upwelling. The extent of EAC encroachment onto the shelf influenced the cross-shelf and vertical phytoplankton abundance, composition and distribution. The diazotroph, warm-water cyanobacterium *T. erythraeum* is seemingly undergoing a seasonal cycle off Coffs Harbour. We conclude that the phytoplankton community in the east Australian tropical-temperate transition zone is driven by a seasonal, as well as, EAC signals and the interaction between both. Our baseline investigation is an important reference for future phytoplankton research aimed at determining latitudinal range expansions along the east Australian coast and improves our understanding of interactions between oceanic forcing and phytoplankton dynamics in a WBC system, potentially being applicable to such systems worldwide.

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