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Henley, Sian, Schofield, Oscar M., Hendry, Katharine R. et al. (20 more authors) (2019) Variability and Change in the West Antarctic Peninsula Marine System: Research Priorities and Opportunities. Progress in Oceanography. pp. 208-237. ISSN 0079-6611

https://doi.org/10.1016/j.pocean.2019.03.003

Variability and change in the west Antarctic Peninsula marine system: research priorities and opportunities

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Keywords:, physical oceanography, nutrient and carbon cycling, ecosystems, primary production, sea ice, climate change

Regional index terms: Southern Ocean, Antarctica, West Antarctic Peninsula

Abstract

The west Antarctic Peninsula (WAP) region has undergone significant changes in temperature and seasonal ice dynamics since the mid-twentieth century, with strong impacts on the regional ecosystem, ocean chemistry and hydrographic properties. Changes to these long-term trends of warming and sea ice decline have been observed in the 21st century, but their consequences for ocean physics, chemistry and the ecology of the high-productivity shelf ecosystem are yet to be fully established. The WAP shelf is important for regional krill stocks and higher trophic levels, whilst the degree of variability and change in the physical environment and documented biological and biogeochemical responses make this a model system for how climate and sea ice changes might restructure high-latitude ecosystems. Although this region is arguably the best-measured and best-understood shelf region around Antarctica, significant gaps remain in spatial and temporal data capable of resolving the atmosphere-ice-ocean-ecosystem feedbacks that control the dynamics and evolution of this complex polar system. Here we summarise the current state of knowledge regarding the key mechanisms and interactions regulating the physical, biogeochemical and biological processes at work, the ways in which the shelf environment is changing, and the ecosystem response to the changes underway. We outline the overarching cross-disciplinary priorities for future research, as well as the most important discipline-specific objectives. Underpinning these priorities and objectives is the need to better-define the causes, magnitude and timescales of variability and change at all levels of the system. A combination of traditional and innovative approaches will be critical to addressing these priorities and developing a co-ordinated observing system for the WAP shelf, which is required to detect and elucidate change into the future.

Introduction

The west Antarctic Peninsula (WAP) continental shelf hosts a productive marine ecosystem, which is regionally important for krill stocks over the shelf and downstream in the Southern Ocean circulation system (e.g. Atkinson et al. 2004; Quetin et al. 1996), and for larger marine organisms as a breeding and/or feeding ground for migratory and year-round species (e.g. Costa and Crocker 1996; Ducklow et al. 2007; Friedlaender et al. 2006). From a climatic and biogeochemical perspective, the WAP is important because the southern flank of the Antarctic circumpolar current (ACC) flows particularly close to the shelf edge in this region (Orsi et al. 1995). As such, circumpolar deep water (CDW) from its mid-depths incurs directly on to the shelf in a less modified form than elsewhere around Antarctica, facilitating greater connectivity and exchange of physical and biogeochemical properties between these intermediate water masses and the atmosphere and surface ocean (Hofmann et al. 1996; Klinck 1998). Significant variability in the physical environment, modulated by strong coupling to climate processes over interannual and decadal timescales, is having a strong impact on regional biogeochemistry and all levels of the shelf ecosystem, making the WAP an important model region in which to understand the impacts of climate on polar marine systems.

Temperature records for the WAP have shown the largest average atmospheric warming in the southern hemisphere during the twentieth century, with particularly pronounced warming during winter (King et al. 2003; Vaughan et al. 2003). This has been accompanied by a significant decadal warming of surface and deeper waters and changes in salinity over large parts of the WAP shelf (Meredith and King 2005). Significant warming and salinification of the deeper waters over the southern and central WAP shelf resulted from shoaling of the thermocline along the slope and increased transport of warm upper circumpolar deep water (UCDW) onto the shelf, as well as increased heat content of the UCDW layers themselves (Martinson et al. 2008; Schmidtko et al.

2014). Significant surface freshening has been observed closer to coastal glacial meltwater sources, whilst upper layer salinification has occurred further offshore (Bers et al. 2013; Meredith and King 2005; Schloss et al. 2012).

Atmospheric and oceanic warming trends have been accompanied by strong changes in ice dynamics along the WAP, with the regional extent and duration of sea ice cover declining significantly since the late 1970s (Stammerjohn et al. 2012). Climate change appears more advanced in the northern region of the WAP as the warmer maritime climate moves southwards displacing the colder drier continental climate that dominated previously (Ducklow et al. 2007; Montes-Hugo et al. 2009). Substantial and widespread glacial retreat along the WAP has been attributed primarily to increasing ocean temperatures (Cook et al. 2016; Padman et al. 2012), with an important role for atmospheric forcing in the northern WAP (Falk and Sala 2015).

Whilst the regional warming and sea ice declines have been particularly rapid since the mid-twentieth century, these trends have slowed and plateaued since the late 1990s (Figure 1), with an absence of statistically significant atmospheric warming and sea ice losses between 1999 and 2014 (Turner et al. 2016). Statistically significant increases in sea ice extent have been observed in the northern WAP since the late 1990s (Turner et al. 2016), and an increase in both the extent and duration of sea ice cover, and its interannual variability, have been observed in the coastal WAP since the late 2000s (Figure 1; Schofield et al. 2017). These recent short-term reversals and the plateauing of longer-term trends reflect significant natural internal variability in the regional climate superimposed on longer-term trends, which leads to substantial short-term variation in sea ice dynamics (Hobbs et al. 2016; Stammerjohn and Maksym 2017; Turner et al. 2016). Whilst the plateauing of temperature and sea ice trends has weakened the magnitude of the longer-term trends, the overall warming and sea ice losses are still statistically significant (Figure 1).

Large-scale atmospheric circulation patterns and in particular the Amundsen Sea Low (ASL) exert a strong control on the observed climatic variability and change at the WAP (Raphael et al. 2016). The ASL is a persistent low pressure region between the Ross Sea and the Bellingshausen Sea/WAP sector, which is strongly influenced by the Southern Annular Mode (SAM) and also by the El Niño Southern Oscillation (ENSO) (Lachlan-Cope et al. 2001; Raphael et al. 2016; Turner et al. 2013). Changes in the ASL affect the strength and direction of winds over the WAP, which act as a key control on the amount and meridional extent of sea ice (Turner et al. 2013). A deepening ASL over the second half of the twentieth century, associated with positive SAM and more persistent La Niña phases, generated stronger north-to-northwesterly winds that advect warm moisture-laden air from the north and drive sea ice to the south, creating warm, low-ice conditions over the WAP and increasing precipitation (Turner et al. 1997). The recent plateauing of temperature and sea ice trends is associated with periods of more neutral to negative SAM phases, or positive SAM offset by El Niño, that promote cyclonic to anticyclonic conditions east to west of the peninsula, respectively, leading to more frequent cold east-to-southeasterly winds over the WAP and increased ice extent (Meredith et al. 2016; Stammerjohn et al. 2008; Turner et al. 2016). The combination of short-term internal variability and longer-term changes in atmospheric and ocean circulation patterns responding to global climate change complicates future projections of Antarctic sea ice, both at WAP and circumpolar scales (Turner and Comiso 2017). Understanding the extent to which the long-term trend of atmospheric warming and declining sea ice will continue in future, and the timescales over which different forcings are relevant, are leading-order challenges for the WAP scientific community.

The pronounced variability and change observed in atmospheric forcing, sea ice dynamics, glacial retreat, freshwater distribution and ocean physics along the WAP have a strong impact on primary production, community composition, ecosystem functioning, ocean chemistry and ocean-atmosphere exchanges of heat and dissolved gases (e.g. Ducklow et al. 2013; Meredith et al. 2017;

Venables and Meredith 2014). Improving our understanding of this dynamic system is of high scientific priority as a result of significant variability and change in the physical environment, important biological and biogeochemical consequences, and documented sensitivity to – and feedbacks on – climate change. The documented responses of ocean chemistry and biology to changes in climate and ocean physics make the WAP shelf region a unique model system for assessing how changes in climate might restructure ecosystems here and in other polar regions where sea ice changes are underway or expected in future. This importance is one of the key reasons why the WAP shelf region is the focus of a large international research effort, with a number of long-term records and spatially-extensive studies that are unparalleled around Antarctica. There are over thirty research stations along the WAP, either permanent or summer only, and a number of research ships that frequent the region, predominantly during summer.

Figure 2 shows the major sustained research efforts along the WAP, delineation of the northern, central and southern sub-regions referred to in this paper, and the major circulation and bathymetric features of the shelf system. The US Palmer Antarctica Long-Term Ecological Research (LTER) project has been in operation since 1990, and consists of spring/summer time-series sampling adjacent to Palmer Station, Anvers Island, and an annual summer cruise occupying a grid of stations over the WAP shelf between Anvers and Charcot Islands. The US National Oceanic and Atmospheric Administration Antarctic Marine Living Resources (AMLR) program has been active around the South Shetland Islands in the northern WAP since 1986, conducting annual research surveys and land-based field measurements with a focus on ecosystem-based management of fisheries, primarily krill. Since 1997, the Rothera Time Series (RaTS) of the British Antarctic Survey, located in Ryder Bay, northern Marguerite Bay adjacent to Rothera Research Station on Adelaide Island, has made year-round quasi-weekly measurements of physical and biogeochemical oceanographic parameters, benthic ecology and sea ice cover, with a large number of linked and complementary studies conducted by UK and international partners. The establishment of additional laboratories at Rothera by the Netherlands Organisation for Scientific Research (NWO) in 2012 increased the Dutch research effort in the WAP region substantially. The Argentinian Antarctic Program consists of time-series and process studies at a number of research stations along the WAP, as well as ship-based campaigns across the shelf. Year-round time-series monitoring of hydrographic and biological variables in Potter Cove, King George Island/ Isla 25 de Mayo, South Shetland Islands, has been conducted fortnightly-monthly since 1991, based at Carlini Station, which has been in operation since 1982. A joint Argentinian-German research program at Dallmann Laboratory on Carlini Station focusing on Potter Cove started in 1994, and forms an important part of the German research efforts in the WAP region, coordinated by the Alfred Wegener Institute (AWI). The Chilean Antarctic Institute (INACH) conducts scientific research programs at four bases along the WAP, supported by the Armed Forces. Chilean base Yelcho on Doumer Island was reopened in 2015 and there are plans to reopen Base Carvajal on Adelaide Island to complete a latitudinal transect from King George Island to Adelaide Island, as well as developing a long-term monitoring program. The Peruvian National Antarctic Program comprises summertime studies at Machu Picchu Research Station on King George Island, which was established in 1989, and oceanographic cruises. Spanish research programs centre on Juan Carlos I and Gabriel de Castilla Stations in the South Shetland Islands, which were opened in the late 1980s, as well as ship-based research. Brazilian research efforts have been underway in the northern WAP since the 1980s, with dedicated ship-based monitoring programs conducted through a number of initiatives coordinated by the Brazilian Antarctic Program since 2000. Chinese monitoring programs at Great Wall Station on King George Island have been in operation as part of the Chinese National Antarctic Program since the base was established in 1985. The Korea Polar Research Institute (KOPRI) runs a year-round marine ecosystem monitoring program in operation since 1996 at King Sejong Station on King George Island, which was inaugurated in 1988.

The Southern Ocean Observing System (SOOS) is an international organisation supported by the Scientific Committees on Antarctic Research (SCAR) and Oceanic Research (SCOR), which aims to co-ordinate Southern Ocean research, disseminate key findings and identify future directions and priorities (Meredith et al. 2013). The WAP working group of SOOS aims to bring together the different national programs, initiatives and projects working in the Peninsula region to maximise the science output across the spectrum of WAP marine research activities, to improve coordination and collaboration amongst ongoing research efforts, and to instigate and promote future developments and progress by identifying key gaps and opportunities to be addressed by future research. In this paper, we summarise the current state of knowledge under two high-priority overarching questions in WAP marine science:

1) What are the key mechanisms and interactions regulating ecosystem functioning and ocean-atmosphere coupling along the WAP shelf?

2) How is the WAP shelf environment changing and what are the ecosystem responses to and ocean-climate feedbacks on the changes underway?

We take a whole ecosystem approach and consider the full range of dynamics and interactions from sea ice and water properties and circulation through phytoplankton dynamics and ocean biogeochemistry to pelagic, benthic and microbial food webs. We then discuss the most significant challenges and key overarching priorities for the international scientific community within the framework of these two questions, and present a model for an observing system for the WAP based on sustained observations of key variables and detailed process studies that will allow us to address these priorities. Figure 3 summarises the current state of knowledge of the key components of the WAP marine system and the most important mechanisms and interactions in the context of the two overarching questions outlined above, as well as the major priorities and approaches for future marine research at the WAP.

1) What are the key mechanisms and interactions regulating ecosystem functioning and ocean-atmosphere coupling along the WAP shelf?

1.1. Physical oceanography

The hydrography and circulation of the WAP shelf are influenced by intrusions of oceanic water from the ACC, inflow around the tip of the Peninsula from the Weddell Sea, and coupling with the atmosphere, cryosphere and land (Klinck et al. 2004; Martinson et al. 2008). Modulated by shelf dynamics, these processes lead to significant spatial and temporal property gradients in this region. Large seasonal variability occurs in surface waters, driven by strong heat loss and ice growth and advection in autumn and winter that leads to the formation of a deep winter mixed layer, and ice melting and partial restratification during spring and summer (Klinck et al. 2004; Meredith et al. 2008). Precipitation, glacial melt and sea ice melt modulate the freshwater content and stratification of the surface layer, with significant variability driven by ENSO and SAM over interannual timescales (Meredith et al. 2010; Meredith et al. 2017). A main feature of the surface circulation is the Antarctic Peninsula Coastal Current (APCC), a seasonal buoyancy- and wind-forced surface current, which flows southwestwards along the coast south of Anvers Island and west of Adelaide and Alexander Islands during summer and autumn with a cyclonic circulation inferred within Marguerite Bay (Beardsley et al. 2004; Moffat et al. 2008; Savidge and Amft 2009).

The deep circulation and properties, particularly in the southern and central WAP, are strongly influenced by the proximity of the ACC to the shelf break, and by shelf topography and vertical mixing with the upper layers (Klinck 1998; Klinck et al. 2004; Martinson et al. 2008; Orsi et al. 1995). The CDW that resides in the mid-depths of the ACC is the main source of heat, salt, macronutrients and carbon for the subsurface shelf waters. Observational studies have revealed that CDW intrusions move across the shelf as small (~5 km wide) subsurface eddies, and are transported preferentially in deep, glacially-scoured submarine troughs that cross-cut the shelf (Couto et al. 2017; Martinson and McKee 2012; Moffat et al. 2009). Numerical models of the region have recently become eddy-resolving and revealed that shoreward transport can be expected via several of these troughs (Graham et al. 2016). The available observational evidence points to only weak seasonal variability in deep water properties, with synoptic-scale intrusion of eddies and other intraseasonal variability dominating instead (Martinson and McKee 2012; Moffat et al. 2009). The intruding waters cool and freshen on the shelf due to mixing with overlying waters and heat loss to the surface layer and atmosphere. Although the drivers of modification and vertical ventilation of CDW remain poorly understood, recent observations suggest that flow-topography interactions along the deep troughs constitute a key mechanism for vertical mixing (Venables et al. 2017). Mean upward heat fluxes from modified CDW to the surface layer are small (on average ~1 W/m^2), with stronger fluxes observed in early spring shortly after the first seasonal retreat of sea ice, but before the upper layer is strongly restratified (Brearley et al. 2017). Both of these processes highlight the importance of small-scale spatial (<1 km) and temporal (days to weeks) variability in controlling mixing rates and water modification at the WAP.

Bransfield Strait in the northern WAP differs markedly from the shelf to the south, with deep properties being modulated by colder, fresher waters originating in the Weddell Sea (Gordon and Nowlin 1978; Hofmann et al. 1996; van Caspel et al. 2018). The circulation in Bransfield Strait is generally cyclonic, with southward flow along the WAP coast and then turning towards the South Shetland Islands (Sangra et al. 2011; Zhou et al. 2002). A significant temperature gradient exists across Bransfield Strait, with warmer waters around the South Shetland Islands than along the mainland. The strong contrast in deep properties between Bransfield Strait and the shelf to the south suggests that deep water exchange between these two basins is limited (Hofmann et al. 1996), although its magnitude, temporal evolution, and dynamics are not fully described and understood.

1.2. Phytoplankton community dynamics

1.2.1. Pelagic primary production

The WAP shelf is a productive marine ecosystem, where primary production varies significantly in time and space, due to its regulation by upper ocean physics, light availability and the supply of macro- and micronutrients. As well as the role of phytoplankton in taking up nutrients and carbon dioxide, thus mediating air-sea gas exchange and larger-scale biogeochemical cycling, these primary producers constitute a critical food source for the entire WAP shelf ecosystem. High-biomass phytoplankton blooms occur during spring and summer (Hart 1942; Nelson and Smith 1991; Prézelin et al. 2000; Smith et al. 2008), when solar illumination increases and sea ice has retreated leaving an exposed ocean surface (Moline and Prézelin 1996; Smith and Stammerjohn 2001). There is a strong productivity gradient with high productivity (~1000 mg C m^{-2} d^{-1}) inshore compared with offshore waters (~100 mg C m^{-2} d^{-1}) (Vernet et al. 2008). Seasonal satellite studies and in situ measurements show that net community production peaks first offshore and follows the inshore retreat of the sea ice (Arrigo et al. 2017; Li et al. 2016). The magnitude of primary productivity on an annual basis is linked to climate modes such as ENSO and SAM, and their effect on the ASL, which influence the amount of sea ice present in the winter (Stammerjohn et al. 2008a), and this in turn affects primary productivity in the following spring and summer seasons (Saba et al. 2014). The duration of winter sea ice and the extent of winter wind-driven mixing, combined with the timing of ice retreat and mixing during spring, has been shown to control upper ocean stability during spring and summer, thus preconditioning the water column for phytoplankton growth (Venables et al. 2013; Saba et al. 2014; Schofield et al. 2017; Rozema et al. 2017a). In high-ice years, less wind-induced mixing over winter and a subsequent strong seasonal melt results in a more stable water column that retains phytoplankton in a shallower surface layer, where light conditions are favourable for growth (Moline 1998; Vernet et al. 2008; Carvalho et al. 2016). In low-ice years, enhanced wind-driven mixing and subsequently deeper mixed layers, combined with a smaller input of meltwater to restabilise the upper ocean, result in phytoplankton cells being mixed over a greater depth interval, experiencing lower light levels overall, such that primary productivity is reduced (Figure 4). Superimposed on the seasonal bloom dynamics are shorter-lived phytoplankton blooms (days-week) facilitated by periods of low wind that lead to increased water column stability (Moline 1998; Vernet et al. 2008; Carvalho et al. 2016). High primary productivity supports a productive food web that is tightly coupled to the seasonal phytoplankton dynamics, suggesting strong bottom-up control of the ecosystem (Saba et al. 2014).

While WAP phytoplankton communities are often dominated by diatoms, other taxa are increasingly recognised as important components of the food web. The importance of nanoplankton (<20 µm) and picoplankton (<2 µm) has been documented, with cryptophytes being the dominant nano-flagellate over much of the region (e.g. Krebs 1983; Buma et al. 1991; Kopczynska 1992; Garibotti et al. 2003; Varela et al. 2002; Rodriguez et al. 2002). Other major phytoplankton taxa include mixed flagellates and haptophytes, with haptophytes (e.g. the prymnesiophyte *Phaeocystis antarctica*) being more prominent than cryptophytes in Marguerite Bay (Garibotti et al. 2003; Kozlowski et al. 2011; Rozema et al. 2017a; Stefels et al. 2018). *P. antarctica* dominated the phytoplankton community during spring 2014 in the central WAP prior to the peak of the diatom bloom (Arrigo et al. 2017). During high-chlorophyll years, the late-spring/summer phytoplankton community is dominated by larger cells, primarily diatoms, with only a minor contribution from smaller size classes, primarily haptophytes and cryptophytes (Moline et al. 2004; Rozema et al. 2017a; Schofield et al. 2017; Schloss et al. 2014). In low-ice low-chlorophyll years, the haptophyte and cryptophyte contributions increase, whilst the diatom contribution is reduced. Cryptophyte abundance increases when a shallow meltwater lens, probably of glacial origin, overlies a well-mixed upper water column (Mura et al. 1995; Moline et al. 2004). Cryptophytes take up less CO_2 per unit chlorophyll than diatoms, such that a greater cryptophyte contribution may lead to reduced carbon uptake compared to diatom-dominated assemblages (Schofield et al. 2017).

Whilst the factors influencing phytoplankton community composition remain poorly understood, it is possible to segregate the presence and abundance of cryptophytes and diatoms at Palmer Station in temperature-salinity phase space (Figure 5a) (Schofield et al. 2017). Diatoms were observed over the full range of observed salinities and temperatures, with their abundance being significantly lower in colder and lower-salinity waters. Conversely, cryptophytes were most abundant in lower-salinity colder waters (-1 to 1° C), and absent at higher temperatures and salinities. The segregation of major phytoplankton taxa based on water mass properties at Palmer Station is not robust at the wider shelf scale (Figure 5b), since ship-based surveys indicate a range of cryptophyte species across the WAP that can occupy a range of hydrographic niches.

1.2.2. Coupling between sea ice and pelagic ecosystems

As well as regulating phytoplankton productivity through its control on upper ocean physics, sea ice can also play an important role in seeding the pelagic community. Primary production rates in Antarctic sea ice are highly variable, ranging from 0.5 to 1250 mg C m^{-2} d^{-1} (Arrigo 2017), and reaching maxima in spring and summer, when ice algae can contribute up to 50-60 % of total primary production in a given area (e.g. McMinn et al. 2010). The direct coupling between sea ice and pelagic ecosystems varies seasonally, according to ice extent and its productivity compared to underlying waters. When ice melts in spring, release of algal cells into the water column can initiate under-ice algal blooms (Lizotte 2001), although differences in species composition between sea ice and water column communities have been documented (e.g. Riaux-Gobin et al. 2011). The timing and pulse size of release act as strong controls on the fate of sympagic (ice-associated) algae (Selz et al. 2018), with a rapid early release contributing substantially to pelagic production, and a later release being more likely to be consumed by pelagic zooplankton or benthic communities (e.g. Riebesell et al. 1991).

Antarctic sympagic algae are an important food source for zooplankton, such as juvenile krill (Kohlbach et al. 2017) and various life stages of copepods (Bluhm et al. 2017). This is especially the case during winter, when chlorophyll concentrations in bottom sea-ice layers close to the ice-water interface can be 10 to 100-fold higher than in the underlying seawater. At the WAP, bottom-ice chlorophyll increased from ~5 µg L^{-1} to ~500 µg L^{-1} from September to December 2014 in land-fast ice adjacent to Rothera Station (Meiners et al. *in press*).

Export of ice-associated organic carbon, that is not remineralised in the sea ice or surface waters, to benthic ecosystems occurs at rates determined by its composition (Riebesell et al. 1991) and the dynamics of ice retreat (e.g. Norkko et al. 2007; Wing et al. 2012). Whilst organic carbon fluxes during ice-covered seasons are small compared to summertime fluxes along the WAP, sea ice algae are most relevant for local and episodic inputs preceding pelagic blooms, and in providing source material that is remineralised in winter to support detritus feeders (Mincks et al. 2005). Biogenic particle fluxes beneath land-fast sea ice were ~0.2 g m^{-2} d^{-1} during winter at King George Island/ Isla 25 de Mayo (Khim et al. 2007), and would be expected to increase dramatically during ice melt in spring. In the Ross Sea, tracer analysis shows that sea ice organic carbon fluxes can contribute >50 % of the total diet of Antarctic benthic organisms (Wing et al. 2012).

1.3. Nutrient biogeochemistry

The supply and cycling of inorganic and organic macro- and micronutrients along the WAP is regulated by physical and biological processes, and influences the spatial and temporal variation in production and ecosystem structure. Inorganic macronutrients are supplied to WAP shelf ecosystems primarily by CDW intruding onto the shelf from the ACC (Klinck et al. 2004; Prezelin et al. 2000). Cross-shelf transport of CDW in deep glacially-scoured canyons increases the supply of nutrients to biota in overlying waters, as well as increasing heat flux and reducing sea ice coverage, such that phytoplankton biomass is higher and more diatom-dominated over the canyons compared with adjacent shelf areas (Kavanaugh et al. 2015). The supply of inorganic nitrogen and silicic acid from sea ice is small compared to CDW, and dominated by regenerated nutrients (Fripiat et al. 2015; Henley et al. 2017). Phosphate accumulates in sea ice (Fripiat et al. 2017), but its effect on water column phosphate and micronutrient inventories remains unclear (Hendry et al. 2010). A glacial source of silicic acid in basal meltwater has been demonstrated around Greenland (Hawkings et al. 2017), and warrants investigation along the WAP.

Vertical nutrient fluxes from the modified CDW source into the surface ocean vary substantially in space and time. Vertical nitrate fluxes during summer in Marguerite Bay and along Marguerite Trough were estimated as 0.18 ± 0.17 mmol NO_3 m^{-2} d^{-1} with a maximum of 0.56 mmol NO_3 m^{-2} d^{-1} (Henley et al. 2018). The mean summertime vertical nitrate flux for the Palmer LTER grid for 1998-2007 was estimated as 1.36 ± 1.79 mmol NO_3 m^{-2} d^{-1} (Pedulli et al. 2014), although the latter study used a uniform value for the vertical eddy diffusivity (K_z) that is likely to overestimate fluxes. Seasonal variability is poorly constrained, although vertical nutrient fluxes are expected to be greatest following the initial retreat of sea ice, in agreement with heat fluxes (Brearley et al. 2017). Whilst macronutrients are normally replete in WAP surface waters, intense biological drawdown by phytoplankton can lead to transient nutrient limitation in coastal areas during some summers (Henley et al. 2017). Interannual variability in CDW-derived nutrient supply is attributed to the degree of wintertime mixing at Palmer Station (Kim et al. 2016), but this cannot fully account for the observed variability at Rothera (Henley et al. 2017).

The degree of summertime surface ocean macronutrient depletion shows an onshore-offshore gradient driven by higher primary production in inshore regions (Pedulli et al. 2014). Seasonal nutrient drawdown during summer follows interannual variability in chlorophyll, sea ice and upper ocean conditions, such that high-ice, high-chlorophyll years lead to greater nutrient drawdown than lower-chlorophyll years (Figure 4) (Henley et al. 2017; Kim et al. 2016), with the potential to influence WAP shelf nutrient budgets and exports. In the coastal regions, the summer N/P uptake ratio varies between ~13, indicative of diatom-dominated phytoplankton communities under bloom conditions, and ~21, indicative of communities dominated by non-diatom phytoplankton and/or lower productivity conditions (Clarke et al. 2008; Henley et al. 2017; Kim et al. 2016). The summer Si/N uptake ratio is usually ≥1 in the Rothera and Palmer time series, indicating diatom-dominated production in these coastal regions (Henley et al. 2017; Kim et al. 2016). Nutrient uptake varies significantly within a season, due to changes in water column structure, sea ice and phytoplankton communities (Hendry et al. 2009). For example, time-series analyses of the stable silicon isotope composition ($\delta^{30}Si$) of silicic acid from northern Marguerite Bay show strong silicic acid drawdown by diatoms, interspersed with wind-driven mixing events that replenish the silicic acid reservoir from underlying waters (Cassarino et al. 2017).

Nitrate, phosphate and inorganic carbon are progressively enriched in subsurface waters as CDW moves across the shelf, and the stable nitrogen ($\delta^{15}N$) and oxygen ($\delta^{18}O$) isotope composition of nitrate (Figure 6) and nutrient stoichiometry show that this is driven by local remineralisation of organic matter and nutrient recycling in the upper water column (≤200 m) (Henley et al. 2017, 2018). Nitrification (regeneration of nitrate via ammonium oxidation) occurs in the deeper darker part of the euphotic layer, making the regenerated nitrate contribution to surface ocean primary production sensitive to whether the base of the euphotic layer resides within the mixed layer. Nitrate and phosphate regenerated in subsurface shelf waters, as opposed to that supplied from the CDW source, can account for up to one third of the surface ocean nutrient pools during summer, with implications for new production, net CO_2 uptake and organic matter export. Silicic acid is also enriched across the shelf, with maximum enrichment at depth (Henley et al. 2018). This indicates biogenic silica dissolution occurring deeper in the water column than organic matter remineralisation, and potentially in sediment porewaters, driving a return flux of silicic acid to the water column. New porewater silicon isotope data provide evidence for down-core changes in silicic acid being driven by dissolution of diatom frustules and potentially reverse weathering reactions (Cassarino et al. *in prep*).

Our understanding of organic nutrient budgets and cycling is more limited. Dissolved organic carbon (DOC) and nitrogen (DON) concentrations are low in the Southern Ocean compared to other ocean regions, with a labile to semi-labile pool in the upper ocean and a large refractory pool in CDW (Hansell et al. 2009; Kirchman et al. 2009; Ogawa et al. 1999). Low DOC concentrations and low bacterial production rates and biomass along the WAP suggest that bacterial production may be limited by the availability of dissolved organic matter (DOM) (Ducklow et al. 2012a; Kim et al. 2016), but this is yet to be fully understood.

The essential micronutrient iron is supplied to the WAP surface ocean primarily from glacial meltwater and shallow sedimentary sources (Annett et al. 2015; Annett et al. 2017; Bown et al.

2018; Monien et al. 2017; Sherrell et al. 2018). Iron concentrations are replete in inshore regions, but can be drawn down by phytoplankton blooms to limiting levels further offshore. Micronutrients other than iron show temporal and spatial variability, although their roles in regulating primary productivity along the WAP are yet to be determined (Bown et al. 2017; Hendry et al. 2008).

1.4. Climate-active gases

1.4.1. Marine carbonate chemistry and air-sea CO_2 fluxes

Carbonate chemistry and air-sea CO_2 fluxes along the WAP are influenced strongly by ocean physics and biological processes. Year-round measurements of dissolved inorganic carbon (DIC) and total alkalinity (TA) taken at the Rothera Time Series since 2010 show that all carbonate chemistry parameters have a strong, asymmetric seasonal cycle in surface waters with some year-to-year variation (Figure 7; Legge et al. 2015, 2017; Jones et al. 2017). Concurrent with the late spring/early summer phytoplankton bloom, DIC, TA and the fugacity of carbon dioxide (fCO_2) decrease sharply, while pH and the saturation state (Ω) of the calcium carbonate minerals calcite and aragonite increase sharply. Values for all parameters then gradually return to winter values. Aragonite saturation state shows notably low wintertime values, just above 1, a critical boundary below which aragonitic organisms can become susceptible to growth impairment and dissolution (Jones et al. 2017). Photosynthesis and respiration dominate these seasonal changes in surface water carbonate chemistry, with biological uptake driving the substantial reductions in DIC during spring and summer (Carrillo et al. 2004; Legge et al. 2017; Tortell et al. 2014). Upwelling and vertical mixing of carbon-rich deep water increase upper ocean DIC, especially during winter, whilst sea ice reduces CO_2 outgassing. Ryder Bay is a net sink for atmospheric CO_2 of 0.90-1.39 mol C m^{-2} yr^{-1} (Legge et al. 2015). It remains unclear whether the WAP shelf as a whole is a net annual sink or source for atmospheric CO_2.

Across the WAP shelf, carbonate system parameters show strong onshore-offshore gradients in the upper ocean during summer, with low DIC and fCO_2 and high pH and aragonite saturation state in near-shore waters, due to strong biological carbon uptake, especially in the southern WAP sub-region (Figure 8) (Carrillo et al. 2004; Hauri et al. 2015; Ruiz-Halpern et al. 2014). The degree of summertime DIC and fCO_2 drawdown is closely related to phytoplankton biomass and primary production (Moreau et al. 2012), which are regulated by winter sea ice coverage and wind patterns during spring (Montes-Hugo et al. 2010). In the central WAP, dilution by meltwater inputs reduces TA and DIC in near-shore waters (Hauri et al. 2015). Most of the WAP shelf exhibited fCO_2 undersaturation and net CO_2 uptake during summers between 2005 and 2009, although there was a region of fCO_2 supersaturation and net CO_2 release in the outer shelf region to the north of Anvers Island (Ruiz-Halpern et al. 2014). Air-sea CO_2 fluxes in Bransfield Strait are highly variable, with surface waters switching between sink and source behaviour in consecutive summer seasons (Ito et al. 2018).

1.4.2. Halogens

Halogen gases can be released from phytoplankton and ice algal communities along the WAP, with consequences for atmospheric chemistry and regional climate. The halogens play an important role in the Antarctic atmospheric boundary layer, being involved in the cycling of O_3, HO_x, NO_x, Hg, CH_4 and the formation of precursor molecules to cloud condensation nuclei (CCN) (reviewed by Saiz-Lopez and von Glasow 2012). Destruction by bromine radicals is thought to be the primary driver for ozone depletion events, during which Antarctic boundary layer O_3 can decrease from around 30 ppb to below instrumental detection (1-2 ppb) for up to a few days (e.g. Jones et al. 2013). Additionally, modelling studies suggest that some halogen oxides are involved in controlling CCN formation through oxidation of the semi-volatile organic sulphur compound dimethyl sulphide by bromine monoxide (Breider et al. 2015) and possibly new particle formation involving iodine oxides (e.g. Saiz-Lopez et al. 2008; Roscoe et al. 2015).

Biotic and abiotic sources of halogens to the Antarctic atmospheric boundary layer have been identified. The 'explosive' emission of bromine needed to initiate ozone depletion events is driven by catalytic liberation from condensed-phase sea-salt bromide present on airborne particulates, and snow and sea ice surfaces (reviewed by von Glasow and Hughes 2015). Sea salt aerosol (Legrand et al. 2016) and blowing saline snow (Yang et al. 2008, 2010; Lieb-Lappen and Obbard 2015) are also thought to be important sources of gaseous inorganic bromine in Antarctica. Whilst these abiotic sources are thought to dominate, Hughes et al. (2009, 2012) show that high rates of biogenic bromoform ($CHBr_3$) flux from diatom blooms in the seasonal ice zone of the WAP could also contribute significantly to gaseous inorganic bromine during certain times of year. Similar to the uptake of macronutrients being reduced during relatively low-productivity spring/summer seasons following winter periods with reduced fast-ice duration (Henley et al. 2017), biogenic bromoform ($CHBr_3$) emissions are also reduced in low-ice low-productivity years (Hughes et al. 2012).

Whilst iodine emissions to the Antarctic atmosphere have also been linked to abiotic reactions on the snowpack (Saiz-Lopez et al. 2008; Freiss et al. 2010), additional biological sources have been proposed for coastal regions at the WAP and elsewhere. These include iodocarbon (e.g. CH_2I_2, CH_3I) emissions from surface waters and sea ice (Chance et al. 2010; Granfors et al. 2013), and microalgal-mediated inorganic iodine flux from sea ice brine channels (Saiz-Lopez et al. 2015).

1.4.3. Organic sulphur compounds

Dimethyl sulphide (DMS) is the most important natural sulphur source to the atmosphere, where it is oxidised to form sulphate aerosols, which act as CCNs and exert a cooling effect through albedo feedbacks. DMS can also be released from phytoplankton and ice algal communities along the WAP, resulting in a direct feedback between the ecosystem and regional climate. Climatologies of DMS concentrations and fluxes show that the Southern Ocean as a whole is a global hotspot of DMS production, and its modelled contribution to atmospheric sulphate is especially high (Gondwe et al. 2003; Lana et al. 2011). The Southern Ocean also exhibits the highest temporal variability in DMS concentrations, and the highest concentrations in the marginal ice zone. The latest Southern Ocean climatology indicates that the WAP is not a particular hotspot of DMS production (Jarníková and Tortell 2016), although this may reflect a shortage of published datasets, particularly from the marginal ice zone. Two time series from the Palmer LTER show highest DMS concentrations in January between 5 and 15 nM (Asher et al. 2017; Herrmann et al. 2012), which compare well with the climatological mean for January of 10.8 ± 6.9 (SD) nM for the whole Austral Polar province (Lana et al. 2011). A recent continuous 5-year time series at Rothera shows large seasonal fluctuations in northern Marguerite Bay, with considerably higher concentrations in January, reaching an average of 24 ± 35 (SD) nM and a maximum of 160 nM in January 2015 (Webb et al. *in review*). This new time series documents a 3-fold higher flux of DMS to the atmosphere than previously calculated. High concentrations were also observed throughout Marguerite Bay and out to the shelf edge in January 2015, and are likely associated with the location of the marginal ice zone (Figure 9; Stefels et al. 2018).

The role of sea ice in the sulphur cycle is complex and the processes involved are poorly quantified. Large phytoplankton blooms and spikes of DMS have been linked to melting sea ice (Trevena and Jones 2006), potentially caused by the release of large amounts of ice algae that produce the DMS precursor, dimethylsulphoniopropionate (DMSP) (Stefels et al. 2018). This is supported by extremely high DMSP concentrations common in sea ice, 2-3 orders of magnitude higher than in underlying surface waters. However, release from sea ice does not necessarily result in high DMS concentrations (Tison et al. 2010). The efficiency of DMSP conversion to DMS depends strongly on phytoplankton community structure, as *Phaeocystis* and dinoflagellates readily convert DMSP into DMS whilst diatoms do not, on bacterial processes, which often demethylate DMSP rather than producing DMS, and on abiotic factors (Stefels et al. 2007). With particular relevance to Antarctic ice and surface waters, high levels of UV radiation can photo-oxidise DMS to dimethylsulphoxide (DMSO), as well as inhibiting algal and bacterial activity (Toole and Siegel 2004; Zemmelink et al. 2008a). Whilst high DMS fluxes have been found above sea ice, it remains unclear how much is derived from surface ice communities, which are often dominated by the well-known DMS producer *Phaeocystis*, and/or from leads between ice floes, where surface-microlayer concentrations of DMS can be an order of magnitude higher than in the underlying water column (Zemmelink et al. 2008a, b). Ice-derived DMS fluxes are likely to be largest during early spring, when surface ice communities are developing and surface ice and snow layers become permeable due to rising temperatures. Sea ice dynamics also impact on pelagic DMSP production, both directly via DMSP release from ice algae input to surface waters, and indirectly by shaping the conditions for pelagic blooms that produce DMSP (Stefels et al. 2018; Webb et al. *in review*).

1.5. Microbial processes

Bacterioplankton (free-floating and particle-attached archaea and bacteria) community dynamics are closely coupled to phytoplankton dynamics in the upper ocean, and strongly influenced by environmental characteristics, such as sea ice, salinity, temperature, stratification and nutrient availability (e.g. Ghiglione and Murray 2012; Luria et al. 2016, 2017; Piquet et al. 2011; Rozema et al. 2017b; Signori et al. 2014; Obryk et al. 2016). These microbial communities play a key role in biogeochemical cycling. Close coupling between bacterial and phytoplankton dynamics along the WAP has been emphasised by microbial studies conducted as part of the Palmer LTER (2002-ongoing) and earlier RACER (1987-1989) projects. Variability in abundance and productivity of bacterioplankton is governed largely by the availability of phytoplankton-derived DOM, as terrestrial input of organic carbon is negligible (Ducklow et al. 2012a) – in great contrast to the Arctic. Bacterioplankton abundance varies across the WAP shelf, being higher further south and towards the inshore regions, in broad agreement with phytoplankton distributions (Figure 10). Pronounced temporal variability is evident as abundance increases from winter minima of $2.0 \pm 0.8 \times 10^8$ cells L^{-1} to a maximum of ~$2\text{-}3 \times 10^9$ cells L^{-1} during summers with high phytoplankton biomass (Ducklow et al. 2012a; Evans et al. 2017). Hotspots of bacterial production and abundance do not necessarily overlap, as production per bacterium can vary by up to an order of magnitude between years, in addition to spatial differences (Figure 10). Multi-year and spatially-extensive studies have suggested a low ratio (~4 %) of bacterial to primary production (Ducklow et al. 2012a; Kim and Ducklow 2016), which is unique to the Southern Ocean and the cause remains unknown (Kirchman et al. 2009). Seasonal-scale studies that have addressed phytoplankton bloom dynamics and bacterioplankton diversity simultaneously suggest that time-lagged responses are important in the coupling between phytoplankton and bacteria, leading to increased heterogeneity in the microbial community (Luria et al. 2014; Moreno-Pino et al. 2016; Piquet et al. 2011; Rozema et al. 2017b; Bowman et al. 2017; Bowman et al. 2016). A stronger relationship between summertime bacterial production and phytoplankton biomass estimated from chlorophyll than with primary production suggests that bacteria preferentially utilise DOM derived from grazing, sloppy feeding and viral lysis, rather than DOM excreted by phytoplankton (Ducklow et al. 2012a; Kim and Ducklow 2016; Ruiz-Halpern et al. 2011). Bacterioplankton itself could be an underestimated source of DOM through grazing by zooplankton and mixotrophic algae, or by viral lysis; an important loss factor for Antarctic bacterioplankton (Brum et al. 2015; Evans et al. 2017; Evans and Brussaard 2012; Vaqué et al. 2017). Although studies of DOM origin, speciation and bioavailability are rare in this region, one winter survey revealed that ~35 % of dissolved amino acids, and thus potentially a large proportion of the DOM pool, was of bacterial origin (Shen et al. 2017).

Whilst low *in situ* temperatures could be co-limiting bacterial production along the WAP (Pomeroy and Wiebe 2001), no significant relationship between bacterial production and temperature was observed for half of the summers since 2002, and for the other summers, only weakly-to-moderately significant relationships were found over seasonal timescales (Kim and Ducklow 2016). Temperature may affect bacterial production indirectly, due to its influence on phytoplankton production, grazer activity and diversity, and viral infection (Ducklow et al. 2012b; Kim and Ducklow 2016; Maat et al. 2017; Vaqué et al. 2017).

Stark contrasts exist between surface and deep (>100 m) community composition along the WAP, with diversity being more stable over time and space at depth than in surface waters (Luria et al. 2014). Metabolic structure also varies seasonally and with depth, and can be used to segment bacterioplankton communities along the WAP (Bowman and Ducklow 2015; Bowman et al. 2017). Microbial communities can be transported by ocean currents and winds, increasing connectivity amongst populations (Bowman and Deming 2017; Wilkins et al. 2013). As in the wider Southern Ocean, the dominant phyla are Alpha- and Gamma- Proteobacteria, Actinobacteria and Bacteroidetes (the Cytophaga-Flavobacterium-Bacteroides group) (Abell and Bowman 2005; Delmont et al. 2014; Gentile et al. 2006; Landa et al. 2016).

The pelagic archaeal community along the WAP is dominated by ammonia-oxidising *Thaumarchaeota* (previously Marine Group I *Crenarchaeota*) (Abele et al. 2017; Grzymski et al. 2012; Hernández et al. 2015; Luria et al. 2014; Signori et al. 2014). *Thaumarchaeota* were also found to dominate sea ice and benthic archaeal communities (Cowie et al. 2011; Learman et al. 2016). The widespread distribution of *Thaumarchaeota* suggests an important ecological function involved in nitrogen recycling (Tolar et al. 2016), particularly in winter when bacterioplankton communities are enriched in archaea compared with summer communities (Church et al. 2003; Grzymski et al. 2012; Hernández et al. 2015; Murray et al. 1998; Murray and Grzymski 2007), and nitrogen recycling pathways have been identified in proteomic data (Williams et al. 2012).

High functional diversity is suggested by studies of species composition using the 16S rRNA gene, and confirmed by metagenomics and metaproteomics approaches, which provide a mechanistic understanding of the microbial processes at work. Bacterioplankton are involved in chemoheterotrophy, photoheterotrophy or aerobic anoxygenic photosynthesis during summer, whilst chemolithoautotrophic pathways dominate during winter (Grzymski et al. 2012; Williams et al. 2012). Abundant Flavobacteria have been shown to bind and exploit polymeric substrates, including carbohydrates, polypeptides, and lipids, thereby providing a crucial function in microbial decomposition (Williams et al. 2013). 16S rRNA sequencing data from King George Island have also revealed a previously unknown clade of Archaea potentially capable of oxidising ferrous iron (Abele et al. 2017; Hernández et al. 2015).

1.6. Zooplankton dynamics

Zooplankton abundance, distribution and species assemblages along the WAP are influenced strongly by the availability and composition of their phytoplankton food source, as well as the physical structure of the water column, and play a pivotal role in food web interactions and carbon and nutrient cycling. The major taxa comprising meso- and macrozooplankton (>200 μm, hereafter macrozooplankton) assemblage composition along the WAP are well known, with the Antarctic krill, *Euphausia superba*, being well-established as a keystone species in the regional food web (e.g. Quetin and Ross 2003). The WAP is an important spawning and nursery area for *E. superba*, where spawning success, larval survival over winter and recruitment the following summer are largely dependent on winter sea ice coverage through provision of the ice algal food source and by setting favourable conditions for summer phytoplankton blooms (Atkinson et al. 2004; Saba et al. 2014). Krill spawning and recruitment along the WAP plays a key role in supporting large krill biomass across the southwest Atlantic (Atkinson et al. 2004). The important roles of other taxa, such as the salp *Salpa thompsoni* and the pteropod *Limacina helicina*, in WAP food web dynamics and biogeochemical cycling are increasingly being recognised (e.g. Bernard et al. 2012). In Potter Cove, South Shetland Islands, inshore macrozooplankton assemblages are numerically dominated by the small copepod *Oithona similis*, whereas large copepods such as *Rhincalanus gigas* and *Calanus propinquus* tend to dominate in terms of biomass (Garcia et al. 2016).

WAP microzooplankton (<200 μm) assemblages are dominated by aloricate ciliates and athecate dinoflagellates (Calbet et al. 2005; Garzio and Steinberg 2013), with tintinnids associated with sea ice (Alder and Boltovskoy 1991). In summer, aloricate ciliate and tintinnid biomass increases with increasing latitude, with high microzooplankton biomass hot spots in productive inner-shelf areas to the south, such as Marguerite Bay (Garzio and Steinberg 2013). Microzooplankton biomass is positively correlated with chlorophyll *a* and particulate organic carbon (POC) concentrations (Garzio and Steinberg 2013).

Consistent with most ocean regions, microzooplankton are the dominant grazers during summer, consuming 55-85 % of primary production per day, whilst macrozooplankton (copepods, krill, salps, pteropods) consume on average ~1 % (Bernard et al. 2012; Garzio et al. 2013; Sailley et al. 2013; Gleiber et al. 2015). However, aggregations of krill, salps or copepods common in the WAP result in higher localized macrozooplankton grazing contributions (Bernard et al. 2012; Gleiber et al. 2015). In summer, the impact of macrozooplankton grazing on phytoplankton increases significantly when salps are present, due to high ingestion rates (Bernard et al. 2012). Krill and pteropods are the major macrozooplankton grazers near the coast and over the shelf, whilst salps dominate in offshore slope waters (Bernard et al. 2012). Ingestion rates of copepods in summer are up to 70 times greater in productive coastal waters than offshore (Gleiber et al. 2015). Daily phytoplankton carbon rations for WAP macrozooplankton are often similar to, or even below, those needed to satisfy their metabolic needs and fuel reproduction, indicating that protozoans and other zooplankton are an important food source even during the productive summer period (Bernard et al. 2012; Gleiber et al. 2015). Macrozooplankton have been shown to feed on smaller zooplankton prey in the WAP (e.g. Atkinson and Snyder 1997; Calbet et al. 2006; Atkinson et al. 2012), although potential trophic cascades that could result have not been investigated. There are also regional differences in zooplankton prey quality that could affect top predators, indicated by lower lipid content of *E. superba* in the central WAP compared to the southern sub-region (Ruck et al. 2014).

A year-round time-series sediment trap located over the WAP shelf indicates that zooplankton fecal pellets (mostly from krill) dominate export, comprising on average 67 % of the total POC flux over 170 m (Gleiber et al. 2012). By comparing copepod fecal pellet flux from the same sediment trap and copepod egestion rates from experiments, Gleiber et al. (2015) estimate on average 58 % retention of copepod fecal pellets in the upper 170 m, such that copepod pellets are likely recycled in surface waters to a greater extent than those from krill. *Salpa thompsoni* along the WAP produce large fecal pellets that sink on average 700 m per day, and have defecation rates that can exceed those of krill (Phillips et al. 2009). Changes in zooplankton species composition can therefore have a significant effect on POC fluxes, biogeochemical cycling, benthic food supply and the biological carbon pump (Gleiber et al. 2012; Steinberg and Landry 2017). *E. superba* is known to forage on the benthos, which has further implications for benthic-pelagic coupling, including the vertical transfer of particulate iron ingested at depth into surface waters where it is subsequently metabolised and made bioavailable to phytoplankton (Schmidt et al. 2011; Schmidt et al. 2016).

1.7. Higher trophic levels

The WAP ecosystem comprises diverse assemblages and high biomass of top predators that represent both Antarctic and sub-Antarctic habitats, supported by the large and persistent biomass of krill predominantly in the central and southern WAP and the pack ice zone (Costa and Crocker 1996; Ducklow et al. 2007; Friedlaender et al. 2011; Kock and Shimadzu 1994; Nowacek et al. 2011). Along the northern slope and in oceanic waters where copepods dominate, mesopelagic fish and squid act as intermediate consumers. Predator hotspots develop in areas where bathymetric troughs facilitate intrusions of nutrient-rich CDW onto the continental shelf (Dinniman et al. 2011; Friedlaender et al. 2011; Friedlaender et al. 2006; Kavanaugh et al. 2015). More ephemeral predator hotspots are found along fronts and filaments that aggregate and concentrate prey (Bost et al. 2009; Cotté et al. 2015; Dragon et al. 2010; Scheffer et al. 2010; Warren et al. 2009). The biophysical coupling by which predators use and rely on mesoscale features that can aggregate their prey, and the dive behaviours that determine the decisions predators make in response to prey availability (Friedlaender et al. 2016), are critical to how top predators partition their habitat.

While top predators exist in similar regions and often share the same prey, they have different life history patterns and habitat preferences that likely alleviate some of the potential for competition. During the summer, penguins, flying seabirds and fur seals forage along the shelf break and the southern boundary of the ACC, periodically returning to their breeding colonies (Ribic et al. 2011). In winter, seabirds are found near the ice edge, along the shelf break and around the Polar Front to the north (Chapman et al. 2004). While gentoo penguins (*Pygoscelis papua)* remain near their breeding colonies throughout the year (Cimino et al. 2016; Miller et al. 2009), Adélie (*P. adeliae)* and chinstrap (*P. antarcticus)* penguins move far away from their colonies in winter, with Adélie penguins preferring winter sea ice, and chinstrap penguins preferring open water (Hinke et al. 2015; Trivelpiece et al. 2007). Adélie penguins forage in shallow (<200 m) waters near land and in deeper waters (200–500 m) near the edge of deep troughs cross-cutting the shelf (Erdmann et al. 2011). Crabeater (*Lobodon carcinophagus*), Weddell (*Leptonychotes weddellii*) and leopard (*Hydrurga leptonyx*) seals remain in the WAP year-round, maintaining access to ice or land to haul out and reproduce (Figure 11) (Costa et al. 2010). While Weddell seals remain in the fjords, crabeater seals move extensively along the shelf, staying closer to the coast in regions with greatest change in bathymetry, and deep within the pack ice throughout the winter (Burns et al. 2004). The short breeding season of southern elephant seals (*Mirounga leonina*) enables them to spend months at sea moving into the pack ice, along the outer shelf and offshore into pelagic waters (Costa et al. 2010). Seals partition their habitat by foraging depth and duration, with the longest and deepest dives by elephant seals (Hindell et al. 2016). Fur seals show significant seasonal variability in their distribution, remaining within a few hundred kilometres of their breeding colonies during summer and dispersing widely during winter (Figure 11). Humpback whales (*Megaptera novaeangliae*) forage broadly across the WAP shelf during summer, moving inshore in autumn, with their density and distribution controlled by those of their krill prey and their preference for ice-free conditions and dense aggregations of larger, older krill (Friedlaender et al. 2006; Johnston et al. 2012; Murphy et al. 2007; Weinstein and Friedlaender 2017; Weinstein et al. 2017). Humpback whales forage in a manner consistent with optimal foraging theory to maximize their energetic gains (Friedlaender et al. 2013; Friedlaender et al. 2016; Tyson et al. 2016) and remain in significant numbers in ice-free areas until the beginning of winter. Minke whales (*Balaenoptera bonaernsis*) avoid competition with humpback whales by foraging on deeper krill aggregations (Friedlaender et al. 2009) and, being smaller and more manoeuvrable, they can forage under the ice, their preferred habitat (Friedlaender et al. 2014). Recent work found long-term preferences of minke whales for ice edge regions during summer (Williams et al. 2014) and throughout the foraging season (Lee et al. 2017). While they are known to be the only endemic cetacean species, present year-round, evidence suggests that some portion of the population migrates to sub-tropical latitudes in winter (Lee et al. 2017). Blue

(*Balaenoptera musculus)* and right (*Eubalena glacialis*) whales are also seasonally present and similarly feed on krill. Different ecotypes of killer whales (*Orcinus orca*) are seasonally present in the WAP following the distribution of their prey (e.g. seals, whales or fish) (Pitman and Ensor 2003).

As well as providing top-down control on the ecosystem, top predators can also influence biogeochemical cycling by transporting macro- and micronutrients vertically and horizontally (Doughty et al. 2016; Ratnarajah et al. 2016; Roman et al. 2014).

1.8. Benthic ecosystems

Benthic organisms and processes play a critical role in whole-ecosystem structure and functioning along the WAP, as well as biogeochemical cycling and sequestration of carbon from the overlying water column. WAP benthic ecosystems are characterised by a rich diversity of macro- and megafauna including echinoderms such as brittle stars, holothurians, sea urchins, asteroids and crinoids, as well as abundant sponges, ascidians, polychaetes, bivalves, gastropods, brachiopods, bryozoans and sipunculan worms (e.g. Clarke et al. 2007; Gutt 2007; Peck 2018; Piepenburg et al. 2002; Sahade et al. 1998; Smith et al. 2012). Hard-substrate communities are widespread in the region around Palmer Station and further north to the South Shetland Islands, and are dominated by large perennial brown macroalgae in shallow waters, with red macroalgae dominating the understory (Wiencke and Amsler 2012; Deregibus et al. 2016; Ducklow et al. 2013). These macroalgae and their epiphytes form important year-round carbon sources in coastal and near-shore systems (Dunton, 2001; Gillies et al. 2012; Jacob et al. 2006; Pasotti et al. 2015), and support rich assemblages of benthic invertebrates, including amphipods, gastropods and echinoderms (Huang et al. 2007; White et al. 2012). South of the Palmer Station region, benthic communities at depths >50 m are dominated by sessile invertebrates including sponges, soft corals, bryozoans and tunicates (Ducklow et al., 2013), whilst mobile scavengers such as starfish, brittle stars and urchins are abundant in shallower waters (Clarke and Johnston 2003). Fjordic systems along the WAP have been shown to exhibit higher abundance and diversity than adjacent shelf areas (Grange and Smith 2013).

In general, benthic organisms in the WAP region are characterised by very slow growth and development rates, which are slowed beyond the expected effects of temperature compared to temperate and tropical species (Figure 12) (Peck 2016, 2018). Rates of activity and other processes including routine oxygen consumption are not similarly slowed, indicating that the limitations on growth and development are likely caused by restricted protein manufacture at low temperatures (Fraser et al. 2004, 2007; Peck 2016). The slow growth rates result in extended longevity and deferred maturity (longer generation times), which has been demonstrated in amphipods (Johnson et al. 2001), the bivalve *Adacnara nitens* (Higgs et al. 2009), and a range of other molluscs, brachiopods and echinoderms (Peck 2018). High-latitude Southern Ocean benthic organisms, such as fish (Leis et al. 2013), hyppolytid shrimps (Clarke 1985) and several starfish (Bosch and Pearse 1990), also produce fewer larger eggs, with egg diameters generally 2-5 times greater than those of lower-latitude species (Arntz et al. 1994; Peck 2018).

Benthic organisms assimilate carbon fixed by primary producers in the overlying water column and/or sea ice, and can store carbon more efficiently and over longer periods than pelagic organisms (Barnes 2017; Peck et al. 2010). The degree and timescale of carbon sequestration is dependent on sea ice dynamics and the duration of the ice algal and phytoplankton blooms, local oceanographic conditions such as current speeds and nutrient supply, organisms' lifespans and behaviours, and the frequency of ice scour, which has a major role in structuring benthic ecosystems (Barnes et al. 2018). The contribution of benthic processes to pelagic productivity via nutrient supply at the WAP is a current area of debate. Nutrient release from sediments and porewaters by diffusion, physical disturbance and bioturbation by burrowing organisms, such as polychaetes, echinoderms and bivalve molluscs (Poigner et al. 2013), has the potential to act as a significant source of nutrients to water column biota. Physical disturbance by iceberg scour can expose buried sediments from water depths exceeding 300 m, and can produce sediment scours over 10 m deep (Lien et al. 1989), releasing large quantities of sediment-derived nutrients. Currents entrained by moving icebergs can redistribute sediment several metres up into the water column for short periods and across many metres of the seabed (Bigg 2016; Peck et al. 2005). Icebergs can also distribute sediments over considerable distances and through the water column as ice melts, and act as a dispersal mechanism for some benthic species (Peck 2018). Mixing of the upper water column by icebergs, winds and currents will regulate the extent to which sediment-derived nutrients reach the surface ocean and influence pelagic primary productivity.

2) How is the WAP shelf environment changing and what are the ecosystem responses to and ocean-climate feedbacks on the changes underway?

Our knowledge of the key mechanisms and interactions regulating ecosystem functioning and ocean-atmosphere coupling along the WAP shelf, and in particular the interdependence between physical, biogeochemical and biological processes, paves the way for understanding the ongoing changes in ice dynamics, ocean physics, biogeochemistry, air-sea exchange, and pelagic, benthic and microbial food webs.

2.1. Physical oceanography and ice dynamics

The long-term change in atmospheric and oceanic properties along the WAP has been a strong focus of scientific efforts given its large magnitude, and its observed and potential impact on the regional ecosystem (Constable et al. 2014a, b; Ducklow et al. 2013; Martinson et al. 2008; Meredith et al. 2017; Schofield et al. 2017; Venables et al. 2013). The evolution of sea ice cover on timescales from seasonal to inter-decadal is a key modulator of physical and biogeochemical processes on the shelf. For example, sea ice extent and its growth and retreat modulate vertical mixing, air-sea fluxes, light penetration, and the salt and heat content of the surface ocean. On average, sea ice extent in the WAP region varies between 1 and 6×10^5 km^2 over the annual cycle (Meredith et al. 2017). Alongside substantial warming of the atmosphere and ocean, the period of seasonal sea ice cover has shortened by more than three months since the late 1970s, with autumn advance being delayed by two months and spring retreat occurring more than one month earlier (Stammerjohn et al. 2012; Stammerjohn et al. 2008a). Strong correspondence between retreat and subsequent advance suggests a strong feedback in ocean thermal properties in autumn in response to changes in the timing of retreat in spring. The trend is less clear in the northern WAP (Schloss et al. 2012) where substantial sea ice declines have already occurred, although Bers et al. (2013) showed the strong effect of climatic forcing even in inshore waters of King George Island.

The warming trends and salinity changes documented in the surface and deep water layers across much of the WAP shelf have not been observed in Bransfield Strait, likely because of the modulation by Weddell Sea inflow around the northern tip of the Peninsula (Bers et al. 2013; Meredith and King 2005; Schloss et al. 2012; Schmidtko et al. 2014). This highlights strong gradients along the shelf in the processes controlling long-term property trends, as well as the mean properties themselves. The alongshore structure of mid-depth (>100 m) ocean temperature plays a pivotal role in glacier retreat rates along the WAP, with warmer subsurface waters in the southern and central WAP (south of Bransfield Strait) acting as the primary driver of substantial glacial retreat along the adjacent coast (Cook et al. 2016; Padman et al. 2012). In contrast, glaciers along Bransfield Strait terminate in colder Weddell-modulated waters and are retreating at slower rates, with some even advancing. In cases where glaciers in the northern WAP are experiencing high melt rates and retreat, for example at King George Island, atmospheric forcing is thought to be the primary driver (Falk and Sala 2015).

The observation that the long-term trends of atmospheric warming and sea ice declines have plateaued since the late 1990s (Figure 1), with recent increases in sea ice extent and duration recorded in some places (Schofield et al. 2017; Turner et al. 2016), reflects substantial natural internal variability that is likely to have broad-scale impacts on ocean properties and circulation of the WAP shelf. The nature and importance of these interactions superimposed onto the long-term trends is still to be determined. In contrast, there is no evidence for a slow-down or reversal in the trends of oceanic warming over the southern and central WAP shelf, or glacial retreat along much of the WAP coast (Cook et al. 2016).

2.2. Phytoplankton and microbial community dynamics

The documented sea ice declines since the late 1970s have led to overall reductions in phytoplankton biomass, with regional differences along the WAP in the response of phytoplankton dynamics to the climatic and oceanic changes observed (Montes-Hugo et al. 2009). These changes in phytoplankton dynamics are attributed to changes in sea ice and upper ocean conditions, rather than any long-term trend in CDW incursion and/or nutrient supply. Satellite analyses suggest that the shelf sub-region to the north of Anvers Island experienced decadal declines in summer chlorophyll levels between the early 1980s and early 2000s concurrent with declining sea ice extent and duration (Montes-Hugo et al. 2009; Stammerjohn et al. 2008a, b). Low sea ice cover during winter and early spring leads to low chlorophyll in summer due to increased wind-driven mixing and potentially increased cloud cover, and consequently a less favourable light environment for phytoplankton growth (Montes-Hugo et al. 2009; Saba et al. 2014; Venables et al. 2013). In contrast, satellite-derived chlorophyll increased in the central and southern sub-regions over the same period, attributed to longer periods of open water (Montes-Hugo et al. 2009) resulting from the seasonal declines in sea ice (Stammerjohn et al. 2008a, b). However, strong decreases in chlorophyll in the northern sub-region outweighed the increases further south, leading to an overall reduction in phytoplankton biomass along the WAP (Montes-Hugo et al. 2009). More recently, the increase in sea ice duration since the late 2000s has led to higher chlorophyll levels in WAP coastal regions (Schofield et al. 2017).

Coastal time-series data from Potter Cove at King George Island/ Isla 25 de Mayo (Schloss et al. 2012) and Palmer Station at Anvers Island (Schofield et al. 2017) suggest that the observed declines in phytoplankton biomass reversed around 2010. In Potter Cove, chlorophyll concentrations were typically low between 1991 and 2009, with maximum values (~4 mg m^{-3}) during short-lived episodic events, when phytoplankton assemblages were dominated by large diatoms from several genera (*Corethron criophilum, Odontella weissflogii, Eucampia antarctica, Thalassiosira sp., Porosira sp.*) (Schloss et al. 1997). Nutrients were not limiting, and low phytoplankton biomass was attributed to adverse physical conditions, with intense turbulent mixing and sediment-rich meltwater inputs limiting light conditions for phytoplankton growth and preventing bloom formation (Schloss et al. 2002; Kim et al. 2018). A first high-chlorophyll bloom (~14 mg m^{-3}) lasted approximately two weeks in January 2010 and was followed by several subsequent high-chlorophyll seasons, with the same genera present as earlier in the time series (Schloss et al. 2014; Kim et al. 2018). Whilst a combination of low air temperatures, which delayed the melting of the surrounding Fourcade glacier, and low wind intensities can explain the bloom duration in January 2010, different mechanisms are behind increased productivity in more recent years. Experimental work has shown that smaller diatoms (e.g. *Navicula*, *Nitzschia*, etc.) have greater tolerance to low salinities than large diatoms (Hernando et al. 2015), such that the phytoplankton response to glacial meltwater inputs may differ depending on community composition and the timing of inputs relative to bloom progression.

Chlorophyll concentrations have also increased since the late 2000s at Palmer Station, ~400 kilometres to the south, concurrent with an increase in the number of days of sea ice cover each year and shallower spring/summer mixed layers, which have led to larger phytoplankton blooms dominated primarily by diatoms (Schofield et al. 2017). This is in contrast to much of the duration of the Palmer time series, where a statistically significant decline in sea ice duration was observed. At the Rothera Time Series (RaTS) in northern Marguerite Bay, ~400 kilometres south of Palmer Station, short-lived winter sea ice cover led to a substantial reduction in summertime chlorophyll levels between 2007 and 2010 (Venables et al. 2013). Since 2010, sea ice duration and chlorophyll have increased again, with sea ice persisting into December and large phytoplankton blooms (chlorophyll >15 mg m^{-3}) in the most recent years. A recent synthesis of chlorophyll and physical oceanographic time-series data from Potter Cove, Palmer and Rothera demonstrates that whilst large-scale climate forcing influences all three sites, local processes such as ice melt and mixing superpose distinct interannual patterns and trends (Kim et al. 2018). Longer-term changes in primary production and community structure over the WAP shelf will depend on the interaction of long-term climatic warming trends and large natural internal variability in regulating seasonal sea ice dynamics over interannual-to-decadal timescales.

Projected increases in glacial meltwater input (Meredith et al. 2010) are likely to modify phytoplankton dynamics by promoting upper ocean stability and altering nutrient availability. Combined with long-term reductions in sea ice cover and persistence of deeper mixed layers, increased surface stratification would potentially favour cryptophytes and smaller diatoms over larger diatoms, with shifting phytoplankton community structure as a result (Moline et al. 2004; Schofield et al. 2017).

There has been significantly less focus on the consequences of sea ice and physical oceanographic changes for the direct coupling between sea ice and pelagic ecosystems, through ice-ocean exchange and sea ice algal inputs to the water column. Changes in the timing of sea ice retreat may lead to phenological changes, and earlier or later ice algal and/or phytoplankton blooms may result in trophic mismatches as pelagic herbivores become less able to synchronize with the blooms, with negative reproductive consequences and the potential for cascading effects through the entire food web (e.g. Søreide et al. 2010).

Relatively little is known about the response of microbial communities to ongoing changes in the physical environment and phytoplankton dynamics. However, response time to changing environmental conditions is known to vary spatially and between phytoplankton and bacterioplankton (Moreno-Pino et al. 2016; Rozema et al. 2017b), likely increasing spatial patchiness in the microbial community (Figure 10) and functional diversity, thus affecting ecosystem resilience. The strong dependence of microbial processes on other rapidly changing ecosystem components, e.g. phytoplankton (Bertrand et al. 2015), zooplankton, benthic organisms, seeding from macrofaunal microbiomes (Bik et al. 2016) or terrestrial systems (Cavicchioli 2015), and the bioavailability of DOM substrate, suggests that continual and pronounced changes in microbial community composition and functioning are likely.

2.3. Biogeochemical changes and air-sea exchange

Physical and biological changes along the WAP are closely related to changes in ocean chemistry and biogeochemistry, in particular the budgets and cycling of macro- and micronutrients, and the production and air-sea exchange of climate-active gases, with the potential for larger-scale consequences and feedbacks. For example, continued glacial retreat can be expected to increase the supply of iron and other micronutrients (Zn, Cd, Co etc.) from glacial and shallow sediment sources, and potentially their availability to phytoplankton (Annett et al. 2015; Annett et al. 2017; Bown et al. 2017, 2018; Hendry et al. 2008; Monien et al. 2017). Seasonal biological uptake of nutrients and carbon will be determined by the documented variability and ongoing changes in seasonal phytoplankton dynamics driven by changes in sea ice and upper ocean conditions (Henley et al. 2017; Legge et al. 2015; Kim et al. 2016).

Changes in the properties, transport and circulation of CDW across the shelf, particularly in the southern and central WAP regions to the south of Bransfield Strait (Martinson et al. 2008; Schmidtko et al. 2014), are likely to increase the supply of macronutrients and CO_2 to subsurface shelf waters. The extent to which this affects surface ocean nutrient and carbon budgets will depend on the evolution of mixing processes in response to sea ice and atmospheric forcing. Carbonate system parameters (DIC, TA, pCO_2) on the Palmer LTER grid do not show statistically significant trends during summer seasons between 1993 and 2012 (Hauri et al. 2015). However, a continuation of the long-term reduction in seasonal sea ice cover and continued strengthening and southward shifting of westerly winds (Le Quéré et al. 2007; Stammerjohn et al. 2008b; Landschützer et al. 2015) may increase upwelling of DIC-rich water and CO_2 outgassing in winter, as well as altering the phytoplankton community and potentially reducing biological CO_2 uptake in summer (Legge et al. 2015; Saba et al. 2014). The resultant reduction in net annual CO_2 uptake along the WAP is unlikely, in itself, to make a significant difference to the functioning of the Southern Ocean CO_2 sink, due to the small size of the WAP shelf region. However, if the changes anticipated at the WAP are manifest across larger areas of the Southern Ocean in the coming decades, the detailed knowledge of the physical and biological mechanisms regulating CO_2 fluxes obtained in the WAP system will be useful in projecting change at the wider scale, which could be significant terms in the global carbon budget.

Given that sea-to-air emissions of halogens and DMS are directly linked to sea ice dynamics (von Glasow and Hughes 2015) or are derived from the ecosystems that exist within or around sea ice (Hughes et al. 2013; Stefels et al. 2018), it is likely that the sea ice changes and variability observed along the WAP in recent decades will alter the fluxes of these gases to the atmosphere over interannual and longer timescales. This will be important for climate (through aerosol and CCN formation) and atmospheric chemistry (via tropospheric ozone destruction) locally and regionally.

2.4. The WAP pelagic food web

Interannual variability in phytoplankton biomass has strong implications for the productivity of the entire food web, with low chlorophyll years leading to less successful recruitment of the keystone species Antarctic krill *(Euphausia superba)* (Atkinson et al. 2004; Saba et al. 2014). As such, low sea ice conditions are likely to hold negative consequences for higher trophic levels such as penguins, flying sea birds, seals and whales (Constable et al. 2014a, b; Costa et al. 2010; Trivelpiece et al. 2011). Conversely, the recent increases in chlorophyll are likely to be beneficial for zooplankton and their pelagic and benthic consumers (Saba et al. 2014).

Seasonal changes in WAP macrozooplankton abundance are driven by a combination of long-term trends linked to warming and sea ice declines, sub-decadal shifts attributed to oscillations in atmospheric forcing, such as SAM and ENSO, which affect sea ice dynamics and sea surface temperature, and local and regional changes in primary production, all of which have strong interdependences (Figure 13; Steinberg et al. 2015). For example, a decrease in krill density between the 1970s and early 2000s in the WAP and southwest Atlantic sector of the Southern Ocean was attributed to long-term warming and sea ice declines, which reduce the availability of the ice algal food source required to promote larval survival and recruitment, as well as driving the overall decline in the summer phytoplankton food source (Atkinson et al. 2004; Montes-Hugo et al. 2009). It has been contested that this decline in krill resulted from a period in the decadal-scale population variability of unusually high krill abundance in the late 1970s, rather than being driven by climate change over subsequent decades (Loeb and Santora 2015). However, more recent evidence has shown a southward contraction of krill distribution throughout the sector over the last 90 years, with a concomitant reduction in juvenile recruitment linked to reduced food availability, and a concentration of the population over the WAP shelf (Atkinson et al. 2019). Since the early 1990s, krill abundance on the Palmer LTER grid (central and southern WAP) has shown a stable 5-year cycle that reflects variability in reproductive and recruitment success linked to ENSO cycles and their influence on sea ice dynamics (Loeb et al. 2009; Quetin and Ross 2003; Ross et al. 2014; Steinberg et al. 2015), in broad agreement with findings from the northern WAP around the South Shetland Islands (Loeb and Santora 2015; Richerson et al. 2017). Accordingly, both *E. superba* and *Thysanoessa macrura* are positively correlated to regional primary production two years prior (Figure 13; Steinberg et al. 2015). Local effects can also be pronounced, for instance high krill mortality in Potter Cove in recent years is attributed to unfavourable conditions caused by high meltwater-sourced particle loads from a retreating glacier (Fuentes et al. 2016). In contrast to krill, abundance of the major copepod taxa showed a regional long-term increase between 1993 and 2013 (Gleiber 2015). Variability in *Salpa thompsoni* over the shelf is influenced by both ENSO (Loeb and Santora 2012) and SAM (Figure 13; Steinberg et al. 2015), whilst long-term increases throughout the southwest Atlantic sector have accompanied the declines in krill (Atkinson et al. 2004). Variability in abundance of the pteropod *Limacina helicina* along the WAP is also linked to ENSO cycles (Figure 13; Loeb et al. 2009; Loeb and Santora 2013; Ross et al. 2014; Steinberg et al. 2015). Shifts in phytoplankton community structure can also affect the abundance of krill relative to other major zooplankton taxa, because the grazing efficiency of *E. superba* is reduced significantly on particles <20 µm, such that diatom-dominated communities are likely to favour krill, whilst communities dominated by cryptophytes and/or haptophytes are likely to favour salps and other taxa (Haberman et al. 2003; Meyer and El-Sayed 1983; Moline et al. 2004). Shifts in the dominance of krill compared to other taxa have major consequences for higher trophic levels that rely on krill as their primary food source, as well as for carbon export and nutrient recycling, and may lead to substantial reorganisations of the pelagic food web (e.g. Atkinson et al. 2004, 2019; Quetin and Ross 2003).

The distribution and abundance of a number of krill-dependent pelagic consumers are changing in concert with changes in the physical environment and the availability of krill (Constable et al. 2014a, b). Winter sea ice conditions along the WAP are particularly important for krill predators, because they regulate krill availability and therefore foraging conditions, which are a key determinant of recruitment and overwinter survival of adult and juvenile animals (Hinke et al. 2017b). Sea ice-driven changes in phenology can also lead to trophic mismatches between predator foraging needs and prey availability, with major demographic consequences (Youngflesh et al. 2017). Populations of ice-dependent Adélie and chinstrap penguins have declined significantly (e.g. Figure 14; Ducklow et al. 2013; Hinke et al. 2017a; Juares et al. 2015; Trivelpiece et al. 2011) and the only Emperor penguin colony at the WAP has been lost due to changes in seasonal sea ice duration (Trathan et al. 2011). Southward shifts of the maritime climate, displacing the Antarctic climate, have also increased precipitation and snow accumulation, which reduces the survival of Adélie penguin chicks (Carlini et al. 2009; Chapman et al. 2011). In the northern WAP in particular, the shift to a more maritime climate is likely to shift southward the distributions of ice- and krill-dependent species, such as Weddell and crabeater seals, minke whales and Adélie penguins, leading to local declines as their habitat contracts with diminishing sea ice (Ducklow et al. 2013; Huckstadt et al. 2012a; Siniff et al. 2008). In contrast, ice-tolerant species such as fur seals (*Arctocephalus gazella*), humpback whales and gentoo penguins and those less dependent on krill, such as elephant seals, have increased in number (Costa et al. 2010; Ducklow et al. 2013) and in the length of time they remain feeding locally (e.g. Friedlaender et al. 2016; Weinstein and Friedlaender 2017). The decline in Adélie penguin numbers slowed down in the mid-2000s and the total number of penguins stabilised, although this was a consequence of increasing gentoo penguin numbers (Figure 14). Some krill predators exhibit trophic plasticity and can increase their consumption of fish in years of lower krill availability (e.g. crabeater seals; Huckstadt et al. 2012a), although the extent to which this plasticity can relieve the dependence on krill remains unknown. Sub-Antarctic King penguins (*Aptenodytes patagonicus*) have extended their distribution southwards, recently being recorded for the first time at King George Island (Juares et al. 2017). Increasing westerly wind intensity has benefitted wandering albatrosses (*Diomedea exulans*), by increasing their foraging speeds and reducing trip length, thus enhancing their foraging efficiency and breeding success (Weimerskirch et al. 2012).

2.5. The WAP benthic food web

Benthic communities along the WAP are sensitive to variability in physical and biogeochemical forcing, because many organisms are sessile and therefore unable to migrate. Benthic responses to ocean warming depend on organisms' abilities to adapt or acclimate to altered conditions. Antarctic benthos have a reduced capacity to adapt compared to lower-latitude populations, due to their low production rates of novel genetic material that enhance survival, which arise from longer generation times and production of fewer larger eggs without an increase in mutation rate or population size (Arntz et al. 1994; Higgs et al. 2009; Johnson et al. 2001; Peck 2018). Geneflow between Antarctic populations is also slower than for temperate or tropical populations due to relatively high levels of protected development and proportionally fewer species using pelagic larval dispersal (Arntz et al. 1994; Peck 2018; Hoffman et al. 2011, 2012). For species that do use pelagic dispersal, rising ocean temperatures increase larval development rates, thus shortening the larval phase substantially (Peck 2016, 2018). This reduces dispersal distances and increases isolation between populations, as well as altering the timings of reproductive cycles in relation to key environmental events (Bowden et al. 2009), such that larval success may decline significantly due to phenological mismatches as warming proceeds.

Given limited rates of adaptation, Antarctic benthos need sufficient phenotypic plasticity to acclimate to altered conditions and survive the projected climate change in coming decades (Peck 2011). Antarctic fish (Bilyk and DeVries 2011) and invertebrates (Morley et al. 2016; Peck 2018; Peck et al. 2009, 2014) have very limited tolerance to warming in laboratory-based experiments, indicating that acclimation to elevated temperature is poor in Antarctic species (Peck et al. 2014). Thermal tolerances are influenced by a number of different species-specific factors (Clark et al. 2017), including heat shock responses to warming (Clark and Peck 2009; Clark et al. 2008), and upper temperature limits being set by accumulation of toxic metabolic end-products (Heise et al. 2007), limitation of energy reserves (Peck 2018; Peck et al. 2014), and temperature sensitivity of critical enzymes (Clark et al. 2016). In general, the rate of oxygen supply to tissues (Pörtner and Farrell 2008; Pörtner et al. 2012) does not exert a major limitation on thermal tolerance (e.g. Devor et al. 2016). The first *in situ* warming experiment in the Southern Ocean, conducted at Rothera, showed that growth of biofouling species was significantly faster at 1°C above ambient than at ambient (Figure 15) and this was attributed to factors including more efficient protein synthesis and faster processing of food allowing greater nutrient intake in a summer season (Ashton et al. 2017). Mixed results from +2°C treatments likely indicate that growth of some species was restricted by their temperature limits.

Benthic community structure is strongly influenced by ice dynamics along the WAP. Whereas sea ice organic fluxes are an important food source for the benthos, solid ice can have a devastating effect by removing a significant proportion of macro- and meiofauna from the seabed (Peck et al. 1999; Lee et al. 2001). Iceberg impacts can be very frequent in shallow waters along the WAP (Brown et al. 2004), and ongoing increases in iceberg scour driven by glacial retreat, receding ice shelves and an overall decline in fast ice have caused a marked drop in biomass of shallow benthic fauna in Ryder Bay, Adelaide Island (Barnes and Souster 2011). This is expected to continue, and potentially intensify in the coming decades (Barnes 2015; Smale et al. 2008). In Potter Cove, South Shetland Islands, increased sedimentation from a retreating glacier was the most important factor driving sudden shifts in nearby benthic assemblage composition with unexpectedly rapid loss of diversity and biomass (Sahade et al. 2015; Torre et al. 2017). Contrary to the adverse effects of ice scour and ice-derived sedimentation, the retreat of coastal glaciers and disintegration of ice shelves along the WAP has opened up new ocean areas for pelagic productivity and benthic ecosystem development (Peck et al. 2010). The loss of benthic carbon storage caused by increased iceberg scour during glacial retreat and ice shelf disintegration is significantly outweighed by the increase in carbon storage resulting from increased primary production and benthic biomass, such that these ice losses lead to a substantial net increase in carbon drawdown to the seabed (Barnes 2015, 2017; Barnes et al. 2018). Glacial retreat has also opened up newly ice-free areas in Potter Cove, including a new island, which have been colonised by communities exhibiting high diversity, biomass and a complex structure at rates far exceeding previously observed or predicted rates in Antarctic benthos (Lagger et al. 2017a, b). Macroalgal forests can colonise recently ice-free hard substrates (Campana et al. 2018; Quartino et al. 2013), and may expand further in the northern WAP in future as more frequent ice-free winters and early spring fast-ice disintegration are expected to increase the annual light budget (Deregibus et al. 2016). Bacterial groups that dominate in sediments enriched with macroalgal detritus (e.g. Proteobacteria, Bacteroidetes, Planctomycetes and Verrucomicrobia) would also become increasingly important with continued macroalgal expansion (Abele et al. 2017; Pasotti et al. 2015). The net effect of ongoing ice changes for benthic communities along the WAP will depend on water depth and proximity to glaciers and/or ice shelves, and their effect on iceberg scour, sedimentation and light availability. Results from Potter Cove show that benthic ecosystem responses may be non-linear and particularly rapid, intense and heterogeneous in fjordic systems. Throughout the coastal WAP, longer-term losses of glaciers and ice shelves may reduce ice scour and sedimentation significantly, increasing benthic carbon drawdown substantially, but the timing of these changes is unknown.

Invasive species occur on the WAP shelf as a result of larval dispersal and anthropogenic vectors such as ship ballast water and hull biofouling (Clayton et al. 1997; Hughes and Ashton 2017; Lee and Chown 2009). The long-term warming and sea ice trends are altering the natural barriers to species invasions along the WAP, by dampening the effect of sea ice cover in reducing dispersal and killing potential invasives, by increasing the coverage of year-round ice-free shallow benthic habitats, and by weakening the temperature limitation of biological processes in warmer-water species. These trends combined with increasing ship traffic are likely to promote the import and success of invasives along the WAP, with potential for major ecosystem disruption, although the timing, magnitude and impact of these invasions is not known.

2.6. Ecosystem responses to ocean acidification

Ocean acidification is expected to be particularly pronounced and to occur earlier in the Southern Ocean, which absorbs more than 40 % of global anthropogenic CO_2 (Fletcher et al. 2006; Orr et al. 2001), than in other ocean regions (Feely et al. 2009; McNeil and Matear 2008; Orr et al. 2005). Whilst statistically significant trends in inorganic carbon and pH have not yet been detected at the WAP (Hauri et al. 2015), aragonite Ω close to 1 has recently been documented in the coastal WAP during winter (Jones et al. 2017), making aragonitic organisms susceptible to small changes in pH. Decadal enrichment in inorganic carbon and acidification have been documented in the Drake Passage to the north (Hauri et al. 2015; Takahashi et al. 2014), suggesting that this mechanism may have significant ecosystem consequences along the WAP in future.

Ocean acidification has the potential to impact on WAP phytoplankton communities, as experiments from the Ross Sea have shown a shift from the small haptophyte *Phaeocystis antarctica* or pennate diatoms at low CO_2 to large centric chain-forming *Chaetoceros* diatoms at elevated CO_2 levels (Tortell et al. 2008; Feng et al. 2010). These findings were supported by laboratory studies that suggest diatoms may have a competitive advantage over other taxa at elevated CO_2 (Chen and Gao 2004; Sobrino et al. 2008; Wu et al. 2010). An acidification-driven shift towards larger diatoms would act against the proposed shift towards smaller diatoms, haptophytes and cryptophytes driven by changing ice distributions and freshwater inputs (e.g. Hernando et al. 2015; Rozema et al. 2017a; Schofield et al. 2017). As such, the phytoplankton response to competing physical and biological forcings along the WAP could vary significantly over time and space, compounding variability in the forcings themselves. Shifts in phytoplankton species composition could have significant consequences throughout the food web due to different feeding preferences of the major zooplankton taxa and their consumers.

The effects of ongoing atmospheric CO_2 uptake and ocean acidification on polar zooplankton are not well understood. To the north of the WAP in the Scotia Sea, live pteropods (*L. helicina*) showed signs of shell dissolution in a region undersaturated with aragonite (Bednaršek et al. 2012). Conversely, recent evidence for *L. helicina* from the Arctic repairing their shells after mechanical and dissolution damage suggests that these pteropods may be more resilient to ocean acidification than previously thought (Peck et al. 2018). *E. superba* in the WAP region have been shown to increase their feeding and excretion rates under high CO_2 conditions, especially in the case of pregnant krill (Saba et al. 2012).

Antarctic benthos are thought to be vulnerable to current and future ocean acidification, because many have calcified skeletons that use up a greater proportion of the organism's energy budget than lower-latitude species (Watson et al. 2017), as well as low physiological rates and a limited ability to resist environmental change in general. Research on the capacity of Antarctic benthos to acclimate to lowered pH is conflicting, with some studies showing poor capacities in certain organisms (e.g. Schram et al. 2016), whilst most studies demonstrate little effect of lowered pH, even on early stages (e.g. Catarino et al. 2012), and several studies demonstrate greater effects of temperature than pH (Byrne et al. 2013; Cross et al. 2015; Kapsenberg and Hofmann 2014). Recent studies show that although long acclimation periods are required, Antarctic benthos can acclimate to altered pH, at least to end-century conditions, and acclimated organisms exhibit physiological and reproductive performance similar to those in controls (Cross et al. 2015; Suckling et al. 2015; Morley et al. 2016).

3. Overarching priorities and approaches for future work

Whilst significant progress has been made in recent decades in understanding the functioning of the WAP shelf ecosystem, its physical and biogeochemical drivers, the coupling between the ocean and atmosphere, and how these interactions are changing over time, critical knowledge gaps remain. Further elucidation is required regarding the relative importance of the different controlling mechanisms and the interactions between these mechanisms, in order to develop a whole-system understanding of the WAP shelf ecosystem and its response to ongoing changes in climate and the physical environment over seasonal-to-decadal timescales. As sea ice dynamics exert such an important control on ocean physics, chemistry and ecosystem functioning, a fundamental challenge for the observational and modelling communities is to unravel the importance of long-term climate-driven trends compared with large natural internal variability, and consequently the extent to which the recent slow-down in warming and sea ice losses will persist against the background long-term trend. This challenge is a highly active area of research for the international community (Reid and Massom 2015; Reid et al. 2018), but will ultimately require longer time series of satellite and in situ ocean and sea ice measurements, and an improvement in the performance of IPCC-class models for the forthcoming Coupled Model Intercomparison Project Phase 6 (CMIP6). Regional models can be used to elucidate the important local-scale ice-ocean-atmosphere feedbacks modulated by relatively small-scale processes (e.g. ocean eddies with scales of a few kilometers). However, given the known dependence of WAP climate on remote processes (e.g. ENSO, and its interaction with the SAM), these models would need to take reliable boundary conditions from global climate/Earth System models that reproduce both the low-latitude modes and their propagation to high latitudes. Such a framework would allow us to increase the reliability of the relevant signals in the IPCC-class models and improve our ability to project future changes in ice coverage and duration.

Table 1 outlines the important discipline-specific research objectives in WAP marine science over the next 2-10 years, and Table 2 outlines the key approaches and innovations required to address these objectives. One of the major findings over the last three decades has been the importance of physical oceanographic processes in modulating biological and biogeochemical processes, from nutrient supply and phytoplankton dynamics to zooplankton distributions and foraging behaviour of pelagic consumers. This degree and multilateral nature of physical control makes defining the processes of oceanic water mass transport onshore, and its modification and vertical ventilation on the shelf, a key priority. The importance of ice-ocean interactions necessitates full characterisation of sea ice dynamics, glacial meltwater and other freshwater inputs, and their modulation of these physical processes. Quantifying these physical dynamics will pave the way for projecting their impacts on biogeochemical and biological processes throughout the entire food web. Pronounced spatial heterogeneity and temporal variability on timescales of several days to decades necessitates longer time series capturing the complete annual cycle and increased temporal and spatial resolution of observations across the shelf, including under the sea ice. This increased resolution and capability can be achieved by developing an observing system for the WAP shelf combining traditional ship- and station-based approaches with novel technologies based on gliders, autonomous underwater vehicles (AUVs), and mooring and high-frequency (HF) radar networks.

HF radar measures ocean surface (upper 1 m) current velocities over hundreds of square miles simultaneously. A shore-based three-site HF radar network deployed recently at the WAP provides hourly surface current data over the entire Palmer Station region (Figure 16), and has been used with penguin foraging data to identify the selection of foraging locations relative to mapped convergent features over the Palmer Deep canyon (Kohut et al. 2014). These systems have proven to be robust and cost-effective with many applications, and a significant opportunity exists to develop a shelf-wide integrated system to define the regional surface ocean circulation, which is currently one of the least understood aspects of the shelf circulation.

Moorings have been deployed routinely along the WAP, providing high-frequency time-series measurements year-round for over a decade. These moorings have been critical in documenting the frequency and mechanisms of subsurface intrusions of modified CDW onto the continental shelf (Martinson and McKee 2012; Moffat et al. 2009). A key limitation of moorings is that they are typically unable to collect data near the surface, due to the presence of seasonal ice and icebergs (Savidge and Amft 2009), and their spatial coverage is limited.

Autonomous gliders (Sherman et al. 2001; Eriksen et al. 2001; Webb et al. 2001) are complementing mooring measurements by providing high-resolution spatial measurements over the full shelf depth (Carvalho et al. 2016; Carvalho et al. 2017; Couto et al. 2017; Brearley et al. 2017). These gliders are capable of sampling over thousands of kilometres and spending months at sea, making them ideal for maintaining a sustained presence and filling critical observational gaps between ship-board surveys, research stations and mooring arrays, and at smaller spatial scales than are captured by shipboard sampling (Venables et al. 2017). These systems are cost-effective, capable of carrying a range of sensors, and have been proven to be effective tools to leverage data collection across a broad range of applications and ocean regions (Schofield et al. 2015).

Powered AUVs have been used in the Southern Ocean for bathymetric, physical oceanographic and biological surveys under and in the vicinity of sea ice (e.g. Brierley et al. 2002). Expanding the use of such AUVs in the WAP region has the potential to provide a wealth of water column data from under-ice environments. Most under-ice powered AUV missions to date have been conducted by large complex platforms capable of under-ice navigation and advanced autonomous decision-making, requiring ship support and making deployments expensive. Transitioning to smaller, less complex and less expensive systems capable of sustained missions would increase the number and scope of deployments at the WAP and elsewhere.

Using autonomous technologies will be of particular value in improving observational coverage during ice formation in autumn, the ice-covered winter period and the springtime transition from winter into the ice-free phytoplankton growing season. These times of year are critically important in regulating phytoplankton bloom dynamics, and other key ecosystem processes, yet remain severely undersampled across all disciplines of WAP marine science. In future, real-time sampling and data transfer using these technologies has the potential to inform predictions of key ecosystem processes at the seasonal scale, e.g. phytoplankton bloom timing, magnitude and distribution based on mooring- and glider-derived measurements/parameterisations of mixed layer depth and stability. Upscaling the use of gliders and powered AUVs in the seasonally ice-covered WAP shelf environment would require a robust and well-integrated system for under-ice navigation, using compact accurate inertial navigation systems and/or acoustic telemetry networks that allow AUVs to triangulate their position. Such systems would facilitate major innovations in future observational studies, for example in elucidating the role of small- and meso-scale processes under the ice, the transports they produce, and their effect on the larger-scale circulation, under-ice ecosystems and biogeochemical cycles. Alongside technological developments in observational approaches, improvements in the resolution of regional ocean circulation models and incorporation of realistic bottom topography are required to fully resolve the most important physical drivers of the shelf ecosystem.

Utilising the WAP shelf region as a natural laboratory or model system to understand the impacts of climate and sea ice changes and the resultant physical oceanographic changes here and in other marginal ice zone settings on phytoplankton dynamics, carbon and nutrient cycling, air-sea fluxes of climate-active gases, and pelagic, benthic and microbial food webs requires an integrated approach. Novel process-based experimental, technological and modelling approaches should be combined with the long-running time-series and spatial measurements that form the backbone of our knowledge of variability and change in the WAP marine system. Given pronounced heterogeneity across the shelf, quantifying the importance of biological hotspots for the regional ecosystem and biogeochemical cycling is a high priority. Detailed process studies and repeat sampling of these hotspots, including along the sea ice edge and in the high-productivity fjords, will improve our understanding of the conditions required to create these hotspots and their change over time.

In such a highly coupled system, it is imperative to cross-cut disciplinary boundaries and characterise the interactions between different system components, e.g. phytoplankton, zooplankton and microbial dynamics in regulating biogeochemical cycling and the biological carbon pump, bottom-up versus top-down predation control of zooplankton distributions, benthic faunal composition and behaviours and benthic-pelagic nutrient fluxes. For example, further application of genomics, transcriptomics and proteomics approaches have the potential to revolutionise our understanding of microbial processes and interactions, and marine ecosystem functioning in general, by revealing vital functions of phytoplankton and bacterioplankton, and identifying the many viruses infecting a range of hosts. Combining a range of methodologies relevant to different processes, interactions and timescales will also be critical to making progress. Adopting such an interdisciplinary whole-system approach offers perhaps the most promising opportunity for driving a step-change in our understanding of the functioning of the WAP marine ecosystem and its response to, and role in, ongoing climatic and environmental changes, making this a clear overarching priority for the international community.

Temporal and spatial coverage of data illuminating these physical-biological-biogeochemical interactions can be augmented by maintaining and strategically enhancing the existing programs of sustained observations, by adopting the essential ocean variables (EOVs; Constable et al. 2016; A Framework for Ocean Observing, 2012) as a framework for an observing system for the WAP, and by employing technological innovations to fill data gaps and increase resolution in time and space. In addition to the discipline-specific approaches and innovations outlined in Table 2 and the physics-based technologies detailed above, a number of sensor-based innovations can be employed across disciplines and provide a more integrated perspective. For example, the utility of AUVs, gliders and moorings can be expanded substantially by increasing the number and reliability of sensors capable of measuring a range of physical, biological and chemical parameters (e.g. turbulence, fluorescence, pCO_2, nitrate). Equipping seals with small CTD tags has provided the extensive hydrographic MEOP (Marine Mammals Exploring the Oceans from Pole to pole) dataset alongside complementary animal behaviour data (Treasure et al. 2017), with significantly greater coverage than otherwise available. Developing and deploying a greater range of sensors (e.g. fluorescence, dissolved oxygen etc.) would facilitate more detailed sampling in ice-covered regions, near-shore embayments and over larger spatial scales than ship-based efforts. Systematic deployment of multi-frequency acoustics on ships, moorings and AUVs would allow us to estimate krill biomass and distribution, and the movement and foraging behaviour of their pelagic predators, with unprecedented accuracy and coverage across the shelf, including in the data-sparse southern region and under ice.

In the context of physical controls on ecosystem structure and functioning, a major question to be addressed is the extent to which organisms at all trophic levels can acclimate, adapt, migrate, and/or change their behaviours, and the rates at which these processes can occur. Process studies and manipulation experiments are required, focusing on the physiological profiles of the major species of phytoplankton, bacterioplankton, viruses, zooplankton and benthic organisms across current and future physical (temperature, salinity, mixing), chemical (macro- and micronutrients, pCO_2 and Ω) and ecological (grazing pressure, viral infection) conditions, and therefore their ability to acclimate. Rates of geneflow within and between populations are needed to quantify the capacity of benthic and pelagic communities to adapt to altered environments. Top predators can be used as sentinels of ecosystem change as their abundance and distributions reflect those of their prey. Reproductive studies targeting major zooplankton taxa and higher trophic level organisms and in-depth studies of the growth, diet and behaviours of juveniles would inform our assessments of recruitment success and population dynamics of key species, and their responses to different conditions. Understanding organisms' abilities to acclimate, adapt, migrate and/or change behaviours, and over what timescales, will shed light on the resilience and sensitivity of different ecosystem components in the face of pronounced environmental variability and change, and their response to multiple natural and anthropogenic stressors.

Direct human pressure on regional krill stocks is increasing as a result of expanding commercial fishing activity, particularly in the northern WAP and adjacent open ocean, potentially reducing food availability for krill predators (Trivelpiece et al. 2011). Management of this fishery by the Convention on Conservation of Antarctic Marine Living Resources (CCAMLR) must be informed by our knowledge of the foraging behaviour of krill predators, for instance using satellite tags and motion-sensing tags to determine the critical locations and times of year for their feeding (Weinstein et al. 2017), so that any overlap and potential competition with fishing activity can be minimised (Hinke et al. 2017b).

Enhancements of our observational capacity and coverage across the WAP shelf must be accompanied by continued development of modelling frameworks and capabilities to reveal the most important mechanisms behind variability and change at all levels of the ecosystem. Improving the resolution and scope of regional physical, biogeochemical and habitat or ecosystem models is a particular priority, given large heterogeneity spatially and over daily to decadal timescales. Better-constraining the rates of key processes, such as onshelf CDW transport, meltwater inputs, algal growth and organic matter remineralisation, and the major fluxes of heat, nutrients, gases and particles based on coherent high-quality observational data is needed for optimisation of model input parameters and boundary conditions. Ongoing development of regional system models will allow us to test the relative importance of different processes, elucidate the combined and/or competing effects of multiple stressors, and explore the feedbacks between the drivers and consequences of change amongst the different system components over a range of timescales. Further, only once we can represent accurately the key processes and interactions at work in modelling frameworks can we be confident in our projections of future changes in upper ocean mixing, nutrient supply, primary production, ecosystem functioning and resilience, and air-sea exchange of climate-active gases as the changes in sea ice extent, duration and atmospheric forcing continue to evolve. Ultimately, better quantification of the processes and feedbacks at the WAP, and their interactions with systems up- and down-stream in regional atmospheric and oceanic circulation systems, will enable us to better-represent this Southern Ocean region in global climate models and understand its role in contemporary global change.

4. Closing remarks

We have demonstrated the importance of the WAP marine system due to pronounced variability and change in the physical environment and ocean-climate interactions, strong biological and biogeochemical consequences locally and regionally, and its utility as a natural laboratory for examining how climate and sea ice changes might restructure ecosystems here and elsewhere. We have summarised the state of knowledge regarding the key mechanisms and interactions regulating ecosystem functioning and ocean-atmosphere coupling, as well as the changes underway and the ecosystem responses and ocean-climate feedbacks. We also highlight the overarching priorities and discipline-specific objectives for future research and present a vision for an observing system capable of addressing these priorities and objectives. Working towards this vision will require further improvements in integration, collaboration and co-ordination across national programs, projects and initiatives, including sharing of expertise, standardisation of field, experimental and analytical techniques, and optimisation of ship-time, station infrastructure and other resources. To this end, SOOS has recently launched the Due South online database of ship- and station-based fieldwork programs in the Southern Ocean (https://data.aad.gov.au/duesouth/), as well as establishing regional working groups for the WAP and other regions. More effective engagement with other research communities, such as the climate science, meteorology, glaciology, terrestrial biogeochemistry and paleoclimate communities will be critical in defining the most important external controls on the WAP marine environment, the key fluxes into and out of the system, and the longer-term context of the changes underway.

Improvements in data accessibility across disciplines and national programs is also called for, following the examples of the Palmer LTER project (http://pal.lternet.edu/data), the KRILLBASE database for zooplankton survey data (Atkinson et al. 2017) and the Surface Ocean CO_2 Atlas (Bakker et al. 2016). Widespread adoption of similar data policies and practices across the international community, and efficient linking of existing publicly available databases, for example using the SOOSmap online data portal (http://www.soos.aq/data/soosmap), would be of significant benefit. Co-ordinating and opening up all data sources is recommended as a significant scientific opportunity for the international community working across multiple disciplines in the WAP region and beyond.

Acknowledgements

This manuscript has emerged from a sequence of international meetings supported by the Southern Ocean Observing System (SOOS), the Scientific Committees for Antarctic and Oceanic Research (SCAR and SCOR), the British Antarctic Survey and the Royal Society (International Scientific Seminar grant IS160003). This work was supported by the UK Natural Environment Research Council (NERC) through an Independent Research Fellowship to SFH (NE/K010034/1), the British Antarctic Survey's Polar Oceans and Biodiversity, Evolution and Adaptation programs, and diverse other awards. This work was also supported by U.S. National Science Foundation grant PLR-1440435 to HWD, OMS, DKS and ASF. CM was funded by NSF-OPP Grant #1543193. We gratefully acknowledge AWI's persistent support of Dallmann research work at Carlini station and funding of the EU research network IMCONet (FP7 IRSES, Action No. 318718) with Argentina. We thank the Dutch Science Foundation for supporting polar sciences. This is contribution number xxxx from the Palmer LTER project and xxxx from the Virginia Institute of Marine Science.

Author contributions: SFH coordinated the project and led the writing of the manuscript. KRH, OMS and MPM instigated and oversaw the project, and contributed substantially to the writing of the manuscript. IRS, DKS, CM, LSP, DPC, DEB, CH, PDR, HWD, DA, JS, MAvL, CPDB, AGJB, JK, RS, ASF, SES and HJV contributed significantly to the writing of the manuscript and the production of figures. All authors have approved the version for submission.

Competing interests: There are no competing interests associated with this work.

Declaration of interests: none

Figures

Note: Figures 2-11 and 13-16 should be published in colour; Figures 1 and 12 should be black and white.

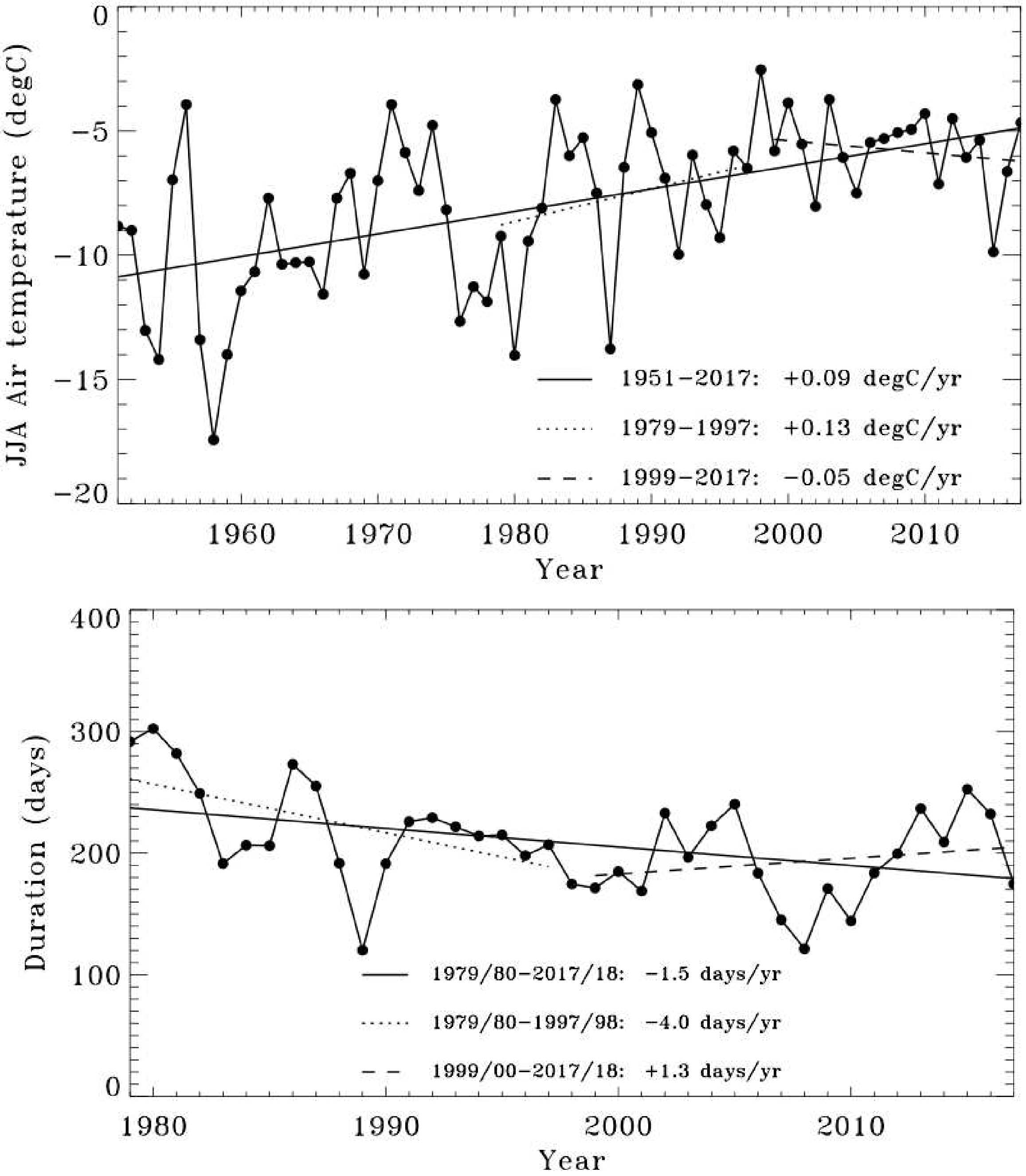

Figure 1. (a) Trend in winter air temperature (June, July, August; JJA) as recorded at Faraday/ Vernadsky Station (65.4 °S, 64.4 °W) from 1951 to 2017. The long-term linear trend (solid line: 1951-2017) is significant at the p <0.001 level, while the shorter-term trends (dotted: 1979-1997; dashed: 1999-2017) are not significant at the p <0.1 level. (b) Trend in the annual ice season duration determined using the GSFC Bootstrap version 2 sea ice concentration time series from Nimbus-7 SMMR and DMSP SSM/I-SSMIS and methods described in Stammerjohn and Maksym (2017). The trend was determined for the WAP continental shelf, extending from Anvers Island to Charcot Island. The long-term trend (solid line: 1979-2017) is significant at the p <0.05 level, while the shorter-term trends (dotted: 1979-1997; dashed: 1999-2017) are not significant at the p <0.1 level.

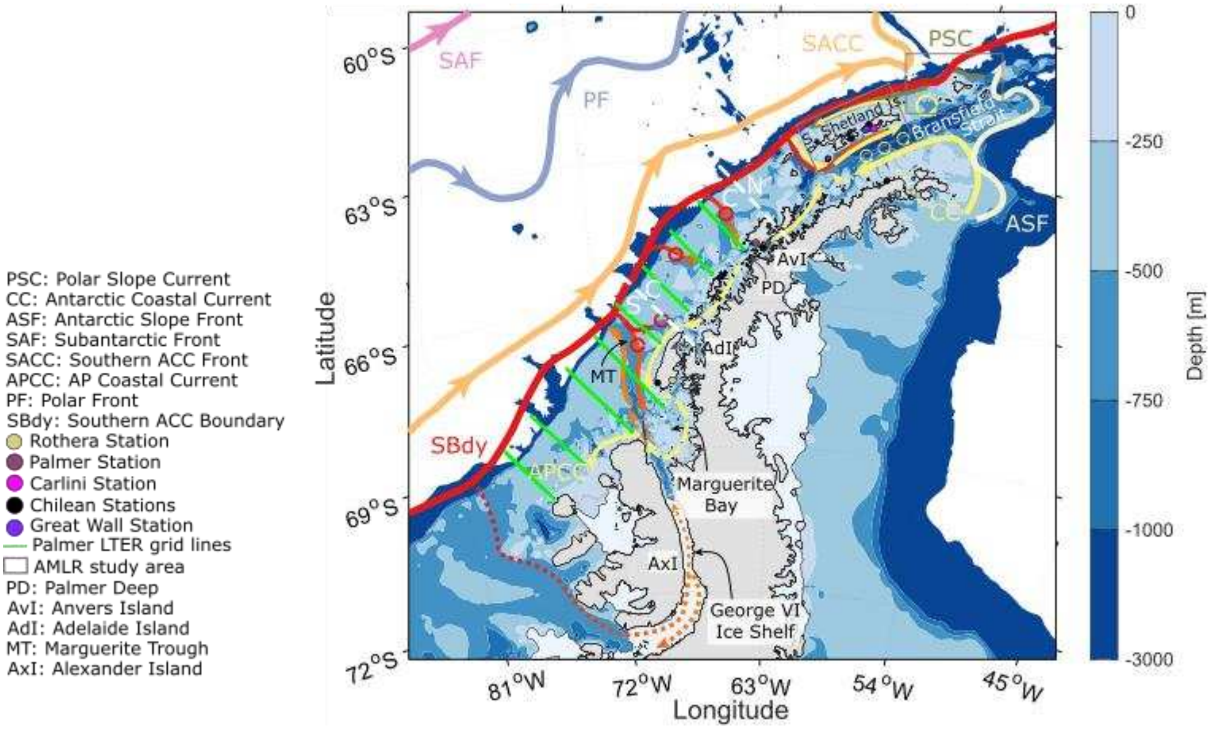

Figure 2. Map of the WAP showing the major sustained research efforts represented, delineation of the northern, central and southern sub-regions referred to in the text (white dashed lines; N = northern sub-region, C = central sub-region, S = southern sub-region), and the major circulation and bathymetric features of the shelf system. Modified from Moffat and Meredith (2018).

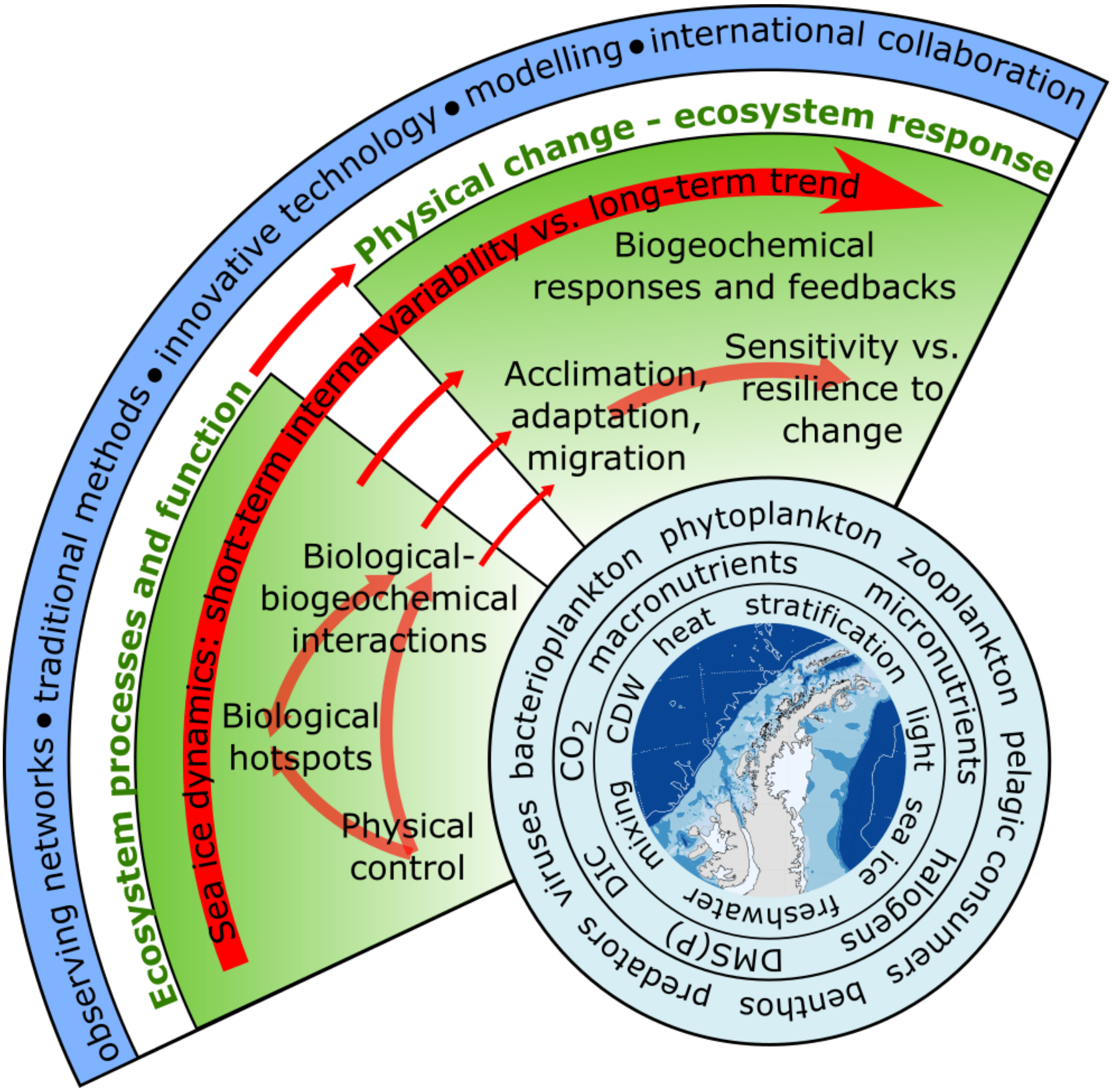

Figure 3: Infographic summarising the key components of the WAP marine system, the most important mechanisms and interactions in the context of the two overarching questions addressed in this paper, and the major priorities and approaches for future marine research at the WAP.

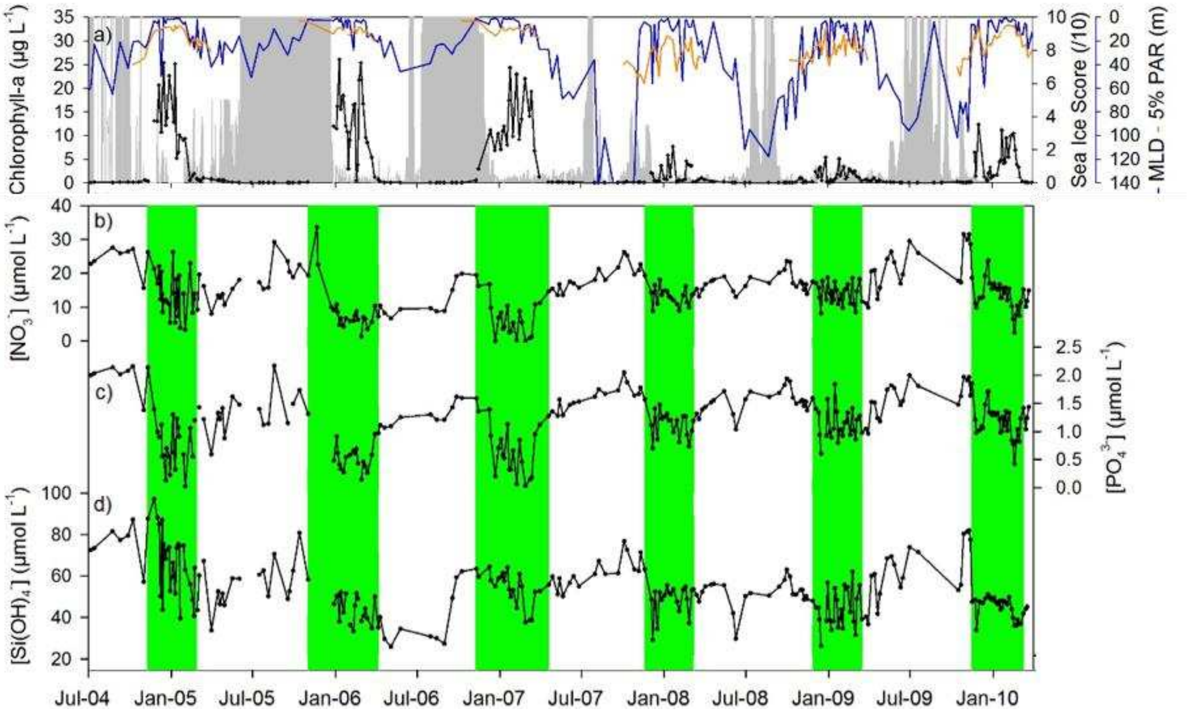

Figure 4. Time-series data from RaTS, July 2004 to April 2010, showing that high sea ice winters lead to shallow mixed layers, high chlorophyll and strong nutrient drawdown, whilst low sea ice years lead to deeper mixing, lower chlorophyll and less nutrient drawdown. (a) sea ice score (grey shading; coverage normalised to ice type, out of ten where ten is full fast-ice cover), mixed layer depth (MLD; blue line; depth where $\sigma = \sigma_{surface} + 0.05$ kg m^{-3}), 5 % PAR depth (orange line; depth where photosynthetically active radiation is 5 % of its surface value), chlorophyll *a* concentration at 15 m (black line). Nutrient concentrations (b) nitrate, (c) phosphate, (d) silicic acid. Green shading depicts the period when chlorophyll *a* >1 ug L^{-1}. Modified from Henley et al. (2017); sea ice, MLD, PAR and chlorophyll data from Venables et al. (2013).

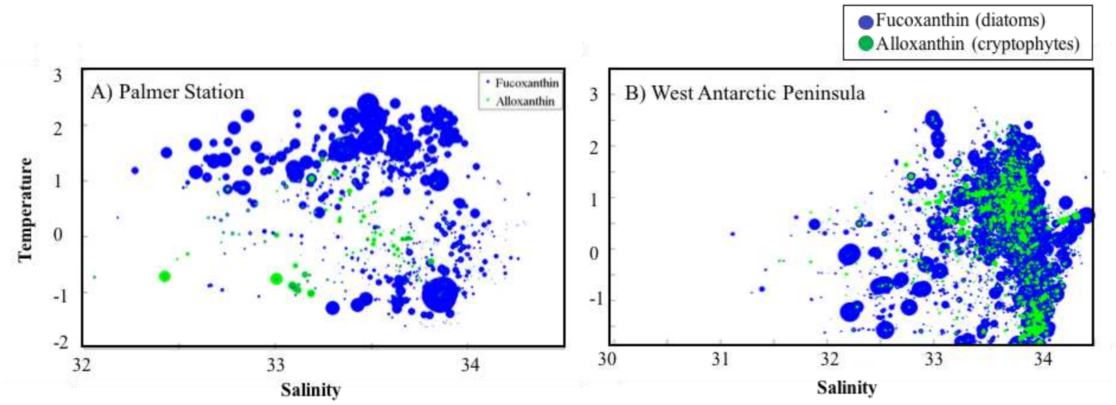

Figure 5. The relative presence of diatoms (from fucoxanthin, blue) and cryptophytes (from alloxanthin, green) plotted in temperature-salinity phase space for (a) Palmer stations B and E, and (b) the Palmer LTER grid. The size of the circles indicates the relative concentration of chlorophyll *a* for discrete samples. Modified from Schofield et al. (2017).

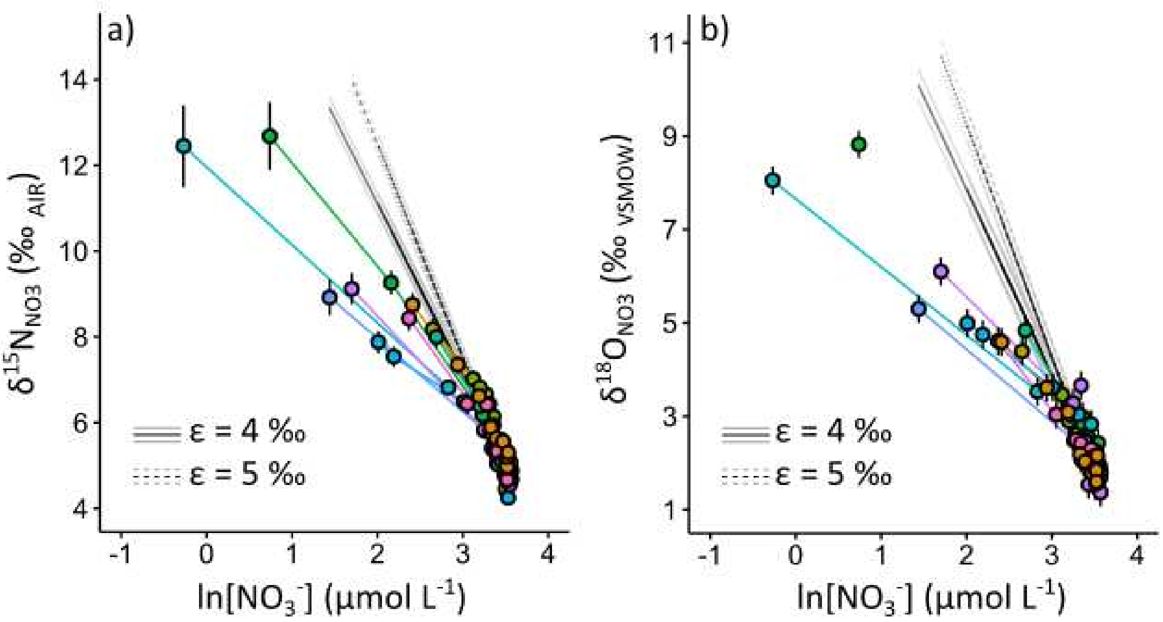

Figure 6. Relationships between nitrate concentration and its (a) nitrogen and (b) oxygen isotope composition, compared to modelled relationships based on nitrate uptake alone with fractionation factors (ε) of 4 and 5 ‰ (solid and dashed black lines, respectively). Both δ^{15}N and δ^{18}O plotting below the modelled lines indicates remineralisation of organic nitrogen where nitrate uptake is high, and subsequent nitrification in the subsurface water column. Data point colours represent different stations. Modified from Henley et al. (2018).

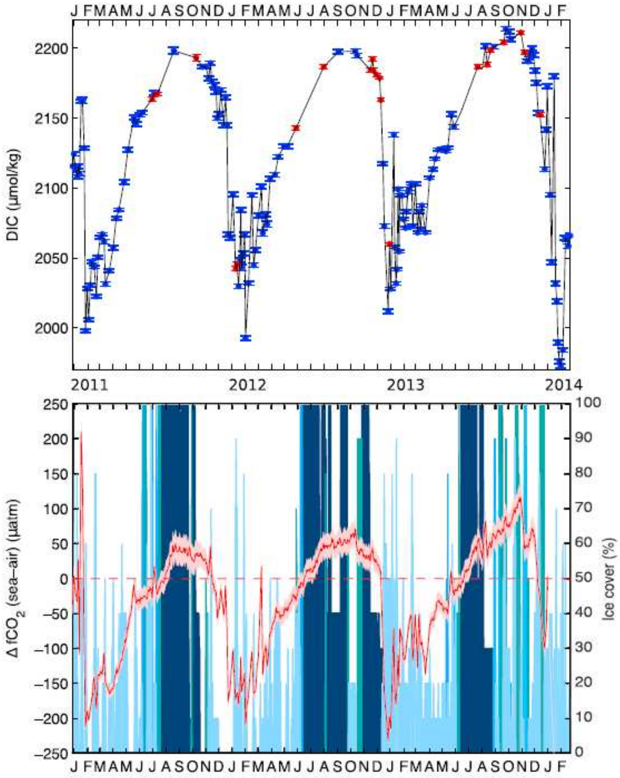

Figure 7. (a) Seasonal cycle of DIC from December 2010 to February 2014 at 15 m depth at RaTS sites 1 (blue) and 2 (red), both in Ryder Bay. Error bars are uncertainty (2SD) based on measurement precision. (b) Red solid line shows the seasonal cycle of the difference in $f\mathrm{CO}_2$ between the sea and air ($\Delta f\mathrm{CO}_2$), with the pink shaded region representing approximate 95 % confidence from uncertainty analysis. Red dashed line shows $\Delta f\mathrm{CO}_2 = 0$, where ocean CO_2 concentration is in equilibrium with the atmosphere. $\Delta f\mathrm{CO}_2 > 0$ during winter indicates supersaturated conditions and an efflux of CO_2 to the atmosphere; $\Delta f\mathrm{CO}_2 < 0$ during summer indicates undersaturated conditions and oceanic uptake of atmospheric CO_2. Blue bars show percentage ice cover, with dark blue representing fast ice, turquoise representing pack ice and light blue representing brash ice. Reproduced with permission from Legge et al. (2015).

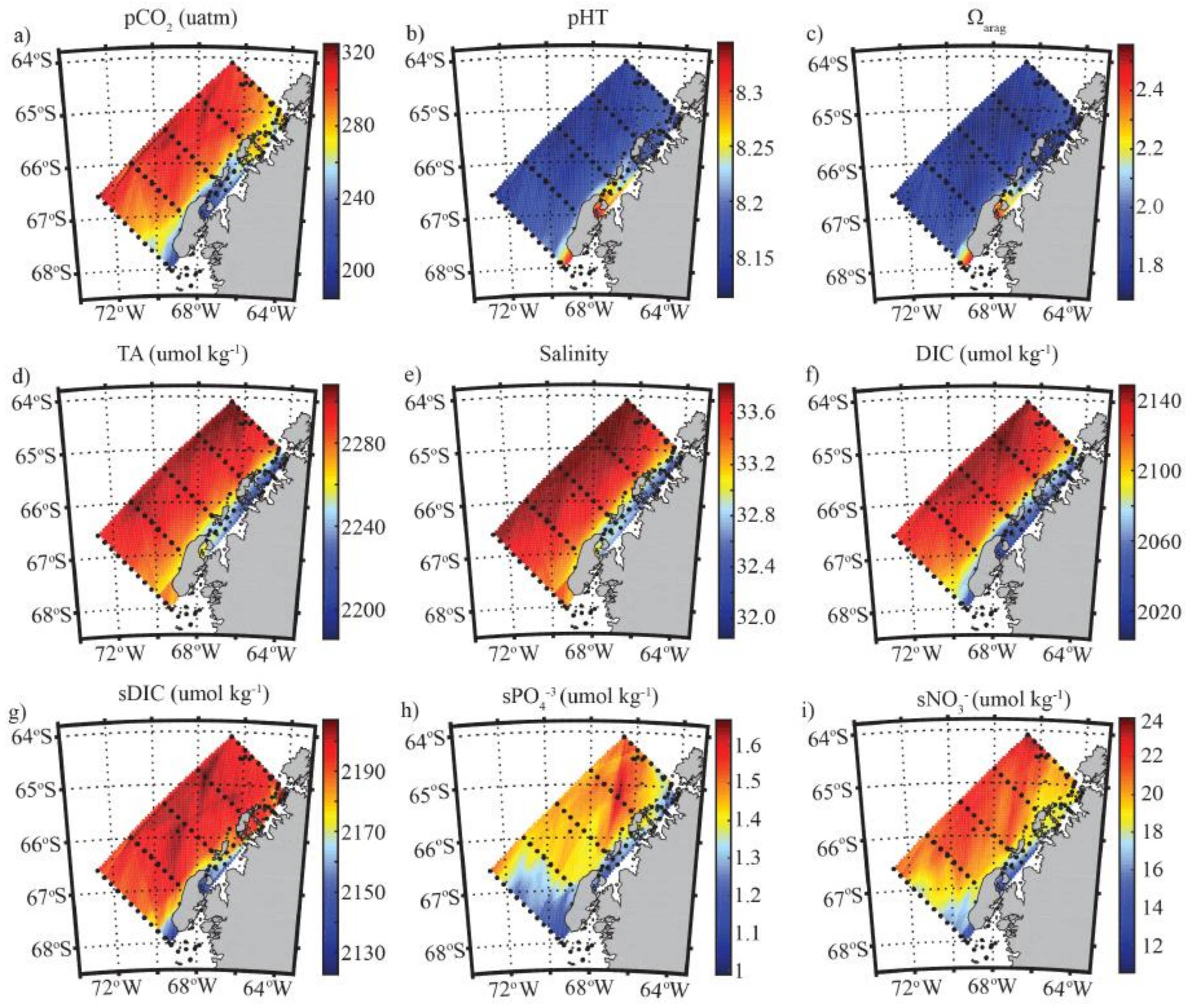

Figure 8. Summertime distribution of inorganic carbon system and other biogeochemical parameters in surface water for the Palmer LTER grid for the period 1993 to 2012, showing onshore-offshore and north-south gradients in carbonate chemistry, salinity and inorganic nutrients. Reproduced with permission from Hauri et al. (2015).

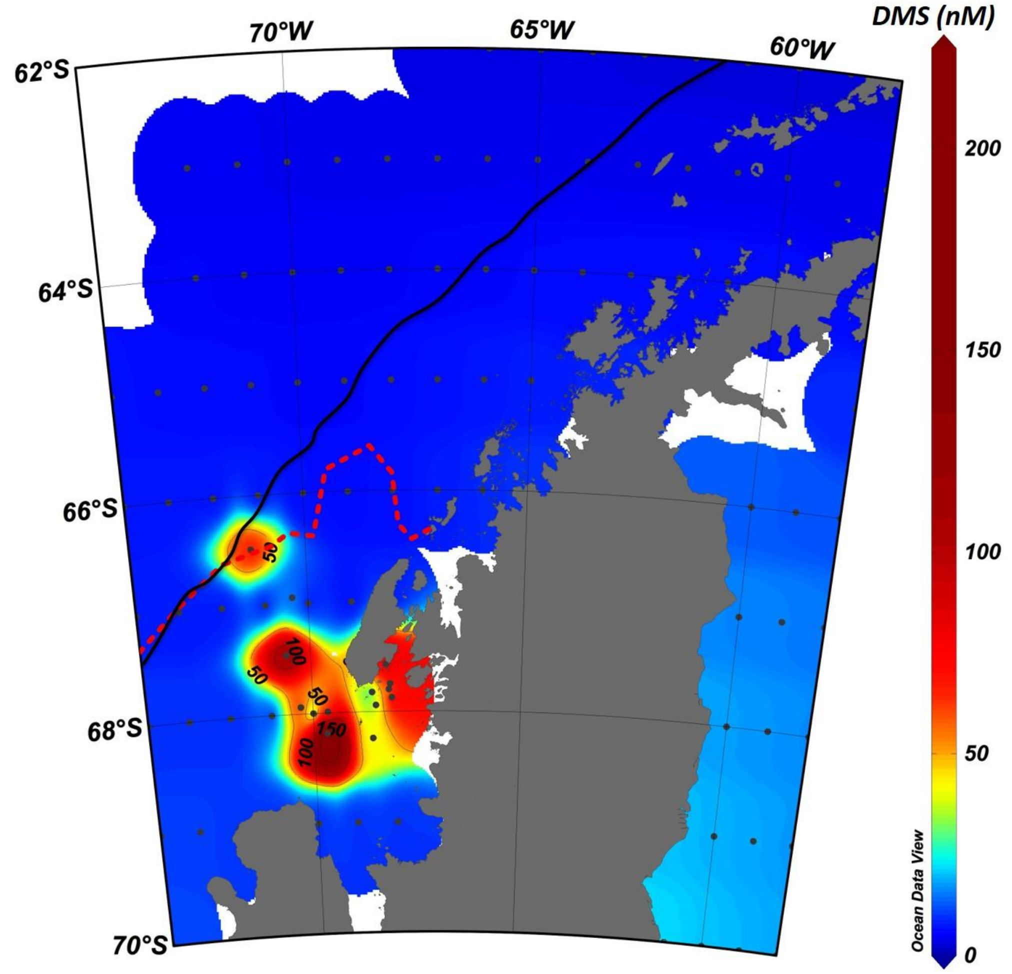

Figure 9. Surface DMS concentrations during cruise JR307 in January 2015 plotted on top of the 1x1 gridded January DMS climatology (Lana et al. 2011). JR307 data were calculated from filtered DMS(P) values (Stefels et al. 2018). The black line depicts the shelf edge; the red dotted line indicates the approximate position of the northern edge of the marginal ice zone during the second half of December 2014, immediately preceding the cruise.

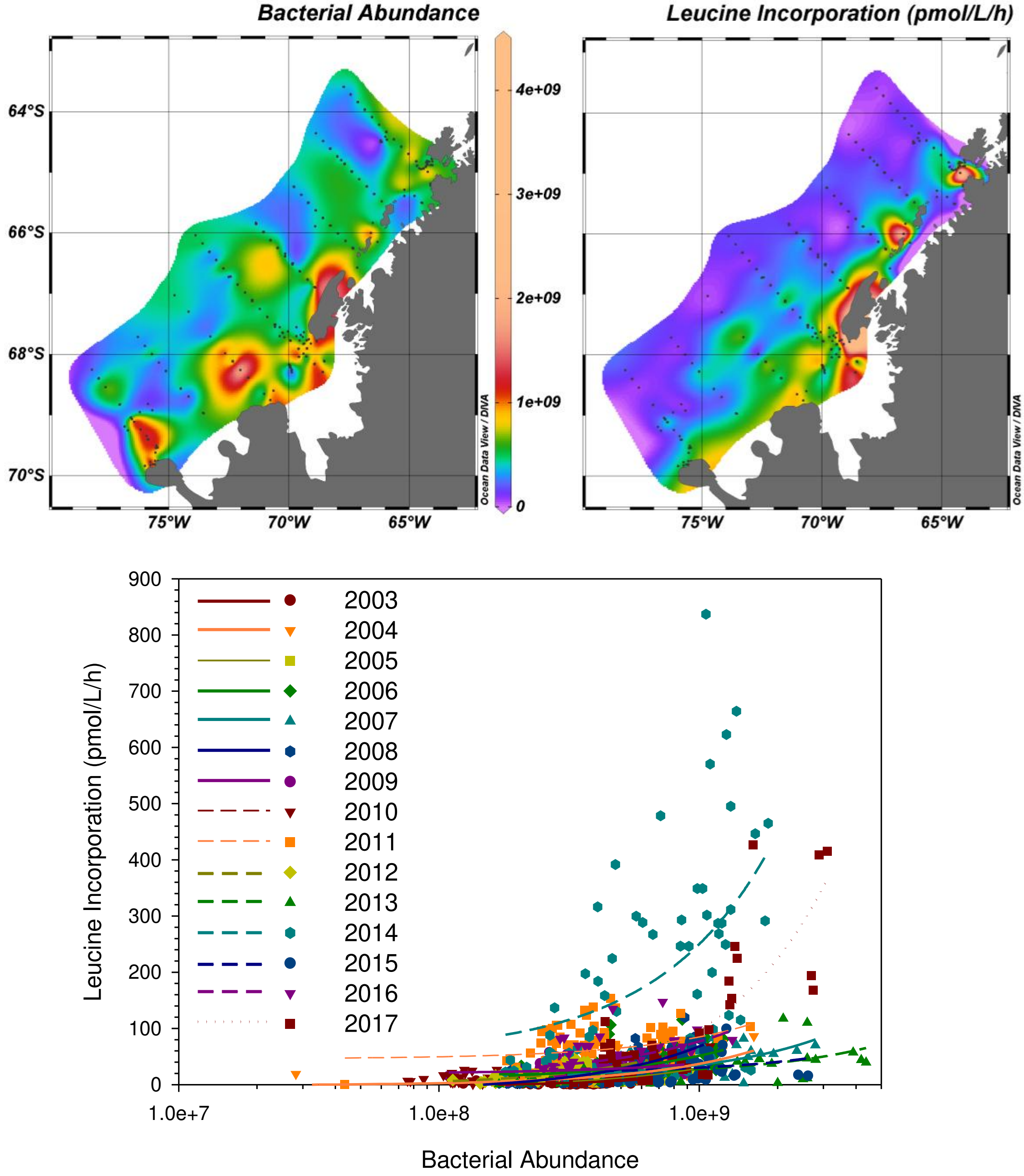

Figure 10. Long-term averages (2003-2017) for January of both bacterial abundance (top left) and production (top right) in the surface ocean (maximum depth 10 m), showing intense spatial heterogeneity with higher abundance and production in inshore regions, and higher abundance further south. Lower panel shows strong variability in bacterial production with abundance for individual January cruises, as per legend. All linear regressions are statistically significant (p <0.05), except for 2012. These data were collected as part of the Palmer LTER project and are updated from Ducklow et al. (2012a).

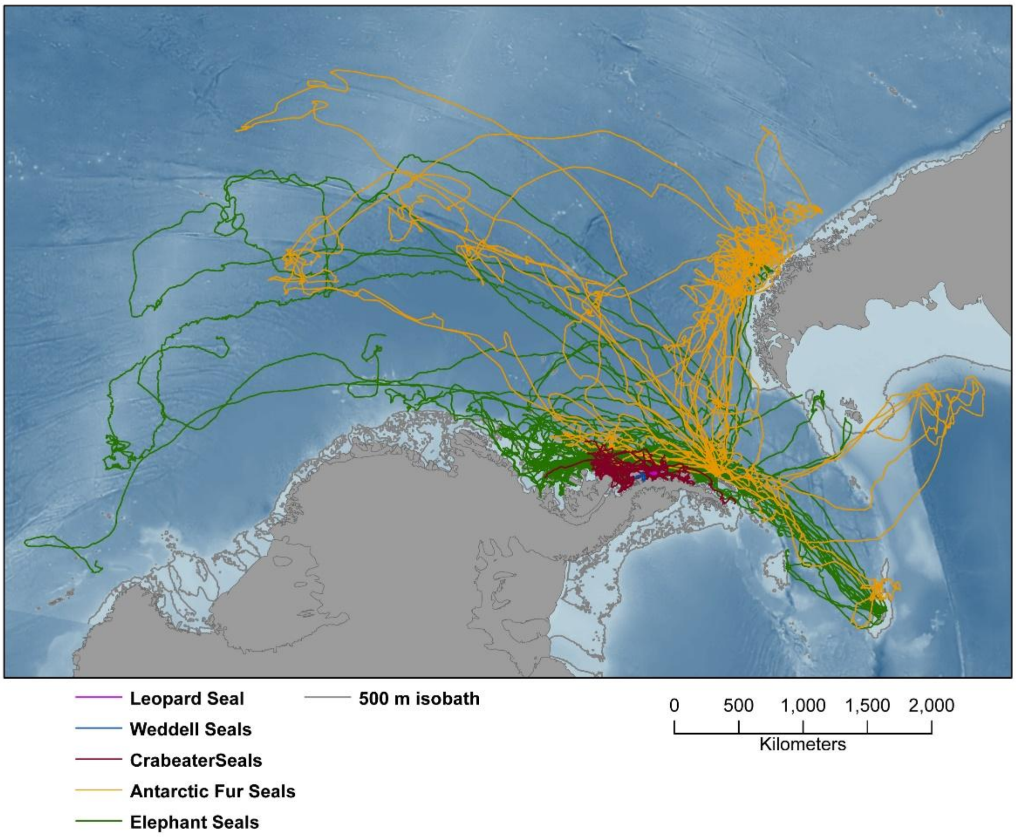

Figure 11. Comparison of the tracks of crabeater seals (dark red) (Burns et al. 2004), elephant seals (green) (Huckstadt et al. 2012b), Weddell seals (blue), leopard seals (purple) (Costa et al. 2010), and fur seals (yellow) (Arthur et al. 2017) over an annual cycle.

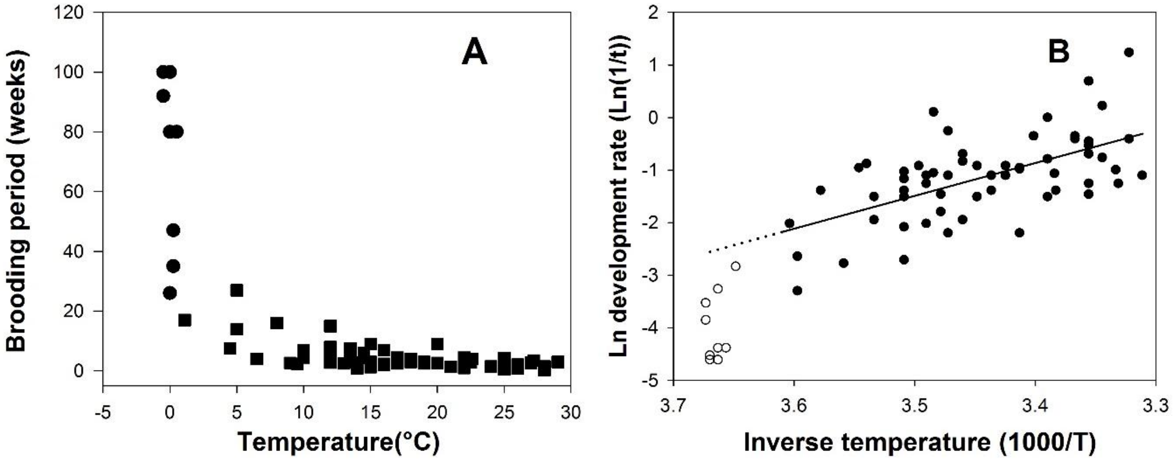

Figure 12. Brooding period and development rates of brooding marine gastropod snails at ambient temperatures for tropical to polar species. (a) Time from brood initiation to release (1/development rate) versus ambient temperature. In most cases release is of crawling juveniles, but for two Antarctic species, release is of veliger larvae and development time to juvenile is approximately double that of brooding per se (Peck et al. 2006b). Data shown for 68 gastropod species, nine of which live at temperatures around 0°C, is the full development period to juvenile. (b) Arrhenius plot of Ln developmental rate to juvenile stage for brooding gastropod molluscs. Fitted line is for temperate and tropical species (filled circles; brooding rate (1/weeks) = 20.37 - 6.25 1000/T; $r^2 = 0.36$, F = 32.4, 58 df, $p < 0.001$); Antarctic species fall significantly below. Reproduced from Peck (2018).

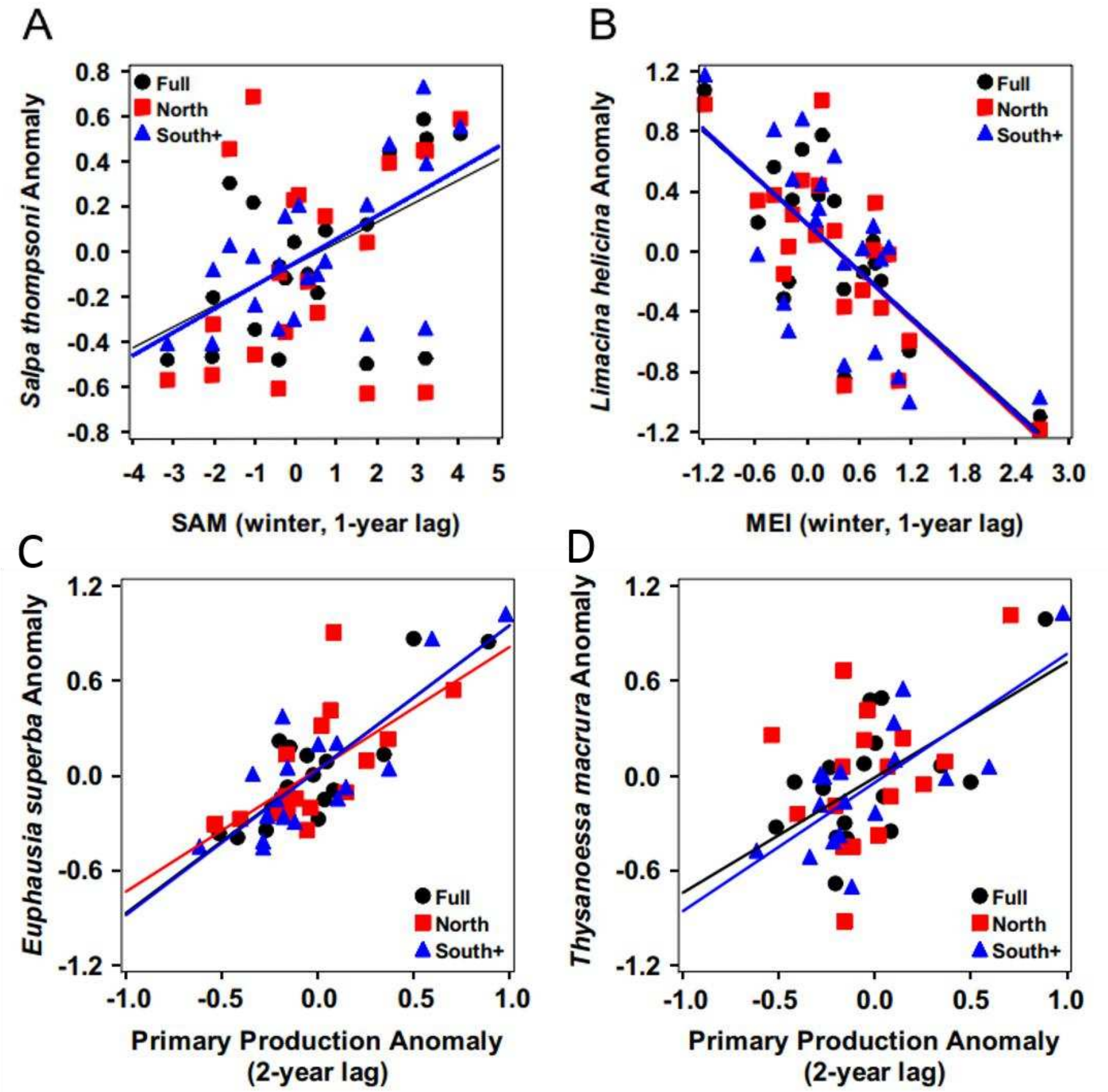

Figure 13. Relationships between annual abundance anomalies of specific zooplankton taxa on the Palmer LTER grid, 1993-2013, and sub-decadal climate oscillations and annual abundance anomalies of primary production. (a) *Salpa thompsonii* and SAM winter index from the year prior, (b) pteropod *Limacina helicina* and multivariate ENSO index (MEI) from winter the year prior, (c) krill *Euphausia superba* and primary production from two years prior, (d) krill *Thysanoessa macrura* and primary production from two years prior. Full refers to the full LTER grid, North refers to the northernmost three sampling lines, which are referred to as the central WAP sub-region in this paper, and South+ refers to the southernmost five sampling lines, referred to as the southern WAP sub-region in this paper (Figure 2). Modified with permission from Steinberg et al. (2015).

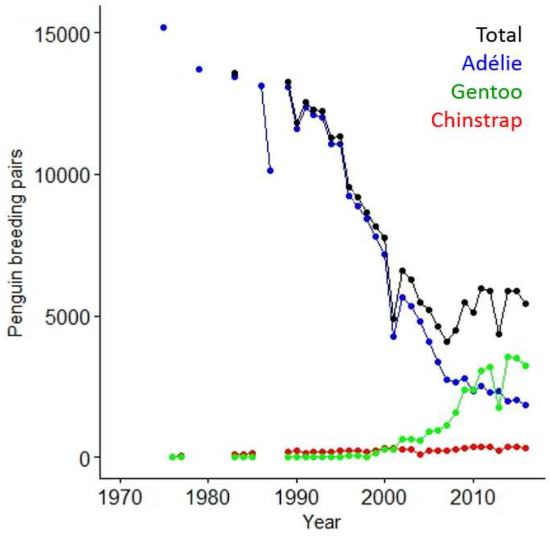

Figure 14. Population census data for Adélie, chinstrap and gentoo penguins in the Palmer Station region, 1975-2016. Updated from Ducklow et al. (2013).

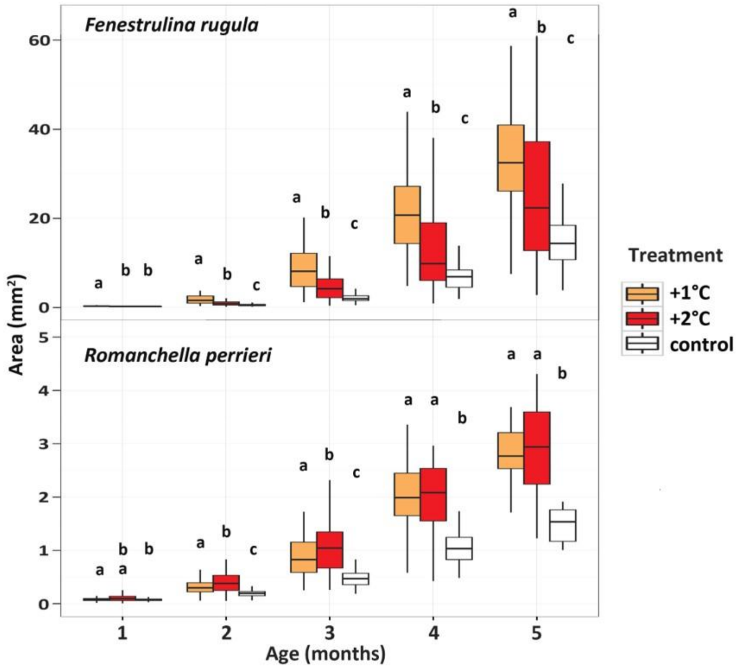

Figure 15. Effects of in situ warming on the growth of common epifaunal marine invertebrates on Rothera Point, Adelaide Island. Panels show area covered by the spatially dominant bryozoan (*Fenestrulina rugula*) and spirorbid (*Romanchella perrieri*) under warming (+1°C and +2°C) and control treatments, showing different growth rate responses between species. Data show the mean and interquartile range of panel surface area covered by a single colony (top) or individual (bottom). Different letters indicate significantly different areas per age ($F_{(1,9)}$ with p <0.01). Modified from Ashton et al. (2017).

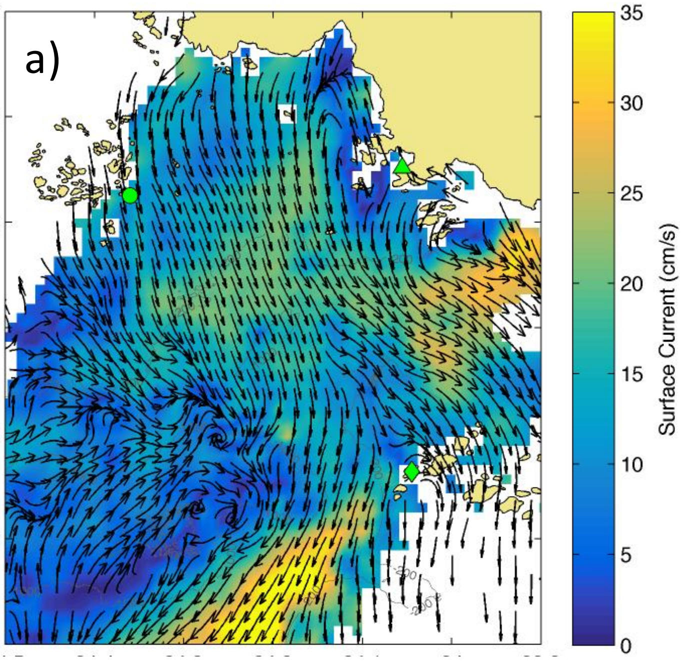

Figure 16. Hourly surface current map for the Palmer Station region for January 27, 08:00 GMT, 2015. The HF radar sites located at Palmer Station (green triangle) and the Wauwermans (green diamond) and Joubin (green circle) island groups are also shown.

References

Abele, D., Vazquez, S., Buma, A.G.J., Hernandez, E., Quiroga, C., Held, C., Frickenhaus, S., Harms, L., Lopez, J.L., Helmke, E., Mac Cormack, W.P., 2017. Pelagic and benthic communities of the Antarctic ecosystem of Potter Cove: Genomics and ecological implications. *Marine Genomics*, 33, 1-11.

Abell, G.C.J., Bowman, J.P., 2005. Ecological and biogeographic relationships of class Flavobacteria in the Southern Ocean. *Fems Microbiology Ecology*, 51, 265-277.

Alder, V.A., Boltovskov, D., 1991. Microplanktonic Distributional Patterns West of the Antarctic Peninsula, with Special Emphasis on the Tintinnids. *Polar Biology*, 11, 103-112.

Annett, A.L., Fitzsimmons, J.N., Séguret, M.J.M., Lagerström, M., Meredith, M.P., Schofield, O., Sherrell, R.M., 2017. Controls on dissolved and particulate iron distributions in surface waters of the Western Antarctic Peninsula shelf. *Marine Chemistry*, 196, 81-97.

Annett, A.L., Skiba, M., Henley, S.F., Venables, H.J., Meredith, M.P., Statham, P.J., Ganeshram, R.S., 2015. Comparative roles of upwelling and glacial iron sources in Ryder Bay, coastal western Antarctic Peninsula. *Marine Chemistry*, 176, 21-33.

Arntz, W.E., Brey, T., Gallardo, V.A., 1994. Antarctic Zoobenthos. *Oceanography and Marine Biology, Vol 32*, 32, 241-304.

Arrigo, K.R., 2017. Sea ice as a habitat for primary producers. In D.N. Thomas (Ed.), *Sea ice, 3rd Edition* (pp. 352-369). Oxford, U. K.: Wiley-Blackwell.

Arrigo, K.R., van Dijken, G.L., Alderkamp, A.C., Erickson, Z.K., Lewis, K.M., Lowry, K.E., Joy-Warren, H.L., Middag, R., Nash-Arrigo, J.E., Selz, V., van de Poll, W., 2017. Early Spring Phytoplankton Dynamics in the Western Antarctic Peninsula. *Journal of Geophysical Research-Oceans*, 122, 9350-9369.

Arthur, B., Hindell, M., Bester, M., De Bniyn, P.J.N., Trathan, P., Goebel, M., Lea, M.A., 2017. Winter habitat predictions of a key Southern Ocean predator, the Antarctic fur seal (Arctocephalus gazella). *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 140, 171-181.

Asher, E.C., Dacey, J.W.H., Stukel, M., Long, M.C., Tortell, P.D., 2017. Processes driving seasonal variability in DMS, DMSP, and DMSO concentrations and turnover in coastal Antarctic waters. *Limnology and Oceanography*, 62, 104-124.

Ashton, G.V., Morley, S.A., Barnes, D.K.A., Clark, M.S., Peck, L.S., 2017. Warming by 1 degrees C Drives Species and Assemblage Level Responses in Antarctica's Marine Shallows. *Current Biology*, 27, 2698-+.

Atkinson, A., Hill, S.L., Pakhomov, E.A., Siegel, V., Reiss, C.S., Loeb, V.J., Steinberg, D.K., Schmidt, K., Tarling, G.A., Gerrish, L., Sailley, S.F., 2019. Krill (*Euphausia superba*) distribution contracts southward during rapid regional warming. *Nature Climate Change*, 9, 142-147.

Atkinson, A., Hill, S.L., Pakhomov, E.A., Siegel, V., Anadon, R., Chiba, S., Daly, K.L., Downie, R., Fielding, S., Fretwell, P., Gerrish, L., Hosie, G., Jessopp, M.J., Kawaguchi, S., Krafft, B.A., Loeb, V., Nishikawa, J., Peat, H.J., Reiss, C.S., Ross, R.M., Quetin, L.B., Schmidt, K., Steinberg, D.K., Subramaniam, R.C., Tarling, G.A., Ward, P., 2017. KRILLBASE: a circumpolar database of Antarctic krill and salp numerical densities, 1926-2016. *Earth System Science Data*, 9, 193-210.

Atkinson, A., Nicol, S., Kawaguchi, S., Pakhomov, E., Quetin, L., Ross, R., Hill, S., Reiss, C., Siegel, V., Tarling, G., 2012. Fitting Euphausia Superba into Southern Ocean Food-Web Models: A Review of Data Sources and Their Limitations. *Ccamlr Science*, 19, 219-245.

Atkinson, A., Siegel, V., Pakhomov, E., Rothery, P., 2004. Long-term decline in krill stock and increase in salps within the Southern Ocean. *Nature*, 432, 100-103.

Atkinson, A., Snyder, R., 1997. Krill-copepod interactions at South Georgia, Antarctica, I. Omnivory by Euphausia superba. *Marine Ecology Progress Series*, 160, 63-76.

Bakker, D.C.E., Pfeil, B., Landa, C.S., Metzl, N., O'Brien, K.M., Olsen, A., Smith, K., Cosca, C., Harasawa, S., Jones, S.D., Nakaoka, S., Nojiri, Y., Schuster, U., Steinhoff, T., Sweeney, C., Takahashi, T., Tilbrook, B., Wada, C., Wanninkhof, R., Alin, S.R., Balestrini, C.F., Barbero, L., Bates, N.R., Bianchi, A.A., Bonou, F., Boutin, J., Bozec, Y., Burger, E.F., Cai, W.J., Castle, R.D., Chen, L.Q., Chierici, M., Currie, K., Evans, W., Featherstone, C., Feely, R.A., Fransson, A., Goyet, C., Greenwood, N., Gregor, L., Hankin, S., Hardman-Mountford, N.J., Harlay, J., Hauck, J., Hoppema, M., Humphreys, M.P., Hunt, C., Huss, B., Ibanhez, J.S.P., Johannessen, T., Keeling, R., Kitidis, V., Kortzinger, A., Kozyr, A., Krasakopoulou, E., Kuwata, A., Landschutzer, P., Lauvset, S.K., Lefevre, N., Lo Monaco, C., Manke, A., Mathis, J.T., Merlivat, L., Millero, F.J., Monteiro, P.M.S., Munro, D.R., Murata, A., Newberger, T., Omar, A.M., Ono, T., Paterson, K., Pearce, D., Pierrot, D., Robbins, L.L., Saito, S., Salisbury, J., Schlitzer, R., Schneider, B., Schweitzer, R., Sieger, R., Skjelvan, I., Sullivan, K.F., Sutherland, S.C., Sutton, A.J., Tadokoro, K., Telszewski, M., Tuma, M., van Heuven, S.M.A.C., Vandemark, D., Ward, B., Watson, A.J., Xu, S.Q., 2016. A multi-decade record of high-quality fCO(2) data in version 3 of the Surface Ocean CO2 Atlas (SOCAT). *Earth System Science Data*, 8, 383-413.

Barnes, D.K.A., 2015. Antarctic sea ice losses drive gains in benthic carbon drawdown. *Current Biology*, 25, R789-R790.

Barnes, D.K.A., 2017. Polar zoobenthos blue carbon storage increases with sea ice losses, because across-shelf growth gains from longer algal blooms outweigh ice scour mortality in the shallows. *Global Change Biology*, 23, 5083-5091.

Barnes, D.K.A., Souster, T., 2011. Reduced survival of Antarctic benthos linked to climate-induced iceberg scouring. *Nature Climate Change*, 1, 365-368.

Barnes, D.K.A., Fleming, A., Sands, C.J., Quartino, M.L., Dereqibus, D., 2018. Icebergs, Sea ice, blue carbon and Antarctic climate feedbacks. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*, 376.

Beardsley, R.C., Limeburner, R., Owens, W.B., 2004. Drifter measurements of surface currents near Marguerite Bay on the western Antarctic Peninsula shelf during austral summer and fall, 2001 and 2002. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 51, 1947-1964.

Bednarsek, N., Tarling, G.A., Bakker, D.C.E., Fielding, S., Jones, E.M., Venables, H.J., Ward, P., Kuzirian, A., Leze, B., Feely, R.A., Murphy, E.J., 2012. Extensive dissolution of live pteropods in the Southern Ocean. *Nature Geoscience*, 5, 881-885.

Bernard, K.S., Steinberg, D.K., Schofield, O.M.E., 2012. Summertime grazing impact of the dominant macrozooplankton off the Western Antarctic Peninsula. *Deep-Sea Research Part I-Oceanographic Research Papers*, 62, 111-122.

Bers, A.V., Momo, F., Schloss, I.R., Abele, D., 2013. Analysis of trends and sudden changes in long-term environmental data from King George Island (Antarctica): relationships between global climatic oscillations and local system response. *Climatic Change*, 116, 789-803.

Bertrand, E.M., McCrow, J.P., Moustafa, A., Zheng, H., McQuaid, J.B., Delmont, T.O., Post, A.F., Sipler, R.E., Spackeen, J.L., Xu, K., Bronk, D.A., Hutchins, D.A., Allen, A.E., 2015. Phytoplankton-bacterial interactions mediate micronutrient colimitation at the coastal Antarctic sea ice edge. *Proceedings of the National Academy of Sciences of the United States of America*, 112, 9938-9943.

Bigg, G.R., 2015. *Icebergs: Their Science and Links to Climate Change*. Cambridge, U. K.: Cambridge University Press.

Bik, E.M., Costello, E.K., Switzer, A.D., Callahan, B.J., Holmes, S.P., Wells, R.S., Carlin, K.P., Jensen, E.D., Venn-Watson, S., Relman, D.A., 2016. Marine mammals harbor unique microbiotas shaped by and yet distinct from the sea. *Nature Communications*, 7.

Bilyk, K.T., DeVries, A.L., 2011. Heat tolerance and its plasticity in Antarctic fishes. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 158, 382-390.

Bluhm, B.A., Swadling, K.M., Gradinger, R., 2017. Sea ice as a habitat for macrograzers. In D.N. Thomas (Ed.), *Sea Ice, 3rd Edition* (pp. 394-414). Oxford, U. K.: Wiley-Blackwell.

Bosch, I., Pearse, J.S., 1990. Developmental Types of Shallow-Water Asteroids of Mcmurdo Sound, Antarctica. *Marine Biology*, 104, 41-46.

Bost, C.A., Cotté, C., Bailleul, F., Cherel, Y., Charrassin, J.B., Guinet, C., Ainley, D.G., Weimerskirch, H., 2009. The importance of oceanographic fronts to marine birds and mammals of the southern oceans. *Journal of Marine Systems*, 78, 363-376.

Bowden, D.A., Clarke, A., Peck, L.S., 2009. Seasonal variation in the diversity and abundance of pelagic larvae of Antarctic marine invertebrates. *Marine Biology*, 156, 2033-2047.

Bowman, J.S., Amaral-Zettler, L.A., Rich, J.J., Luria, C.M., Ducklow, H.W., 2017. Bacterial community segmentation facilitates the prediction of ecosystem function along the coast of the western Antarctic Peninsula. *Isme Journal*, 11, 1460-1471.

Bowman, J.S., Deming, J.W., 2017. Wind-driven distribution of bacteria in coastal Antarctica: evidence from the Ross Sea region. *Polar Biology*, 40, 25-35.

Bowman, J.S., Ducklow, H.W., 2015. Microbial Communities Can Be Described by Metabolic Structure: A General Framework and Application to a Seasonally Variable, Depth-Stratified Microbial Community from the Coastal West Antarctic Peninsula. *Plos One*, 10.

Bowman, J.S., Vick-Majors, T.J., Morgan-Kiss, R., Takacs-Vesbach, C., Ducklow, H.W., Priscu, J.C., 2016. Microbial Community Dynamics in Two Polar Extremes: The Lakes of the McMurdo Dry Valleys and the West Antarctic Peninsula Marine Ecosystem. *Bioscience*, 66, 829-847.

Bown, J., Laan, P., Ossebaar, S., Bakker, K., Rozema, P., de Baar, H.J.W., 2017. Bioactive trace metal time series during Austral summer in Ryder Bay, Western Antarctic Peninsula. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 139, 103-119.

Bown, J., van Haren, H., Meredith, M.P., Venables, H.J., Laan, P., Brearley, J.A., de Baar, H.J.W., 2018. Evidences of strong sources of DFe and DMn in Ryder Bay, Western Antarctic Peninsula. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*, 376.

Brearley, J.A., Meredith, M.P., Garabato, A.C.N., Venables, H.J., Inall, M.E., 2017. Controls on turbulent mixing on the West Antarctic Peninsula shelf. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 139, 18-30.

Breider, T.J., Chipperfield, M.P., Mann, G.W., Woodhouse, M.T., Carslaw, K.S., 2015. Suppression of CCN formation by bromine chemistry in the remote marine atmosphere. *Atmospheric Science Letters*, 16, 141-147.

Brierley, A.S., Fernandes, P.G., Brandon, M.A., Armstromg, F., Millard, N.W., McPhail, S.D., Stevenson, P., Pebody, M., Perrett, J., Squires, M., Bone, D.G., Griffiths, G., 2002. Antarctic krill under sea ice: Elevated abundance in a narrow band just south of ice edge. *Science*, 295, 1890-1892.

Brown, K.M., Fraser, K.P., Barnes, D.K., Peck, L.S., 2004. Links between the structure of an Antarctic shallow-water community and ice-scour frequency. *Oecologia*, 141, 121-129.

Brum, J.R., Hurwitz, B.L., Schofield, O., Ducklow, H.W., Sullivan, M.B., 2016. Seasonal time bombs: dominant temperate viruses affect Southern Ocean microbial dynamics. *Isme Journal*, 10, 437-449.

Buma, A.G.J., Debaar, H.J.W., Nolting, R.F., Vanbennekom, A.J., 1991. Metal Enrichment Experiments in the Weddell-Scotia Seas - Effects of Iron and Manganese on Various Plankton Communities. *Limnology and Oceanography*, 36, 1865-1878.

Burns, J.M., Costa, D.P., Fedak, M.A., Hindell, M.A., Bradshaw, C.J.A., Gales, N.J., McDonald, B., Trumble, S.J., Crocker, D.E., 2004. Winter habitat use and foraging behavior of crabeater seals along the Western Antarctic Peninsula. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 51, 2279-2303.

Byrne, M., Ho, M.A., Koleits, L., Price, C., King, C.K., Virtue, P., Tilbrook, B., Lamarek, M., 2013. Vulnerability of the calcifying larval stage of the Antarctic sea urchin Sterechinus neumayeri to near-future ocean acidification and warming. *Global Change Biology*, 19, 2264-2275.

Calbet, A., Alcaraz, M., Atienza, D., Broglio, E., Vaque, D., 2005. Zooplankton biomass distribution patterns along the western Antarctic Peninsula (December 2002). *Journal of Plankton Research*, 27, 1195-1203.

Calbet, A., Atienza, D., Broglio, E., Alcaraz, M., Vaque, D., 2006. Trophic ecology of Calanoides acatus in Gerlache Strait and Bellingshausen Sea waters (Antarctica, December 2002). *Polar Biology*, 29, 510-518.

Campana, G.L., Zacher, K., Deregibus, D., Momo, F.R., Wiencke, C., Quartino, M.L., 2018. Succession of Antarctic benthic algae (Potter Cove, South Shetland Islands): structural patterns and glacial impact over a four-year period. *Polar Biology*, 41, 377-396.

Carlini, A.R., Coria, N.R., Santos, M.M., Negrete, J., Juares, M.A., Daneri, G.A., 2009. Responses of Pygoscelis adeliae and P. papua populations to environmental changes at Isla 25 de Mayo (King George Island). *Polar Biology*, 32, 1427-1433.

Carrillo, C.J., Smith, R.C., Karl, D.M., 2004. Processes regulating oxygen and carbon dioxide in surface waters west of the Antarctic Peninsula. *Marine Chemistry*, 84, 161-179.

Carvalho, F., Kohut, J., Oliver, M.J., Schofield, O., 2017. Defining the ecologically relevant mixed-layer depth for Antarctica's coastal seas. *Geophysical Research Letters*, 44, 338-345.

Carvalho, F., Kohut, J., Oliver, M.J., Sherrell, R.M., Schofield, O., 2016. Mixing and phytoplankton dynamics in a submarine canyon in the West Antarctic Peninsula. *Journal of Geophysical Research-Oceans*, 121, 5069-5083.

Cassarino, L., Hendry, K.R., Meredith, M.P., Venables, H.J., De La Rocha, C.L., 2017. Silicon isotope and silicic acid uptake in surface waters of Marguerite Bay, West Antarctic Peninsula. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 139, 143-150.

Catarino, A.I., De Ridder, C., Gonzalez, M., Gallardo, P., Dubois, P., 2012. Sea urchin Arbacia dufresnei (Blainville 1825) larvae response to ocean acidification. *Polar Biology*, 35, 455-461.

Cavicchioli, R., 2015. Microbial ecology of Antarctic aquatic systems. *Nature Reviews Microbiology*, 13, 691-706.

Chance, R., Weston, K., Baker, A.R., Hughes, C., Malin, G., Carpenter, L., Meredith, M.P., Clarke, A., Jickells, T.D., Mann, P., Rossetti, H., 2010. Seasonal and interannual variation of dissolved iodine speciation at a coastal Antarctic site. *Marine Chemistry*, 118, 171-181.

Chapman, E.W., Hofmann, E.E., Patterson, D.L., Ribic, C.A., Fraser, W.R., 2011. Marine and terrestrial factors affecting Adelie penguin Pygoscelis adeliae chick growth and recruitment off the western Antarctic Peninsula. *Marine Ecology Progress Series*, 436, 273-289.

Chapman, E.W., Ribic, C.A., Fraser, W.R., 2004. The distribution of seabirds and pinnipeds in Marguerite Bay and their relationship to physical features during austral winter 2001. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 51, 2261-2278.

Chen, X.W., Gao, K.S., 2004. Characterization of diurnal photosynthetic rhythms in the marine diatom Skeletonema costatum grown in synchronous culture under ambient and elevated CO2. *Functional Plant Biology*, 31, 399-404.

Church, M.J., DeLong, E.F., Ducklow, H.W., Karner, M.B., Preston, C.M., Karl, D.M., 2003. Abundance and distribution of planktonic Archaea and Bacteria in the waters west of the Antarctic Peninsula. *Limnology and Oceanography*, 48, 1893-1902.

Cimino, M.A., Moline, M.A., Fraser, W.R., Patterson-Fraser, D.L., Oliver, M.J., 2016. Climate-driven sympatry may not lead to foraging competition between congeneric top-predators. *Scientific Reports*, 6.

Clark, M.S., Fraser, K.P., Peck, L.S., 2008. Antarctic marine molluscs do have an HSP70 heat shock response. *Cell Stress Chaperones*, 13, 39-49.

Clark, M.S., Peck, L.S., 2009. HSP70 heat shock proteins and environmental stress in Antarctic marine organisms: A mini-review. *Mar Genomics*, 2, 11-18.

Clark, M.S., Sommer, U., Sihra, J.K., Thorne, M.A., Morley, S.A., King, M., Viant, M.R., Peck, L.S., 2017. Biodiversity in marine invertebrate responses to acute warming revealed by a comparative multi-omics approach. *Glob Chang Biol*, 23, 318-330.

Clark, M.S., Thorne, M.A., Burns, G., Peck, L.S., 2016. Age-related thermal response: the cellular resilience of juveniles. *Cell Stress Chaperones*, 21, 75-85.

Clarke, A., 1985. The reproductive biology of the polar hippolytid shrimp Chorismus antarcticus at South Georgia. In J.S. Gray, M.E. Christiansen (Eds.), *Marine Biology of Polar regions and Effects of Stress on Marine Organisms* (pp. 237-246). New York: John Wiley and Sons.

Clarke, A., Johnston, N.M., 2003. Antarctic marine benthic diversity. *Oceanography and Marine Biology, Vol 41*, 41, 47-114.

Clarke, A., Meredith, M.P., Wallace, M.I., Brandon, M.A., Thomas, D.N., 2008. Seasonal and interannual variability in temperature, chlorophyll and macronutrients in northern Marguerite Bay, Antarctica. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 55, 1988-2006.

Clarke, A., Murphy, E.J., Meredith, M.P., King, J.C., Peck, L.S., Barnes, D.K.A., Smith, R.C., 2007. Climate change and the marine ecosystem of the western Antarctic Peninsula. *Philosophical Transactions of the Royal Society B-Biological Sciences*, 362, 149-166.

Clayton, M.N., Wiencke, C., Kloser, H., 1997. New records of temperate and sub Antarctic marine benthic macroalgae from Antarctica. *Polar Biology*, 17, 141-149.

Constable, A.J., Melbourne-Thomas, J., Corney, S.P., Arrigo, K.R., Barbraud, C., Barnes, D.K.A., Bindoff, N.L., Boyd, P.W., Brandt, A., Costa, D.P., Davidson, A.T., Ducklow, H.W., Emmerson, L., Fukuchi, M., Gutt, J., Hindell, M.A., Hofmann, E.E., Hosie, G.W., Iida, T., Jacob, S., Johnston, N.M., Kawaguchi, S., Kokubun, N., Koubbi, P., Lea, M.A., Makhado, A., Massom, R.A., Meiners, K., Meredith, M.P., Murphy, E.J., Nicol, S., Reid, K., Richerson, K., Riddle, M.J., Rintoul, S.R., Smith, W.O., Southwell, C., Stark, J.S., Sumner, M., Swadling, K.M., Takahashi, K.T., Trathan, P.N., Welsford, D.C., Weimerskirch, H., Westwood, K.J., Wienecke, B.C., Wolf-Gladrow, D., Wright, S.W., Xavier, J.C., Ziegler, P., 2014a. Climate change and Southern Ocean ecosystems I: how changes in physical habitats directly affect marine biota. *Global Change Biology*, 20, 3004-3025.

Constable, A.J., Costa, D.P., Murphy, E., Hofmann, E., Schofield, O., Press, A., Johnson, N.M., Newman, L., 2014b. Assessing status and change in Southern Ocean ecosystems. In C. De Broyer, P. Koubbi, H.J. Griffiths, B. Raymond, C. Udekem d'Acoz, A.P. Van de Putte, B. Danis, B. David, S. Grant, J. Gutt, C. Held, G. Hosie, F. Huettmann, A. Post, Y. Ropert-Coudert (Eds.), *Biogeographic Atlas of the Southern Ocean. Scientific Committee on Antarctic Research* (pp. 404-407). Cambridge, England: Scientific Committee on Antarctic Research.

Constable, A.J., Costa, D.P., Schofield, O., Newman, L., Urban, E.R., Fulton, E.A., Melbourne-Thomas, J., Ballerini, T., Boyd, P.W., Brandt, A., de la Mare, W.K., Edwards, M., Eleaume, M., Emmerson, L., Fennel, K., Fielding, S., Griffiths, H., Gutt, J., Hindell, M.A., Hofmann, E.E., Jennings, S., La, H.S., McCurdy, A., Mitchell, B.G., Moltmann, T., Muelbert, M., Murphy, E., Press, A.J., Raymond, B., Reid, K., Reiss, C., Rice, J., Salter, I., Smith, D.C., Song, S., Southwell, C., Swadling, K.M., Van de Putte, A.V., Zdenka, W., 2016. Developing priority variables ("ecosystem Essential Ocean Variables" - eEOVs) for observing dynamics and change in Southern Ocean ecosystems. *Journal of Marine Systems*, 161, 26-41.

Cook, A.J., Holland, P.R., Meredith, M.P., Murray, T., Luckman, A., Vaughan, D.G., 2016. Ocean forcing of glacier retreat in the western Antarctic Peninsula. *Science*, 353, 283-286.

Costa, D.P., Crocker, D.E., 1996. Marine mammals of the Southern Ocean. *Antarctic Research Series*, 70, 287-301.

Costa, D.P., Huckstadt, L.A., Crocker, D.E., McDonald, B.I., Goebel, M.E., Fedak, M.A., 2010. Approaches to Studying Climatic Change and its Role on the Habitat Selection of Antarctic Pinnipeds. *Integrative and Comparative Biology*, 50, 1018-1030.

Cotté, C., d'Ovidio, F., Dragon, A.-C., Guinet, C., Lévy, M., 2015. Flexible preference of southern elephant seals for distinct mesoscale features within the Antarctic Circumpolar Current. *Progress in Oceanography*, 131, 46-58.

Couto, N., Martinson, D.G., Kohut, J., Schofield, O., 2017. Distribution of Upper Circumpolar Deep Water on the warming continental shelf of the West Antarctic Peninsula. *Journal of Geophysical Research-Oceans*, 122, 5306-5315.

Cowie, R.O.M., Maas, E.W., Ryan, K.G., 2011. Archaeal diversity revealed in Antarctic sea ice. *Antarctic Science*, 23, 531-536.

Cross, E.L., Peck, L.S., Harper, E.M., 2015. Ocean acidification does not impact shell growth or repair of the Antarctic brachiopod Liothyrella uva (Broderip, 1833). *Journal of Experimental Marine Biology and Ecology*, 462, 29-35.

Davies, N., Field, D., Amaral-Zettler, L., Clark, M.S., Deck, J., Drummond, A., Faith, D.P., Geller, J., Gilbert, J., Glockner, F.O., Hirsch, P.R., Leong, J.A., Meyer, C., Obst, M., Planes, S., Scholin, C., Vogler, A.P., Gates, R.D., Toonen, R., Berteaux-Lecellier, V., Barbier, M., Barker, K., Bertilsson, S., Bicak, M., Bietz, M.J., Bobe, J., Bodrossy, L., Borja, A., Coddington, J., Fuhrman, J., Gerdts, G., Gillespie, R., Goodwin, K., Hanson, P.C., Hero, J.M., Hoekman, D., Jansson, J., Jeanthon, C., Kao, R., Klindworth, A., Knight, R., Kottmann, R., Koo, M.S., Kotoulas, G., Lowe, A.J., Marteinsson, V.T., Meyer, F., Morrison, N., Myrold, D.D., Pafilis, E., Parker, S., Parnell, J.J., Polymenakou, P.N., Ratnasingham, S., Roderick, G.K., Rodriguez-Ezpeleta, N., Schonrogge, K., Simon, N., Valette-Silver, N.J., Springer, Y.P., Stone, G.N., Stones-Havas, S., Sansone, S.A., Thibault, K.M., Wecker, P., Wichels, A., Wooley, J.C., Yahara, T., Zingone, A., GOs-COS, 2014. The founding charter of the Genomic Observatories Network. *Gigascience*, 3.

Delmont, T.O., Hammar, K.M., Ducklow, H.W., Yager, P.L., Post, A.F., 2014. Phaeocystis antarctica blooms strongly influence bacterial community structures in the Amundsen Sea polynya. *Frontiers in Microbiology*, 5.

Deregibus, D., Quartino, M.L., Campana, G.L., Momo, F.R., Wiencke, C., Zacher, K., 2016. Photosynthetic light requirements and vertical distribution of macroalgae in newly ice-free areas in Potter Cove, South Shetland Islands, Antarctica. *Polar Biology*, 39, 153-166.

Devor, D.P., Kuhn, D.E., O'Brien, K.M., Crockett, E.L., 2016. Hyperoxia Does Not Extend Critical Thermal Maxima (CTmax) in White- or Red-Blooded Antarctic Notothenioid Fishes. *Physiol Biochem Zool*, 89, 1-9.

Dinniman, M.S., Klinck, J.M., Smith, W.O., 2011. A model study of Circumpolar Deep Water on the West Antarctic Peninsula and Ross Sea continental shelves. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 58, 1508-1523.

Doughty, C.E., Roman, J., Faurby, S., Wolf, A., Haque, A., Bakker, E.S., Malhi, Y., Dunning, J.B., Svenning, J.C., 2016. Global nutrient transport in a world of giants. *Proceedings of the National Academy of Sciences of the United States of America*, 113, 868-873.

Dragon, A.C., Monestiez, P., Bar-Hen, A., Guinet, C., 2010. Linking foraging behaviour to physical oceanographic structures: Southern elephant seals and mesoscale eddies east of Kerguelen Islands. *Progress in Oceanography*, 87, 61-71.

Ducklow, H.W., Schofield, O., Vernet, M., Stammerjohn, S., Erickson, M., 2012a. Multiscale control of bacterial production by phytoplankton dynamics and sea ice along the western Antarctic Peninsula: A regional and decadal investigation. *Journal of Marine Systems*, 98-99, 26-39.

Ducklow, H.W., Clarke, A., Dickhut, R., Doney, S.C., Geisz, H., Huang, K., Martinson, D.G., Meredith, M.P., Moeller, H.V., Montes-Hugo, M., Schofield, O., Stammerjohn, S.E., Steinberg, D., Fraser, W., 2012b. The Marine System of the Western Antarctic Peninsula. In A.D. Rogers, N.M. Johnston, E.J. Murphy, A. Clarke (Eds.), *Antarctic Ecosystems* (pp. 121-159). Chichester, U. K.: John Wiley and Sons, Ltd.

Ducklow, H.W., Baker, K., Martinson, D.G., Quetin, L.B., Ross, R.M., Smith, R.C., Stammerjohn, S.E., Vernet, M., Fraser, W., 2007. Marine pelagic ecosystems: The West Antarctic Peninsula. *Philosophical Transactions of the Royal Society B-Biological Sciences*, 362, 67-94.

Ducklow, H.W., Fraser, W.R., Meredith, M.P., Stammerjohn, S.E., Doney, S.C., Martinson, D.G., Sailley, S.F., Schofield, O.M., Steinberg, D.K., Venables, H.J., Amsler, C.D., 2013. West Antarctic Peninsula: An Ice-Dependent Coastal Marine Ecosystem in Transition. *Oceanography*, 26, 190-203.

Dunton, K.H., 2001. delta N-15 and delta C-13 measurements of Antarctic peninsula fauna: Trophic relationships and assimilation of benthic seaweeds. *American Zoologist*, 41, 99-112.

Erdmann, E.S., Ribic, C.A., Patterson-Fraser, D.L., Fraser, W.R., 2011. Characterization of winter foraging locations of Adelie penguins along the Western Antarctic Peninsula, 2001-2002. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 58, 1710-1718.

Eriksen, C.C., Osse, T.J., Light, R.D., Wen, T., Lehman, T.W., Sabin, P.L., Ballard, J.W., Chiodi, A.M., 2001. Seaglider: A long-range autonomous underwater vehicle for oceanographic research. *Ieee Journal of Oceanic Engineering*, 26, 424-436.

Evans, C., Brandsma, J., Pond, D.W., Venables, H.J., Meredith, M.P., Witte, H.J., Stammerjohn, S., Wilson, W.H., Clarke, A., Brussaard, C.P.D., 2017. Drivers of interannual variability in virioplankton abundance at the coastal western Antarctic peninsula and the potential effects of climate change. *Environmental Microbiology*, 19, 740-755.

Evans, C., Brussaard, C.P.D., 2012. Regional Variation in Lytic and Lysogenic Viral Infection in the Southern Ocean and Its Contribution to Biogeochemical Cycling. *Applied and Environmental Microbiology*, 78, 6741-6748.

Falk, U., Sala, H., 2015. Winter Melt Conditions of the Inland Ice Cap on King George Island, Antarctic Peninsula. *Erdkunde*, 69, 341-363.

Feely, R.A., Doney, S.C., Cooley, S.R., 2009. Ocean Acidification: Present Conditions and Future Changes in a High-CO2 World. *Oceanography*, 22, 36-47.

Feng, Y., Hare, C.E., Rose, J.M., Handy, S.M., DiTullio, G.R., Lee, P.A., Smith, W.O., Peloquin, J., Tozzi, S., Sun, J., Zhang, Y., Dunbar, R.B., Long, M.C., Sohst, B., Lohan, M., Hutchins, D.A., 2010. Interactive effects of iron, irradiance and CO2 on Ross Sea phytoplankton. *Deep-Sea Research Part I-Oceanographic Research Papers*, 57, 368-383.

Fletcher, S.E.M., Gruber, N., Jacobson, A.R., Doney, S.C., Dutkiewicz, S., Gerber, M., Follows, M., Joos, F., Lindsay, K., Menemenlis, D., Mouchet, A., Muller, S.A., Sarmiento, J.L., 2006. Inverse estimates of anthropogenic CO2 uptake, transport, and storage by the ocean. *Global Biogeochemical Cycles*, 20.

Fraser, K.P., Clarke, A., Peck, L.S., 2007. Growth in the slow lane: protein metabolism in the Antarctic limpet Nacella concinna (Strebel 1908). *J Exp Biol*, 210, 2691-2699.

Fraser, K.P., Peck, L.S., Clarke, A., 2004. Protein synthesis, RNA concentrations, nitrogen excretion, and metabolism vary seasonally in the Antarctic holothurian Heterocucumis steineni (Ludwig 1898). *Physiol Biochem Zool*, 77, 556-569.

Friedlaender, A.S., Goldbogen, J.A., Nowacek, D.P., Read, A.J., Johnston, D., Gales, N., 2014. Feeding rates and under-ice foraging strategies of the smallest lunge filter feeder, the Antarctic minke whale (Balaenoptera bonaerensis). *Journal of Experimental Biology*, 217, 2851-2854.

Friedlaender, A.S., Halpin, P.N., Qian, S.S., Lawson, G.L., Wiebe, P.H., Thiele, D., Read, A.J., 2006. Whale distribution in relation to prey abundance and oceanographic processes in shelf waters of the Western Antarctic Peninsula. *Marine Ecology Progress Series*, 317, 297-310.

Friedlaender, A.S., Johnston, D.W., Fraser, W.R., Burns, J., Halpin, P.N., Costa, D.P., 2011. Ecological niche modeling of sympatric krill predators around Marguerite Bay, Western Antarctic Peninsula. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 58, 1729-1740.

Friedlaender, A.S., Johnston, D.W., Tyson, R.B., Kaltenberg, A., Goldbogen, J.A., Stimpert, A.K., Curtice, C., Hazen, E.L., Halpin, P.N., Read, A.J., Nowacek, D.P., 2016. Multiple-stage decisions in a marine central-place forager. *Royal Society Open Science*, 3.

Friedlaender, A.S., Lawson, G.L., Halpin, P.N., 2009. Evidence of resource partitioning between humpback and minke whales around the western Antarctic Peninsula. *Marine Mammal Science*, 25, 402-415.

Friedlaender, A.S., Tyson, R.B., Stimpert, A.K., Read, A.J., Nowacek, D.P., 2013. Extreme diel variation in the feeding behavior of humpback whales along the western Antarctic Peninsula during autumn. *Marine Ecology Progress Series*, 494, 281-289.

Friess, U., Deutschmann, T., Gilfedder, B.S., Weller, R., Platt, U., 2010. Iodine monoxide in the Antarctic snowpack. *Atmospheric Chemistry and Physics*, 10, 2439-2456.

Fripiat, F., Meiners, K.M., Vancoppenolle, M., Papadimitriou, S., Thomas, D.N., Ackley, S.F., Arrigo, K.R., Carnat, G., Cozzi, S., Delille, B., Dieckmann, G.S., Dunbar, R.B., Fransson, A., Kattner, G., Kennedy, H., Lannuzel, D., Munro, D.R., Nomura, D., Rintala, J.M., Schoemann, V., Stefels, J., Steiner, N., Tison, J.L., 2017. Macro-nutrient concentrations in Antarctic pack ice: Overall patterns and overlooked processes. *Elementa-Science of the Anthropocene*, 5.

Fripiat, F., Sigman, D.M., Masse, G., Tison, J.L., 2015. High turnover rates indicated by changes in the fixed N forms and their stable isotopes in Antarctic landfast sea ice. *Journal of Geophysical Research-Oceans*, 120, 3079-3097.

Fuentes, V., Alurralde, G., Meyer, B., Aguirre, G.E., Canepa, A., Wolfl, A.C., Hass, H.C., Williams, G.N., Schloss, I.R., 2016. Glacial melting: an overlooked threat to Antarctic krill. *Scientific Reports*, 6.

Garcia, M.D., Hoffmeyer, M.S., Abbate, M.C.L., Barría de Cao, M.S., Pettigrosso, R.E., Almandoz, G.O., Hernando, M.P., Schloss, I.R., 2016. Micro- and mesozooplankton responses during two contrasting summers in a coastal Antarctic environment. *Polar Biology*, 39, 123-137.

Garibotti, I.A., Vernet, M., Ferrario, M.E., Smith, R.C., Ross, R.M., Quetin, L.B., 2003. Phytoplankton spatial distribution patterns along the western Antarctic Peninsula (Southern Ocean). *Marine Ecology Progress Series*, 261, 21-39.

Garzio, L.M., Steinberg, D.K., 2013. Microzooplankton community composition along the Western Antarctic Peninsula. *Deep-Sea Research Part I-Oceanographic Research Papers*, 77, 36-49.

Garzio, L.M., Steinberg, D.K., Erickson, M., Ducklow, H.W., 2013. Microzooplankton grazing along the Western Antarctic Peninsula. *Aquatic Microbial Ecology*, 70, 215-232.

Gentile, G., Giuliano, L., D'Auria, G., Smedile, F., Azzaro, M., De Domenico, M., Yakimov, M.M., 2006. Study of bacterial communities in Antarctic coastal waters by a combination of 16S rRNA and 16S rDNA sequencing. *Environmental Microbiology*, 8, 2150-2161.

Ghiglione, J.F., Murray, A.E., 2012. Pronounced summer to winter differences and higher wintertime richness in coastal Antarctic marine bacterioplankton. *Environmental Microbiology*, 14, 617-629.

Gillies, C.L., Stark, J.S., Johnstone, G.J., Smith, S.D.A., 2012. Carbon flow and trophic structure of an Antarctic coastal benthic community as determined by delta C-13 and delta N-15. *Estuarine Coastal and Shelf Science*, 97, 44-57.

Gleiber, M.R., 2015. Long-term change in copepod community structure in the Western Antarctic Peninsula: Linkage to climate and implications for carbon cycling Vol. Master's (pp. 26-96): Gloucester Point (VA): Virginia Institute of Marine Science.

Gleiber, M.R., Steinberg, D.K., Ducklow, H.W., 2012. Time series of vertical flux of zooplankton fecal pellets on the continental shelf of the western Antarctic Peninsula. *Marine Ecology Progress Series*, 471, 23-36.

Gleiber, M.R., Steinberg, D.K., Schofield, O.M.E., 2016. Copepod summer grazing and fecal pellet production along theWestern Antarctic Peninsula. *Journal of Plankton Research*, 38, 732-750.

Goebel, M.E., Perryman, W.L., Hinke, J.T., Krause, D.J., Hann, N.A., Gardner, S., LeRoi, D.J., 2015. A small unmanned aerial system for estimating abundance and size of Antarctic predators. *Polar Biology*, 38, 619-630.

Gondwe, M., Krol, M., Gieskes, W., Klaassen, W., de Baar, H., 2003. The contribution of ocean-leaving DMS to the global atmospheric burdens of DMS, MSA, SO2, and NSS SO4. *Global Biogeochemical Cycles*, 17.

Gordon, A.L., Nowlin, W.D., 1978. Basin Waters of Bransfield Strait. *Journal of Physical Oceanography*, 8, 258-264.

Graham, J.A., Dinniman, M.S., Klinck, J.M., 2016. Impact of model resolution for on-shelf heat transport along the West Antarctic Peninsula. *Journal of Geophysical Research-Oceans*, 121, 7880-7897.

Granfors, A., Karlsson, A., Mattsson, E., Smith, W.O., Abrahamsson, K., 2013. Contribution of sea ice in the Southern Ocean to the cycling of volatile halogenated organic compounds. *Geophysical Research Letters*, 40, 3950-3955.

Grange, L.J., Smith, C.R., 2013. Megafaunal Communities in Rapidly Warming Fjords along the West Antarctic Peninsula: Hotspots of Abundance and Beta Diversity. *Plos One*, 8.

Grzymski, J.J., Riesenfeld, C.S., Williams, T.J., Dussaq, A.M., Ducklow, H., Erickson, M., Cavicchioli, R., Murray, A.E., 2012. A metagenomic assessment of winter and summer bacterioplankton from Antarctica Peninsula coastal surface waters. *Isme Journal*, 6, 1901-1915.

Gutt, J., 2007. Antarctic macro-zoobenthic communities: a review and an ecological classification. *Antarctic Science*, 19, 165-182.

Haberman, K.L., Ross, R.M., Quetin, L.B., 2003. Diet of the Antarctic krill (Euphausia superba Dana): II. Selective grazing in mixed phytoplankton assemblages. *Journal of Experimental Marine Biology and Ecology*, 283, 97-113.

Hansell, D.A., Carlson, C.A., Repeta, D.J., Schlitzer, R., 2009. Dissolved Organic Matter in the Ocean a Controversy Stimulates New Insights. *Oceanography*, 22, 202-211.

Hart, T.J., 1942. Phytoplankton periodicity in Antarctic surface waters. *Discovery Reports*, 21, 261-356.

Hauri, C., Doney, S.C., Takahashi, T., Erickson, M., Jiang, G., Ducklow, H.W., 2015. Two decades of inorganic carbon dynamics along the West Antarctic Peninsula. *Biogeosciences*, 12, 6761-6779.

Hawkings, J.R., Wadham, J.L., Benning, L.G., Hendry, K.R., Tranter, M., Tedstone, A., Nienow, P., Raiswell, R., 2017. Ice sheets as a missing source of silica to the polar oceans. *Nature Communications*, 8.

Heise, K., Estevez, M.S., Puntarulo, S., Galleano, M., Nikinmaa, M., Portner, H.O., Abele, D., 2007. Effects of seasonal and latitudinal cold on oxidative stress parameters and activation of hypoxia inducible factor (HIF-1) in zoarcid fish. *J Comp Physiol B*, 177, 765-777.

Hendry, K.R., Rickaby, R.E.M., de Hoog, J.C.M., Weston, K., Rehkamper, M., 2008. Cadmium and phosphate in coastal Antarctic seawater: Implications for Southern Ocean nutrient cycling. *Marine Chemistry*, 112, 149-157.

Hendry, K.R., Rickaby, R.E.M., de Hoog, J.C.M., Weston, K., Rehkamper, M., 2010. The cadmium-phosphate relationship in brine: biological versus physical control over micronutrients in sea ice environments. *Antarctic Science*, 22, 11-18.

Hendry, K.R., Rickaby, R.E.M., Meredith, M.P., Elderfield, H., 2009. Controls on stable isotope and trace metal uptake in Neogloboquadrina pachyderma (sinistral) from an Antarctic sea-ice environment. *Earth and Planetary Science Letters*, 278, 67-77.

Henley, S.F., Tuerena, R.E., Annett, A.L., Fallick, A.E., Meredith, M.P., Venables, H.J., Clarke, A., Ganeshram, R.S., 2017. Macronutrient supply, uptake and recycling in the coastal ocean of the west Antarctic Peninsula. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 139, 58-76.

Henley, S.F., Jones, E.J., Venables, H.J., Meredith, M.P., Firing, Y.L., Dittrich, R., Heiser, S., Stefels, J., Dougans, J. 2018. Macronutrient and carbon supply, uptake and cycling across the Antarctic Peninsula shelf during summer. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*, 376.

Hernandez, E., Piquet, A.M.T., Lopez, J.L., Buma, A.G.J., Mac Cormack, W.P., 2015. Marine archaeal community structure from Potter Cove, Antarctica: high temporal and spatial dominance of the phylum Thaumarchaeota. *Polar Biology*, 38, 117-130.

Hernando, M., Schloss, I.R., Malanga, G., Almandoz, G.O., Ferreyra, G.A., Aguiar, M.B., Puntarulo, S., 2015. Effects of salinity changes on coastal Antarctic phytoplankton physiology and assemblage composition. *Journal of Experimental Marine Biology and Ecology*, 466, 110-119.

Herrmann, M., Najjar, R.G., Neeley, A.R., Vila-Costa, M., Dacey, J.W.H., DiTullio, G.R., Kieber, D.J., Kiene, R.P., Matrai, P.A., Simo, R., Vernet, M., 2012. Diagnostic modeling of dimethylsulfide production in coastal water west of the Antarctic Peninsula. *Continental Shelf Research*, 32, 96-109.

Higgs, N.D., Reed, A.J., Hooke, R., Honey, D.J., Heilmayer, O., Thatje, S., 2009. Growth and reproduction in the Antarctic brooding bivalve Adacnarca nitens (Philobryidae) from the Ross Sea. *Marine Biology*, 156, 1073-1081.

Hindell, M.A., McMahon, C.R., Bester, M.N., Boehme, L., Costa, D., Fedak, M.A., Guinet, C., Herraiz-Borreguero, L., Harcourt, R.G., Huckstadt, L., Kovacs, K.M., Lydersen, C., McIntyre, T., Muelbert, M., Patterson, T., Roquet, F., Williams, G., Charrassin, J.-B., 2016. Circumpolar habitat use in the southern elephant seal: implications for foraging success and population trajectories. *Ecosphere*, 7, e01213.

Hinke, J.T., Cossio, A.M., Goebel, M.E., Reiss, C.S., Trivelpiece, W.Z., Watters, G.M., 2017b. Identifying Risk: Concurrent Overlap of the Antarctic Krill Fishery with Krill-Dependent Predators in the Scotia Sea. *Plos One*, 12.

Hinke, J.T., Polito, M.J., Goebel, M.E., Jarvis, S., Reiss, C.S., Thorrold, S.R., Trivelpiece, W.Z., Watters, G.M., 2015. Spatial and isotopic niche partitioning during winter in chinstrap and Adelie penguins from the South Shetland Islands. *Ecosphere*, 6.

Hinke, J.T., Trivelpiece, S.G., Trivelpiece, W.Z., 2017a. Variable vital rates and the risk of population declines in Adelie penguins from the Antarctic Peninsula region. *Ecosphere*, 8.

Hobbs, W.R., Massom, R., Stammerjohn, S., Reid, P., Williams, G., Meier, W., 2016. A review of recent changes in Southern Ocean sea ice, their drivers and forcings. *Global and Planetary Change*, 143, 228-250.

Hoffman, J.I., Clarke, A., Linse, K., Peck, L.S., 2011. Effects of brooding and broadcasting reproductive modes on the population genetic structure of two Antarctic gastropod molluscs. *Marine Biology*, 158, 287-296.

Hoffman, J.I., Clarke, A., Clark, M.S., Fretwell, P., Peck, L.S., 2012. Unexpected fine-scale population structure in a broadcast-spawning Antarctic marine mollusc. *Plos One*, 7, e32415.

Hofmann, E.E., Klinck, J.M., Lascara, C.M., Smith, D.A., 1996. Water mass distribution and circulation west of the Antarctic Peninsula and including Bransfield Strait. In R.M. Ross, E.E. Hofmann, L.B. Quetin (Eds.), *Foundations for ecological research west of the Antarctic Peninsula*. Washington, D. C.: American Geophysical Union.

Huang, Y.M., Amsler, M.O., McClintock, J.B., Amsler, C.D., Baker, B.J., 2007. Patterns of gammaridean amphipod abundance and species composition associated with dominant subtidal macroalgae from the western Antarctic Peninsula. *Polar Biology*, 30, 1417-1430.

Huckstadt, L.A., Burns, J.M., Koch, P.L., McDonald, B.I., Crocker, D.E., Costa, D.P., 2012a. Diet of a specialist in a changing environment: the crabeater seal along the western Antarctic Peninsula. *Marine Ecology Progress Series*, 455, 287-301.

Huckstadt, L.A., Koch, P.L., McDonald, B.I., Goebel, M.E., Crocker, D.E., Costa, D.P., 2012b. Stable isotope analyses reveal individual variability in the trophic ecology of a top marine predator, the southern elephant seal. *Oecologia*, 169, 395-406.

Hughes, C., Chuck, A.L., Rossetti, H., Mann, P.J., Turner, S.M., Clarke, A., Chance, R., Liss, P.S., 2009. Seasonal cycle of seawater bromoform and dibromomethane concentrations in a coastal bay on the western Antarctic Peninsula. *Global Biogeochemical Cycles*, 23.

Hughes, C., Johnson, M., Utting, R., Turner, S., Malin, G., Clarke, A., Liss, P.S., 2013. Microbial control of bromocarbon concentrations in coastal waters of the western Antarctic Peninsula. *Marine Chemistry*, 151, 35-46.

Hughes, C., Johnson, M., von Glasow, R., Chance, R., Atkinson, H., Souster, T., Lee, G.A., Clarke, A., Meredith, M., Venables, H.J., Turner, S.M., Malin, G., Liss, P.S., 2012. Climate-induced change in biogenic bromine emissions from the Antarctic marine biosphere. *Global Biogeochemical Cycles*, 26.

Hughes, K.A., Ashton, G.V., 2017. Breaking the ice: the introduction of biofouling organisms to Antarctica on vessel hulls. *Aquatic Conservation-Marine and Freshwater Ecosystems*, 27, 158-164.

Ito, R.G., Tavano, V.M., Mendes, C.R.B., Garcia, C.A.E., 2018. Sea-air CO2 fluxes and pCO2 variability in the Northern Antarctic Peninsula during three summer periods (2008–2010). *Deep Sea Research Part II: Topical Studies in Oceanography*, 149, 84-98.

Jacob, U., Brey, T., Fetzer, I., Kaehler, S., Mintenbeck, K., Dunton, K., Beyer, K., Struck, U., Pakhomov, E.A., Arntz, W.E., 2006. Towards the trophic structure of the Bouvet Island marine ecosystem. *Polar Biology*, 29, 106-113.

Jarníková, T., Tortell, P.D., 2016. Towards a revised climatology of summertime dimethylsulfide concentrations and sea–air fluxes in the Southern Ocean. *Environmental Chemistry*, 13, 364-378.

Johnson, W.S., Stevens, M., Watling, L., 2001. Reproduction and development of marine peracaridans. *Advances in Marine Biology*, Vol. 39 (pp. 105-260): Academic Press.

Johnston, D.W., Friedlaender, A.S., Read, A.J., Nowacek, D.P., 2012. Initial density estimates of humpback whales Megaptera novaeangliae in the inshore waters of the western Antarctic Peninsula during the late autumn. *Endangered Species Research*, 18, 63-71.

Jones, A.E., Wolff, E.W., Brough, N., Bauguitte, S.J.B., Weller, R., Yela, M., Navarro-Comas, M., Ochoa, H.A., Theys, N., 2013. The spatial scale of ozone depletion events derived from an autonomous surface ozone network in coastal Antarctica. *Atmospheric Chemistry and Physics*, 13, 1457-1467.

Jones, E.M., Fenton, M., Meredith, M.P., Clargo, N.M., Ossebaar, S., Ducklow, H.W., Venables, H.J., de Baar, H.J.W., 2017. Ocean acidification and calcium carbonate saturation states in the coastal zone of the West Antarctic Peninsula. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 139, 181-194.

Juares, M.A., Ferrer, F., Coria, N.R., Santos, M.M., 2017. Breeding events of king penguin at the South Shetland Islands: Has it come to stay? *Polar Biology*, 40, 457-461.

Juares, M.A., Santos, M., Negrete, J., Mennucci, J.A., Perchivale, P.J., Casaux, R., Coria, N.R., 2015. Adelie penguin population changes at Stranger Point: 19 years of monitoring. *Antarctic Science*, 27, 455-461.

Kapsenberg, L., Hofmann, G.E., 2014. Signals of resilience to ocean change: high thermal tolerance of early stage Antarctic sea urchins (Sterechinus neumayeri) reared under present-day and future pCO(2) and temperature. *Polar Biology*, 37, 967-980.

Kavanaugh, M.T., Abdala, F.N., Ducklow, H., Glover, D., Fraser, W., Martinson, D., Stammerjohn, S., Schofield, O., Doney, S.C., 2015. Effect of continental shelf canyons on phytoplankton biomass and community composition along the western Antarctic Peninsula. *Marine Ecology Progress Series*, 524, 11-26.

Khim, B.K., Shim, J., Yoon, H.I., Kang, Y.C., Jang, Y.H., 2007. Lithogenic and biogenic particle deposition in an Antarctic coastal environment (Marian Cove, King George Island): Seasonal patterns from a sediment trap study. *Estuarine Coastal and Shelf Science*, 73, 111-122.

Kim, H., Doney, S.C., Iannuzzi, R.A., Meredith, M.P., Martinson, D.G., Ducklow, H.W., 2016. Climate forcing for dynamics of dissolved inorganic nutrients at Palmer Station, Antarctica: An interdecadal (1993-2013) analysis. *Journal of Geophysical Research-Biogeosciences*, 121, 2369-2389.

Kim, H., Ducklow, H.W., 2016. A Decadal (2002–2014) Analysis for Dynamics of Heterotrophic Bacteria in an Antarctic Coastal Ecosystem: Variability and Physical and Biogeochemical Forcings. *Frontiers in Marine Science*, 3.

Kim, H., Ducklow, H.W., Abele, D., Barlett, E.M.R., Buma, A.G.J., Meredith, M.P., Rozema, P.D., Schofield, O.M., Venables, H.J., Schloss, I.R., 2018. Inter-decadal variability of phytoplankton biomass along the coastal West Antarctic Peninsula. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*, 376.

King, J.C., Turner, J., Marshall, G.J., Connolley, W.M., Lachlan-Cope, T.A., 2003. Antarctic peninsula climate variability and its causes as revealed by analysis of instrumental records. *Antarctic Peninsula Climate Variability: Historical and Paleoenvironmental Perspectives*, 79, 17-30.

Kirchman, D.L., Moran, X.A.G., Ducklow, H., 2009. Microbial growth in the polar oceans - role of temperature and potential impact of climate change. *Nature Reviews Microbiology*, 7, 451-459.

Klinck, J.M., 1998. Heat and salt changes on the continental shelf west of the Antarctic Peninsula between January 1993 and January 1994. *Journal of Geophysical Research-Oceans*, 103, 7617-7636.

Klinck, J.M., Hofmann, E.E., Beardsley, R.C., Salihoglu, B., Howard, S., 2004. Water-mass properties and circulation on the west Antarctic Peninsula Continental Shelf in Austral Fall and Winter 2001. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 51, 1925-1946.

Kock, K.H., Shimadzu, Y., 1994. Trophic Relationships and Trends in Population-Size and Reproductive Parameters in Antarctic High-Level Predators. *Southern Ocean Ecology: The Biomass Perspective*, 287-312.

Kohlbach, D., Lange, B.A., Schaafsma, F.L., David, C., Vortkamp, M., Graeve, M., van Franeker, J.A., Krumpen, T., Flores, H., 2017. Ice Algae-Produced Carbon Is Critical for Overwintering of Antarctic Krill Euphausia superba. *Frontiers in Marine Science*, 4.

Kohut, J., Bernard, K., Fraser, W., Oliver, M.J., Statscevvich, H., Winsor, P., Miles, T., 2014. Studying the Impacts of Local Oceanographic Processes on Adelie Penguin Foraging Ecology. *Marine Technology Society Journal*, 48, 25-34.

Kopczynska, E., 1992. Dominance of Microflagellates over Diatoms in the Antarctic Areas of Deep Vertical Mixing and Krill Concentrations. *Journal of Plankton Research*, 14, 1031-1054.

Kozlowski, W.A., Deutschman, D., Garibotti, I., Trees, C., Vernet, M., 2011. An evaluation of the application of CHEMTAX to Antarctic coastal pigment data. *Deep-Sea Research Part I-Oceanographic Research Papers*, 58, 350-364.

Krebs, W.N., 1983. Ecology of Neritic Marine Diatoms, Arthur Harbor, Antarctica. *Micropaleontology*, 29, 267-297.

Lachlan-Cope, T.A., Connolley, W.M., Turner, J., 2001. The role of the non-axisymmetric Antarctic orography in forcing the observed pattern of variability of the Antarctic climate. *Geophysical Research Letters*, 28, 4111-4114.

Lagger, C., Nime, M., Torre, L., Servetto, N., Tatián, M., Sahade, R., 2017a. Climate change, glacier retreat and a new ice-free island offer new insights on Antarctic benthic responses. *Ecography*, 41, 579-591.

Lagger, C., Servetto, N., Torre, L., Sahade, R., 2017b. Benthic colonization in newly ice-free soft-bottom areas in an Antarctic fjord. *Plos One*, 12, e0186756.

Lana, A., Bell, T.G., Simo, R., Vallina, S.M., Ballabrera-Poy, J., Kettle, A.J., Dachs, J., Bopp, L., Saltzman, E.S., Stefels, J., Johnson, J.E., Liss, P.S., 2011. An updated climatology of surface dimethlysulfide concentrations and emission fluxes in the global ocean. *Global Biogeochemical Cycles*, 25.

Landa, M., Blain, S., Christaki, U., Monchy, S., Obernosterer, I., 2016. Shifts in bacterial community composition associated with increased carbon cycling in a mosaic of phytoplankton blooms. *Isme Journal*, 10, 39-50.

Landschutzer, P., Gruber, N., Haumann, A., Rodenbeck, C., Bakker, D.C.E., van Heuven, S., Hoppema, M., Metzl, N., Sweeney, C., Takahashi, T., Tilbrook, B., Wanninkhof, R., 2015. The reinvigoration of the Southern Ocean carbon sink. *Science*, 349, 1221-1224.

Le Quere, C., Rodenbeck, C., Buitenhuis, E.T., Conway, T.J., Langenfelds, R., Gomez, A., Labuschagne, C., Ramonet, M., Nakazawa, T., Metzl, N., Gillett, N., Heimann, M., 2007. Saturation of the Southern Ocean CO2 sink due to recent climate change. *Science*, 316, 1735-1738.

Learman, D.R., Henson, M.W., Thrash, J.C., Temperton, B., Brannock, P.M., Santos, S.R., Mahon, A.R., Halanych, K.M., 2016. Biogeochemical and Microbial Variation across 5500 km of Antarctic Surface Sediment Implicates Organic Matter as a Driver of Benthic Community Structure. *Frontiers in Microbiology*, 7.

Lee, H.J., Vanhove, S., Peck, L.S., Vincx, M., 2001. Recolonisation of meiofauna after catastrophic iceberg scouring in shallow Antarctic sediments. *Polar Biology*, 24, 918-925.

Lee, J.E., Chown, S.L., 2009. Temporal development of hull-fouling assemblages associated with an Antarctic supply vessel. *Marine Ecology Progress Series*, 386, 97-105.

Lee, J.F., Friedlaender, A.S., Oliver, M.J., DeLiberty, T.L., 2017. Behavior of satellite-tracked Antarctic minke whales (Balaenoptera bonaerensis) in relation to environmental factors around the western Antarctic Peninsula. *Animal Biotelemetry*, 5, 23.

Legge, O.J., Bakker, D.C.E., Johnson, M.T., Meredith, M.P., Venables, H.J., Brown, P.J., Lee, G.A., 2015. The seasonal cycle of ocean-atmosphere CO2 flux in Ryder Bay, west Antarctic Peninsula. *Geophysical Research Letters*, 42, 2934-2942.

Legge, O.J., Bakker, D.C.E., Meredith, M.P., Venables, H.J., Brown, P.J., Jones, E.M., Johnson, M.T., 2017. The seasonal cycle of carbonate system processes in Ryder Bay, West Antarctic Peninsula. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 139, 167-180.

Legrand, M., Yang, X., Preunkert, S., Theys, N., 2016. Year-round records of sea salt, gaseous, and particulate inorganic bromine in the atmospheric boundary layer at coastal (Dumont d'Urville) and central (Concordia) East Antarctic sites. *Journal of Geophysical Research-Atmospheres*, 121, 997-1023.

Leis, J.M., Caselle, J.E., Bradbury, I.R., Kristiansen, T., Llopiz, J.K., Miller, M.J., O'Connor, M.I., Paris, C.B., Shanks, A.L., Sogard, S.M., Swearer, S.E., Treml, E.A., Vetter, R.D., Warner, R.R., 2013. Does fish larval dispersal differ between high and low latitudes? *Proceedings of the Royal Society B-Biological Sciences*, 280.

Li, Z.C., Cassar, N., Huang, K., Ducklow, H., Schofield, O., 2016. Interannual variability in net community production at the Western Antarctic Peninsula region (1997-2014). *Journal of Geophysical Research-Oceans*, 121, 4748-4762.

Lieb-Lappen, R.M., Obbard, R.W., 2015. The role of blowing snow in the activation of bromine over first-year Antarctic sea ice. *Atmospheric Chemistry and Physics*, 15, 7537-7545.

Lien, R., Solheim, A., Elverhøi, A., Rokoengen, K., 1989. Iceberg scouring and sea bed morphology on the eastern Weddell Sea shelf, Antarctica. *Polar Research*, 7, 43-57.

Lizotte, M.P., 2001. The contributions of sea ice algae to Antarctic marine primary production. *American Zoologist*, 41, 57-73.

Loeb, V.J., Hofmann, E.E., Klinck, J.M., Holm-Hansen, O., White, W.B., 2009. ENSO and variability of the Antarctic Peninsula pelagic marine ecosystem. *Antarctic Science*, 21, 135-148.

Loeb, V.J., Santora, J.A., 2012. Population dynamics of Salpa thompsoni near the Antarctic Peninsula: Growth rates and interannual variations in reproductive activity (1993-2009). *Progress in Oceanography*, 96, 93-107.

Loeb, V.J., Santora, J.A., 2013. Pteropods and climate off the Antarctic Peninsula. *Progress in Oceanography*, 116, 31-48.

Loeb, V.J., Santora, J.A., 2015. Climate variability and spatiotemporal dynamics of five Southern Ocean krill species. *Progress in Oceanography*, 134, 93-122.

Luria, C.M., Amaral-Zettler, L.A., Ducklow, H.W., Repeta, D.J., Rhyne, A.L., Rich, J.J., 2017. Seasonal Shifts in Bacterial Community Responses to Phytoplankton-Derived Dissolved Organic Matter in the Western Antarctic Peninsula. *Frontiers in Microbiology*, 8.

Luria, C.M., Amaral-Zettler, L.A., Ducklow, H.W., Rich, J.J., 2016. Seasonal Succession of Free-Living Bacterial Communities in Coastal Waters of the Western Antarctic Peninsula. *Frontiers in Microbiology*, 7.

Luria, C.M., Ducklow, H.W., Amaral-Zettler, L.A., 2014. Marine bacterial, archaeal and eukaryotic diversity and community structure on the continental shelf of the western Antarctic Peninsula. *Aquatic Microbial Ecology*, 73, 107-121.

Maat, D.S., Biggs, T., Evans, C., van Bleijswijk, J.D.L., van der Wel, N.N., Dutilh, B.E., Brussaard, C.P.D., 2017. Characterization and Temperature Dependence of Arctic Micromonas polaris Viruses. *Viruses-Basel*, 9.

Martinson, D.G., McKee, D.C., 2012. Transport of warm Upper Circumpolar Deep Water onto the western Antarctic Peninsula continental shelf. *Ocean Science*, 8, 433-442.

Martinson, D.G., Stammerjohn, S.E., Iannuzzi, R.A., Smith, R.C., Vernet, M., 2008. Western Antarctic Peninsula physical oceanography and spatio-temporal variability. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 55, 1964-1987.

McMinn, A., Pankowskii, A., Ashworth, C., Bhagooli, R., Ralph, P., Ryan, K., 2010. In situ net primary productivity and photosynthesis of Antarctic sea ice algal, phytoplankton and benthic algal communities. *Marine Biology*, 157, 1345-1356.

McNeil, B.I., Matear, R.J., 2008. Southern Ocean acidification: A tipping point at 450-ppm atmospheric CO(2). *Proceedings of the National Academy of Sciences of the United States of America*, 105, 18860-18864.

Meiners, K.M., M. Vancoppenolle, G. Carnat, G. Castellani, B. Delille, H. Flores, F. Fripiat, M. Grotti, B. Lange, D. Lannuzel, A. Martin, A. McMinn, D. Nomura, I. Peeken, K. Ryan, J. Stefels, K. Swadling, D.N. Thomas, J.-L. Tison, P. van der Merwe, M.A. van Leeuwe, C. Weldrick, *in press*. Chlorophyll-*a* in Antarctic land-fast sea ice: a first synthesis of historical ice-core data. *JGR-Oceans*.

Meredith, M.P., Brandon, M.A., Wallace, M.I., Clarke, A., Leng, M.J., Renfrew, I.A., van Lipzig, N.P.M., King, J.C., 2008. Variability in the freshwater balance of northern Marguerite Bay, Antarctic

Peninsula: Results from delta O-18. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 55, 309-322.

Meredith, M.P., King, J.C., 2005. Rapid climate change in the ocean west of the Antarctic Peninsula during the second half of the 20th century. *Geophysical Research Letters*, 32.

Meredith, M.P., Schofield, O., Newman, L., Urban, E., Sparrow, M., 2013. The vision for a Southern Ocean Observing System. *Current Opinion in Environmental Sustainability*, 5, 306-313.

Meredith, M.P., Stammerjohn, S.E., Venables, H.J., Ducklow, H.W., Martinson, D.G., Iannuzzi, R.A., Leng, M.J., van Wessem, J.M., Reijmer, C.H., Barrand, N.E., 2017. Changing distributions of sea ice melt and meteoric water west of the Antarctic Peninsula. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 139, 40-57.

Meredith, M.P., Wallace, M.I., Stammerjohn, S.E., Renfrew, I.A., Clarke, A., Venables, H.J., Shoosmith, D.R., Souster, T., Leng, M.J., 2010. Changes in the freshwater composition of the upper ocean west of the Antarctic Peninsula during the first decade of the 21st century. *Progress in Oceanography*, 87, 127-143.

Meredith, M.P., Falk, U., Bers, A.V., Mackensen, A., Schloss, I.R., Barlett, E.R., Jerosch, K., Busso, A.S., Abele, D., 2018. Anatomy of a glacial meltwater discharge event in an Antarctic cove. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*, 376.

Meyer, M.A., El-Sayed, S.Z., 1983. Grazing of Euphausia-Superba Dana on Natural Phytoplankton Populations. *Polar Biology*, 1, 193-197.

Miller, A.K., Karnovsky, N.J., Trivelpiece, W.Z., 2009. Flexible foraging strategies of gentoo penguins Pygoscelis papua over 5 years in the South Shetland Islands, Antarctica. *Marine Biology*, 156, 2527-2537.

Mincks, S.L., Smith, C.R., DeMaster, D.J., 2005. Persistence of labile organic matter and microbial biomass in Antarctic shelf sediments: evidence of a sediment 'food bank'. *Marine Ecology Progress Series*, 300, 3-19.

Moffat, C., Beardsley, R.C., Owens, B., van Lipzig, N., 2008. A first description of the Antarctic Peninsula Coastal Current. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 55, 277-293.

Moffat, C., Owens, B., Beardsley, R.C., 2009. On the characteristics of Circumpolar Deep Water intrusions to the west Antarctic Peninsula Continental Shelf. *Journal of Geophysical Research-Oceans*, 114.

Moffat, C., Meredith, M.P., 2018. Shelf-ocean exchange and hydrography west of the Antarctic Peninsula: a review. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*, 376.

Moline, M.A., 1998. Photoadaptive response during the development of a coastal Antarctic diatom bloom and relationship to water column stability. *Limnology and Oceanography*, 43, 146-153.

Moline, M.A., Claustre, H., Frazer, T.K., Schofield, O., Vernet, M., 2004. Alteration of the food web along the Antarctic Peninsula in response to a regional warming trend. *Global Change Biology*, 10, 1973-1980.

Moline, M.A., Prezelin, B.B., 1996. Long-term monitoring and analyses of physical factors regulating variability in coastal Antarctic phytoplankton biomass, in situ productivity and taxonomic composition over subseasonal, seasonal and interannual time scales. *Marine Ecology Progress Series*, 145, 143-160.

Monien, D., Monien, P., Brunjes, R., Widmer, T., Kappenberg, A., Busso, A.A.S., Schnetger, B., Brumsack, H.J., 2017. Meltwater as a source of potentially bioavailable iron to Antarctica waters. *Antarctic Science*, 29, 277-291.

Montes-Hugo, M., Doney, S.C., Ducklow, H.W., Fraser, W., Martinson, D., Stammerjohn, S.E., Schofield, O., 2009. Recent Changes in Phytoplankton Communities Associated with Rapid Regional Climate Change Along the Western Antarctic Peninsula. *Science*, 323, 1470-1473.

Montes-Hugo, M., Sweeney, C., Doney, S.C., Ducklow, H., Frouin, R., Martinson, D.G., Stammerjohn, S., Schofield, O., 2010. Seasonal forcing of summer dissolved inorganic carbon and chlorophyll a on the western shelf of the Antarctic Peninsula. *Journal of Geophysical Research-Oceans*, 115.

Moreau, S., Schloss, I.R., Mostajir, B., Demers, S., Almandoz, G.O., Ferrario, M.E., Ferreyra, G.A., 2012. Influence of microbial community composition and metabolism on air-sea Delta pCO(2) variation off the western Antarctic Peninsula. *Marine Ecology Progress Series*, 446, 45-59.

Moreno-Pino, M., De la Iglesia, R., Valdivia, N., Henriquez-Castilo, C., Galan, A., Diez, B., Trefault, N., 2016. Variation in coastal Antarctic microbial community composition at sub-mesoscale: spatial distance or environmental filtering? *Fems Microbiology Ecology*, 92.

Morley, S.A., Bates, A.E., Lamare, M., Richard, J., Nguyen, K.D., Brown, J., Peck, L.S., 2016. Rates of warming and the global sensitivity of shallow water marine invertebrates to elevated temperature. *Journal of the Marine Biological Association of the United Kingdom*, 96, 159-165.

Mura, M.P., Satta, M.P., Agusti, S., 1995. Water-Mass Influence on Summer Antarctic Phytoplankton Biomass and Community Structure. *Polar Biology*, 15, 15-20.

Murphy, E.J., Watkins, J.L., Trathan, P.N., Reid, K., Meredith, M.P., Thorpe, S.E., Johnston, N.M., Clarke, A., Tarling, G.A., Collins, M.A., Forcada, J., Shreeve, R.S., Atkinson, A., Korb, R., Whitehouse, M.J., Ward, P., Rodhouse, P.G., Enderlein, P., Hirst, A.G., Martin, A.R., Hill, S.L., Staniland, I.J., Pond, D.W., Briggs, D.R., Cunningham, N.J., Fleming, A.H., 2007. Spatial and temporal operation of the Scotia Sea ecosystem: a review of large-scale links in a krill centred food web. *Philosophical Transactions of the Royal Society B-Biological Sciences*, 362, 113-148.

Murray, A.E., Grzymski, J.J., 2007. Diversity and genomics of Antarctic marine micro-organisms. *Philosophical Transactions of the Royal Society B-Biological Sciences*, 362, 2259-2271.

Murray, A.E., Preston, C.M., Massana, R., Taylor, L.T., Blakis, A., Wu, K., DeLong, E.F., 1998. Seasonal and spatial variability of bacterial and archaeal assemblages in the coastal waters near Anvers Island, Antarctica. *Applied and Environmental Microbiology*, 64, 2585-2595.

Nelson, D.M., Smith, W.O., 1991. Sverdrup Revisited - Critical Depths, Maximum Chlorophyll Levels, and the Control of Southern-Ocean Productivity by the Irradiance-Mixing Regime. *Limnology and Oceanography*, 36, 1650-1661.

Norkko, A., Thrush, S.F., Cummings, V.J., Gibbs, M.M., Andrew, N.L., Norkko, J., Schwarz, A.M., 2007. Trophic structure of coastal antarctic food webs associated with changes in sea ice and food supply. *Ecology*, 88, 2810-2820.

Nowacek, D.P., Friedlaender, A.S., Halpin, P.N., Hazen, E.L., Johnston, D.W., Read, A.J., Espinasse, B., Zhou, M., Zhu, Y., 2011. Super-aggregations of krill and humpback whales in Wilhelmina Bay, Antarctic Peninsula. *Plos One*, 6, e19173.

Obryk, M.K., Doran, P.T., Friedlaender, A.S., Gooseff, M.N., Li, W., Morgan-Kiss, R.M., Priscu, J.C., Schofield, O., Stammerjohn, S.E., Steinberg, D.K., Ducklow, H.W., 2016. Responses of Antarctic Marine and Freshwater Ecosystems to Changing Ice Conditions. *Bioscience*, 66, 864-879.

Ogawa, H., Fukuda, R., Koike, I., 1999. Vertical distributions of dissolved organic carbon and nitrogen in the Southern Ocean. *Deep-Sea Research Part I-Oceanographic Research Papers*, 46, 1809-1826.

Orr, J.C., Fabry, V.J., Aumont, O., Bopp, L., Doney, S.C., Feely, R.A., Gnanadesikan, A., Gruber, N., Ishida, A., Joos, F., Key, R.M., Lindsay, K., Maier-Reimer, E., Matear, R., Monfray, P., Mouchet, A., Najjar, R.G., Plattner, G.K., Rodgers, K.B., Sabine, C.L., Sarmiento, J.L., Schlitzer, R., Slater, R.D., Totterdell, I.J., Weirig, M.F., Yamanaka, Y., Yool, A., 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature*, 437, 681-686.

Orr, J.C., Maier-Reimer, E., Mikolajewicz, U., Monfray, P., Sarmiento, J.L., Toggweiler, J.R., Taylor, N.K., Palmer, J., Gruber, N., Sabine, C.L., Le Quere, C., Key, R.M., Boutin, J., 2001. Estimates of anthropogenic carbon uptake from four three-dimensional global ocean models. *Global Biogeochemical Cycles*, 15, 43-60.

Orsi, A.H., Whitworth, T., Nowlin, W.D., 1995. On the Meridional Extent and Fronts of the Antarctic Circumpolar Current. *Deep-Sea Research Part I-Oceanographic Research Papers*, 42, 641-673.

Padman, L., Costa, D.P., Dinniman, M.S., Fricker, H.A., Goebel, M.E., Huckstadt, L.A., Humbert, A., Joughin, I., Lenaerts, J.T.M., Ligtenberg, S.R.M., Scambos, T., van den Broeke, M.R., 2012. Oceanic controls on the mass balance of Wilkins Ice Shelf, Antarctica. *Journal of Geophysical Research-Oceans*, 117.

Pasotti, F., Manini, E., Giovannelli, D., Wolfl, A.C., Monien, D., Verleyen, E., Braeckman, U., Abele, D., Vanreusel, A., 2015. Antarctic shallow water benthos in an area of recent rapid glacier retreat. *Marine Ecology-an Evolutionary Perspective*, 36, 716-733.

Peck, L.S., 2011. Organisms and responses to environmental change. *Marine Genomics*, 4, 237-243.

Peck, L.S., 2016. A Cold Limit to Adaptation in the Sea. *Trends in Ecology & Evolution*, 31, 13-26.

Peck, L.S., 2018. Cold adaptation: the ecophysiology of Antarctic marine ectotherms. *Oceanography and Marine Biology Annual Reviews*, 56, 105-236.

Peck, L.S., Barnes, D.K.A., Cook, A.J., Fleming, A.H., Clarke, A., 2010. Negative feedback in the cold: ice retreat produces new carbon sinks in Antarctica. *Global Change Biology*, 16, 2614-2623.

Peck, L.S., Barnes, D.K.A., Willmott, J., 2005. Responses to extreme seasonality in food supply: diet plasticity in Antarctic brachiopods. *Marine Biology*, 147, 453-463.

Peck, L.S., Brockington, S., Vanhove, S., Beghyn, M., 1999. Community recovery following catastrophic iceberg impacts in a soft-sediment shallow-water site at Signy Island, Antarctica. *Marine Ecology Progress Series*, 186, 1-8.

Peck, L.S., Morley, S., Clark, M.S., 2009. Animal temperature limits and ecological relevance: Effects of size, activity and rates of change. *Comparative Biochemistry and Physiology a-Molecular & Integrative Physiology*, 153a, S57-S57.

Peck, L.S., Morley, S.A., Richard, J., Clark, M.S., 2014. Acclimation and thermal tolerance in Antarctic marine ectotherms. *Journal of Experimental Biology*, 217, 16-22.

Peck, V.L., Oakes, R.L., Harper, E.M., Manno, C., Tarling, G.A., 2018. Pteropods counter mechanical damage and dissolution through extensive shell repair. *Nature Communications*, 9.

Pedulli, M., Bisagni, J.J., Ducklow, H.W., Beardsley, R., Pilskaln, C., 2014. Estimates of potential new production (PNP) for the waters off the western Antarctic Peninsula (WAP) region. *Continental Shelf Research*, 84, 54-69.

Phillips, B., Kremer, P., Madin, L.P., 2009. Defecation by Salpa thompsoni and its contribution to vertical flux in the Southern Ocean. *Marine Biology*, 156, 455-467.

Piepenburg, D., Schmid, M.K., Gerdes, D., 2002. The benthos off King George Island (South Shetland Islands, Antarctica): further evidence for a lack of a latitudinal biomass cline in the Southern Ocean. *Polar Biology*, 25, 146-158.

Piquet, A.M.T., Bolhuis, H., Meredith, M.P., Buma, A.G.J., 2011. Shifts in coastal Antarctic marine microbial communities during and after melt water-related surface stratification. *Fems Microbiology Ecology*, 76, 413-427.

Pitman, R.L., Ensor, P., 2003. Three forms of killer whales (*Orcinus orca*) in Antarctic waters. *Journal of Cetacean Research and Management*, 5, 131-139.

Poigner, H., Monien, P., Monien, D., Kriews, M., Brumsack, H.J., Wilhelms-Dick, D., Abele, D., 2013. Influence of the porewater geochemistry on Fe and Mn assimilation in Laternula elliptica at King George Island (Antarctica). *Estuarine Coastal and Shelf Science*, 135, 285-295.

Pomeroy, L.R., Wiebe, W.J., 2001. Temperature and substrates as interactive limiting factors for marine heterotrophic bacteria. *Aquatic Microbial Ecology*, 23, 187-204.

Portner, H.O., Farrell, A.P., 2008. Physiology and Climate Change. *Science*, 322, 690-692.

Pörtner, H.O., Peck, L., Somero, G., 2007. Thermal limits and adaptation in marine Antarctic ectotherms: an integrative view. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 362, 2233-2258.

Prezelin, B.B., Hofmann, E.E., Mengelt, C., Klinck, J.M., 2000. The linkage between Upper Circumpolar Deep Water (UCDW) and phytoplankton assemblages on the west Antarctic Peninsula continental shelf. *Journal of Marine Research*, 58, 165-202.

Quartino, M.L., Deregibus, D., Campana, G.L., Latorre, G.E.J., Momo, F.R., 2013. Evidence of Macroalgal Colonization on Newly Ice-Free Areas following Glacial Retreat in Potter Cove (South Shetland Islands), Antarctica. *Plos One*, 8.

Quetin, L.B., Ross, R.M., 2003. Episodic recruitment in Antarctic krill Euphausia superba in the Palmer LTER study region. *Marine Ecology Progress Series*, 259, 185-200.

Quetin, L.B., Ross, R.M., Frazer, T.K., Haberman, K.L., 1996. Factors affecting distribution and abundance of zooplankton, with an emphasis on Antarctic krill, *Euphausia superba*. *Antarctic Research Series*, 70, 357-371.

Raphael, M.N., Marshall, G.J., Turner, J., Fogt, R.L., Schneider, D., Dixon, D.A., Hosking, J.S., Jones, J.M., Hobbs, W.R., 2016. THE AMUNDSEN SEA LOW Variability, Change, and Impact on Antarctic Climate. *Bulletin of the American Meteorological Society*, 97, 111-121.

Ratnarajah, L., Melbourne-Thomas, J., Marzloff, M.P., Lannuzel, D., Meiners, K.M., Chever, F., Nicol, S., Bowie, A.R., 2016. A preliminary model of iron fertilisation by baleen whales and Antarctic krill in the Southern Ocean: Sensitivity of primary productivity estimates to parameter uncertainty. *Ecological Modelling*, 320, 203-212.

Reid, P., Massom, R.A., 2015. Successive Antarctic sea ice extent records during 2012, 2013 and 2014. *State of the Climate in 2014*, Vol. 96 (7) (pp. S163-S164): Bulletin of the American Meteorological Society.

Reid, P., Stammerjohn, S.E., Massom, R.A., Lieser, J.L., Barreira, S., Scambos, T., 2018. Antarctica: Sea ice extent, concentration and seasonality. *State of the Climate in 2017*, Vol. 98 (8) (pp. S183-S192): Bulletin of the American Meteorological Society.

Riaux-Gobin, C., Poulin, M., Dieckmann, G., Labrune, C., Vetion, G., 2011. Spring phytoplankton onset after the ice break-up and sea-ice signature (Adelie Land, East Antarctica). *Polar Research*, 30.

Ribic, C.A., Ainley, D.G., Ford, R.G., Fraser, W.R., Tynan, C.T., Woehler, E.J., 2011. Water masses, ocean fronts, and the structure of Antarctic seabird communities: Putting the eastern Bellingshausen Sea in perspective. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 58, 1695-1709.

Richerson, K., Santora, J.A., Mangel, M., 2017. Climate variability and multi-scale assessment of the krill preyscape near the north Antarctic Peninsula. *Polar Biology*, 40, 697-711.

Riebesell, U., Schloss, I., Smetacek, V., 1991. Aggregation of Algae Released from Melting Sea Ice - Implications for Seeding and Sedimentation. *Polar Biology*, 11, 239-248.

Rodriguez, F., Varela, M., Zapata, M., 2002. Phytoplankton assemblages in the Gerlache and Bransfield Straits (Antarctic Peninsula) determined by light microscopy and CHEMTAX analysis of HPLC pigment data. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 49, 723-747.

Roman, J., Estes, J.A., Morissette, L., Smith, C., Costa, D., McCarthy, J., Nation, J.B., Nicol, S., Pershing, A., Smetacek, V., 2014. Whales as marine ecosystem engineers. *Frontiers in Ecology and the Environment*, 12, 377-385.

Roscoe, H.K., Jones, A.E., Brough, N., Weller, R., Saiz-Lopez, A., Mahajan, A.S., Schoenhardt, A., Burrows, J.P., Fleming, Z.L., 2015. Particles and iodine compounds in coastal Antarctica. *Journal of Geophysical Research-Atmospheres*, 120, 7144-7156.

Ross, R.M., Quetin, L.B., Martinson, D.G., Iannuzzi, R.A., Stammerjohn, S.E., Smith, R.C., 2008. Palmer LTER: Patterns of distribution of five dominant zooplankton species in the epipelagic zone west of the Antarctic Peninsula, 1993-2004. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 55, 2086-2105.

Rozema, P.D., Venables, H.J., Poll, W.H., Clarke, A., Meredith, M.P., Buma, A.G.J., 2017a. Interannual variability in phytoplankton biomass and species composition in northern Marguerite Bay (West Antarctic Peninsula) is governed by both winter sea ice cover and summer stratification. *Limnology and Oceanography*, 62, 235-252.

Rozema, P.D., Biggs, T., Sprong, P.A.A., Buma, A.G.J., Venables, H.J., Evans, C., Meredith, M.P., Bolhuis, H., 2017b. Summer microbial community composition governed by upper-ocean stratification and nutrient availability in northern Marguerite Bay, Antarctica. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 139, 151-166.

Ruck, K.E., Steinberg, D.K., Canuel, E.A., 2014. Regional differences in quality of krill and fish as prey along the Western Antarctic Peninsula. *Marine Ecology Progress Series*, 509, 39-55.

Ruiz-Halpern, S., Duarte, C.M., Tovar-Sanchez, A., Pastor, M., Horstkotte, B., Lasternas, S., Agusti, S., 2011. Antarctic krill as a source of dissolved organic carbon to the Antarctic ecosystem. *Limnology and Oceanography*, 56, 521-528.

Ruiz-Halpern, S., Calleja, M.L., Dachs, J., Del Vento, S., Pastor, M., Palmer, M., Agusti, S., Duarte, C.M., 2014. Ocean-atmosphere exchange of organic carbon and CO2 surrounding the Antarctic Peninsula. *Biogeosciences*, 11, 2755-2770.

Saba, G.K., Fraser, W.R., Saba, V.S., Iannuzzi, R.A., Coleman, K.E., Doney, S.C., Ducklow, H.W., Martinson, D.G., Miles, T.N., Patterson-Fraser, D.L., Stammerjohn, S.E., Steinberg, D.K., Schofield, O.M., 2014. Winter and spring controls on the summer food web of the coastal West Antarctic Peninsula. *Nature Communications*, 5.

Saba, G.K., Schofield, O., Torres, J.J., Ombres, E.H., Steinberg, D.K., 2012. Increased Feeding and Nutrient Excretion of Adult Antarctic Krill, Euphausia superba, Exposed to Enhanced Carbon Dioxide (CO2). *Plos One*, 7.

Sahade, R., Tatian, M., Kowalke, J., Kuhne, S., Esnal, G.B., 1998. Benthic faunal associations on soft substrates at Potter Cove, King George Island, Antarctica. *Polar Biology*, 19, 85-91.

Sahade, R., Lagger, C., Torre, L., Momo, F., Monien, P., Schloss, I., Barnes, D.K.A., Servetto, N., Tarantelli, S., Tatian, M., Zamboni, N., Abele, D., 2015. Climate change and glacier retreat drive shifts in an Antarctic benthic ecosystem. *Science Advances*, 1.

Sailley, S.F., Ducklow, H.W., Moeller, H.V., Fraser, W.R., Schofield, O.M., Steinberg, D.K., Garzio, L.M., Doney, S.C., 2013. Carbon fluxes and pelagic ecosystem dynamics near two western Antarctic Peninsula Adelie penguin colonies: an inverse model approach. *Marine Ecology Progress Series*, 492, 253-272.

Saiz-Lopez, A., Blaszczak-Boxe, C.S., Carpenter, L.J., 2015. A mechanism for biologically induced iodine emissions from sea ice. *Atmospheric Chemistry and Physics*, 15, 9731-9746.

Saiz-Lopez, A., Plane, J.M.C., Mahajan, A.S., Anderson, P.S., Bauguitte, S.J.B., Jones, A.E., Roscoe, H.K., Salmon, R.A., Bloss, W.J., Lee, J.D., Heard, D.E., 2008. On the vertical distribution of boundary layer halogens over coastal Antarctica: implications for O-3, HOx, NOx and the Hg lifetime. *Atmospheric Chemistry and Physics*, 8, 887-900.

Saiz-Lopez, A., von Glasow, R., 2012. Reactive halogen chemistry in the troposphere. *Chemical Society Reviews*, 41, 6448-6472.

Sangra, P., Gordo, C., Hernandez-Arencibia, M., Marrero-Diaz, A., Rodriguez-Santana, A., Stegner, A., Martinez-Marrero, A., Pelegri, J.L., Pichon, T., 2011. The Bransfield current system. *Deep-Sea Research Part I-Oceanographic Research Papers*, 58, 390-402.

Savidge, D.K., Amft, J.A., 2009. Circulation on the West Antarctic Peninsula derived from 6 years of shipboard ADCP transects. *Deep-Sea Research Part I-Oceanographic Research Papers*, 56, 1633-1655.

Scheffer, A., Trathan, P.N., Collins, M., 2010. Foraging behaviour of King Penguins (Aptenodytes patagonicus) in relation to predictable mesoscale oceanographic features in the Polar Front Zone to the north of South Georgia. *Progress in Oceanography*, 86, 232-245.

Schloss, I.R., Abele, D., Moreau, S., Demers, S., Bers, A.V., Gonzalez, O., Ferreyra, G.A., 2012. Response of phytoplankton dynamics to 19-year (1991-2009) climate trends in Potter Cove (Antarctica). *Journal of Marine Systems*, 92, 53-66.

Schloss, I.R., Ferreyra, G.A., Ruiz-Pino, D., 2002. Phytoplankton biomass in Antarctic shelf zones: a conceptual model based on Potter Cove, King George Island. *Journal of Marine Systems*, 36, 129-143.

Schloss, I.R., Kloser, H., Ferreyram, G.A., Mecuri, G., Pinola, E., 1997. Factors governing phytoplankton and particulate matter variation in Potter Cove, King George Island, Antarctica. *Antarctic Communities*, 135-141.

Schloss, I.R., Wasilowska, A., Dumont, D., Almandoz, G.O., Hernando, M.P., Michaud-Tremblay, C.A., Saravia, L., Rzepecki, M., Monien, P., Monien, D., Kopczynska, E.E., Bers, A.V., Ferreyra, G.A., 2014. On the phytoplankton bloom in coastal waters of southern King George Island (Antarctica) in January 2010: An exceptional feature? *Limnology and Oceanography*, 59, 195-210.

Schmidt, K., Atkinson, A., Steigenberger, S., Fielding, S., Lindsay, M.C.M., Pond, D.W., Tarling, G.A., Klevjer, T.A., Allen, C.S., Nicol, S., Achterberg, E.P., 2011. Seabed foraging by Antarctic krill: Implications for stock assessment, bentho-pelagic coupling, and the vertical transfer of iron. *Limnology and Oceanography*, 56, 1411-1428.

Schmidt, K., Schlosser, C., Atkinson, A., Fielding, S., Venables, H.J., Waluda, C.M., Achterberg, E.P., 2016. Zooplankton Gut Passage Mobilizes Lithogenic Iron for Ocean Productivity. *Current Biology*, 26, 2667-2673.

Schmidtko, S., Heywood, K.J., Thompson, A.F., Aoki, S., 2014. Multidecadal warming of Antarctic waters. *Science*, 346, 1227-1231.

Schofield, O., Jones, C., Kohut, J., Kremer, U., Miles, T., Saba, G., Webb, D., Glenn, S., 2015. Developing Coordinated Communities of Autonomous Gliders for Sampling Coastal Ecosystems. *Marine Technology Society Journal*, 49, 9-16.

Schofield, O., Saba, G., Coleman, K., Carvalho, F., Couto, N., Ducklow, H., Finkel, Z., Irwin, A., Kahl, A., Miles, T., Montes-Hugo, M., Stammerjohn, S., Waite, N., 2017. Decadal variability in coastal phytoplankton community composition in a changing West Antarctic Peninsula. *Deep-Sea Research Part I-Oceanographic Research Papers*, 124, 42-54.

Schram, J.B., Amsler, M.O., Amsler, C.D., Schoenrock, K.M., McClintock, J.B., Angus, R.A., 2016. Antarctic crustacean grazer assemblages exhibit resistance following exposure to decreased pH. PANGAEA.

Selz, V., Lowry, K.E., Lewis, K.M., Joy-Warren, H.L., van de Poll, W., Nirmel, S., Tong, A., Arrigo, K.R., 2018. Distribution of Phaeocystis antarctica-dominated sea ice algal communities and their potential to seed phytoplankton across the western Antarctic Peninsula in spring. *Marine Ecology Progress Series*, 586, 91-112.

Shen, Y., Benner, R., Murray, A.E., Gimpel, C., Mitchell, B.G., Weiss, E.L., Reiss, C., 2017. Bioavailable dissolved organic matter and biological hot spots during austral winter in Antarctic waters. *Journal of Geophysical Research-Oceans*, 122, 508-520.

Sherman, J., Davis, R.E., Owens, W.B., Valdes, J., 2001. The autonomous underwater glider "spray". *Ieee Journal of Oceanic Engineering*, 26, 437-446.

Sherrell, R.M., Annett, A.L., Fitzsimmons, J.N., Roccanova, V.J., Meredith, M.P., 2018. A'shallow bathtub ring'of local sedimentary iron input maintains the Palmer Deep biological hotspot on the West Antarctic Peninsula shelf. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*, 376.

Signori, C.N., Thomas, F., Enrich-Prast, A., Pollery, R.C.G., Sievert, S.M., 2014. Microbial diversity and community structure across environmental gradients in Bransfield Strait Western Antarctic Peninsula. *Frontiers in Microbiology*, 5.

Siniff, D.B., Garrott, R.A., Rotella, J.J., Fraser, W.R., Ainley, D.G., 2008. Opinion Projecting the effects of environmental change on Antarctic seals. *Antarctic Science*, 20, 425-435.

Smale, D.A., Brown, K.M., Barnes, D.K.A., Fraser, K.P.P., Clarke, A., 2008. Ice scour disturbance in Antarctic waters. *Science*, 321, 371-371.

Smith, C.R., DeMaster, D.J., Thomas, C., Srsen, P., Grange, L., Evrard, V., DeLeo, F., 2012. Pelagic-Benthic Coupling, Food Banks, and Climate Change on the West Antarctic Peninsula Shelf. *Oceanography*, 25, 188-201.

Smith, R.C., Martinson, D.G., Stammerjohn, S.E., Iannuzzi, R.A., Ireson, K., 2008. Bellingshausen and western Antarctic Peninsula region: Pigment biomass and sea-ice spatial/temporal distributions and interannual variabilty. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 55, 1949-1963.

Smith, R.C., Stammerjohn, S.E., 2001. Variations of surface air temperature and sea-ice extent in the western Antarctic Peninsula region. *Annals of Glaciology, Vol 33*, 33, 493-500.

Sobrino, C., Ward, M.L., Neale, P.J., 2008. Acclimation to elevated carbon dioxide and ultraviolet radiation in the diatom Thalassiosira pseudonana: Effects on growth, photosynthesis, and spectral sensitivity of photoinhibition. *Limnology and Oceanography*, 53, 494-505.

Soreide, J.E., Leu, E., Berge, J., Graeve, M., Falk-Petersen, S., 2010. Timing of blooms, algal food quality and Calanus glacialis reproduction and growth in a changing Arctic. *Global Change Biology*, 16, 3154-3163.

Stammerjohn, S.E., Maksym, T., 2017. Gaining (and losing) Antarctic sea ice: variability, trends and mechanisms. In D.N. Thomas (Ed.), *Sea Ice* (pp. 261-289). Oxford, U.K.: Wiley-Blackwell.

Stammerjohn, S.E., Martinson, D.G., Smith, R.C., Yuan, X., Rind, D., 2008a. Trends in Antarctic annual sea ice retreat and advance and their relation to El Nino-Southern Oscillation and Southern Annular Mode variability. *Journal of Geophysical Research-Oceans*, 113.

Stammerjohn, S.E., Martinson, D.G., Smith, R.C., Iannuzzi, R.A., 2008b. Sea ice in the western Antarctic Peninsula region: Spatio-temporal variability from ecological and climate change perspectives. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 55, 2041-2058.

Stammerjohn, S.E., Massom, R., Rind, D., Martinson, D., 2012. Regions of rapid sea ice change: An inter-hemispheric seasonal comparison. *Geophysical Research Letters*, 39, L06501.

Statscewich, H., Weingartner, T., Danielsen, S., Grunau, B., Egan, G., Timm, J., 2011. A High-Latitude Modular Autonomous Power, Control, and Communication System for Application to High-Frequency Surface Current Mapping Radars. *Marine Technology Society Journal*, 45, 59-68.

Stefels, J., Steinke, M., Turner, S., Malin, G., Belviso, S., 2007. Environmental constraints on the production and removal of the climatically active gas dimethylsulphide (DMS) and implications for ecosystem modelling. *Biogeochemistry*, 83, 245-275.

Stefels, J., van Leeuwe, M.A., Jones, E.M., Meredith, M.P., Venables, H.J., Webb, A.L., Henley, S.F., 2018. Impact of sea-ice melt on dimethyl sulfide (sulfoniopropionate) inventories in surface waters of Marguerite Bay, West Antarctic Peninsula. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*, 376.

Steinberg, D.K., Landry, M.R., 2017. Zooplankton and the Ocean Carbon Cycle. *Annual Review of Marine Sciences, Vol 9*, 9, 413-444.

Steinberg, D.K., Ruck, K.E., Gleiber, M.R., Garzio, L.M., Cope, J.S., Bernard, K.S., Stammerjohn, S.E., Schofield, O.M.E., Quetin, L.B., Ross, R.M., 2015. Long-term (1993-2013) changes in macrozooplankton off the Western Antarctic Peninsula. *Deep-Sea Research Part I-Oceanographic Research Papers*, 101, 54-70.

Suckling, C.C., Clark, M.S., Richard, J., Morley, S.A., Thorne, M.A.S., Harper, E.M., Peck, L.S., 2015. Adult acclimation to combined temperature and pH stressors significantly enhances reproductive outcomes compared to short-term exposures. *Journal of Animal Ecology*, 84, 773-784.

Takahashi, T., Sutherland, S.C., Chipman, D.W., Goddard, J.G., Ho, C., Newberger, T., Sweeney, C., Munro, D.R., 2014. Climatological distributions of pH, pCO(2), total CO2, alkalinity, and CaCO3 saturation in the global surface ocean, and temporal changes at selected locations. *Marine Chemistry*, 164, 95-125.

Tison, J.L., Brabant, F., Dumont, I., Stefels, J., 2010. High-resolution dimethyl sulfide and dimethylsulfoniopropionate time series profiles in decaying summer first-year sea ice at Ice Station Polarstern, western Weddell Sea, Antarctica. *Journal of Geophysical Research-Biogeosciences*, 115.

Tolar, B.B., Ross, M.J., Wallsgrove, N.J., Liu, Q., Aluwihare, L.I., Popp, B.N., Hollibaugh, J.T., 2016. Contribution of ammonia oxidation to chemoautotrophy in Antarctic coastal waters. *Isme Journal*, 10, 2605-2619.

Toole, D.A., Siegel, D.A., 2004. Light-driven cycling of dimethylsulfide (DMS) in the Sargasso Sea: Closing the loop. *Geophysical Research Letters*, 31.

Torre, L., Tabares, P.C.C., Momo, F., Meyer, J.F.C.A., Sahade, R., 2017. Climate change effects on Antarctic benthos: a spatially explicit model approach. *Climatic Change*, 141, 733-746.

Tortell, P.D., Asher, E.C., Ducklow, H.W., Goldman, J.A.L., Dacey, J.W.H., Grzymski, J.J., Young, J.N., Kranz, S.A., Bernard, K.S., Morel, F.M.M., 2014. Metabolic balance of coastal Antarctic waters revealed by autonomous pCO2 and ΔO2/Ar measurements. *Geophysical Research Letters*, 41, 6803-6810.

Tortell, P.D., Payne, C.D., Li, Y.Y., Trimborn, S., Rost, B., Smith, W.O., Riesselman, C., Dunbar, R.B., Sedwick, P., DiTullio, G.R., 2008. CO(2) sensitivity of Southern Ocean phytoplankton. *Geophysical Research Letters*, 35.

Trathan, P.N., Fretwell, P.T., Stonehouse, B., 2011. First Recorded Loss of an Emperor Penguin Colony in the Recent Period of Antarctic Regional Warming: Implications for Other Colonies. *Plos One*, 6.

Treasure, A., Roquet, F., Ansorge, I., Bester, M., Boehme, L., Bornemann, H., Charrassin, J.-B., Chevallier, D., Costa, D., Fedak, M., Guinet, C., Hammill, M., Harcourt, R., Hindell, M., Kovacs, K., Lea, M.-A., Lovell, P., Lowther, A., Lydersen, C., McIntyre, T., McMahon, C., Muelbert, M., Nicholls, K., Picard, B., Reverdin, G., Trites, A., Williams, G., de Bruyn, P.J.N., 2017. Marine Mammals Exploring the Oceans Pole to Pole: A Review of the MEOP Consortium. *Oceanography*, 30, 132-138.

Trevena, A.J., Jones, G.B., 2006. Dimethylsulphide and dimethylsulphoniopropionate in Antarctic sea ice and their release during sea ice melting. *Marine Chemistry*, 98, 210-222.

Trivelpiece, W.Z., Buckelew, S., Reiss, C., Trivelpiece, S.G., 2007. The winter distribution of chinstrap penguins from two breeding sites in the South Shetland Islands of Antarctica. *Polar Biology*, 30, 1231-1237.

Trivelpiece, W.Z., Hinke, J.T., Miller, A.K., Reiss, C.S., Trivelpiece, S.G., Watters, G.M., 2011. Variability in krill biomass links harvesting and climate warming to penguin population changes in Antarctica. *Proceedings of the National Academy of Sciences of the United States of America*, 108, 7625-7628.

Turner, J., Comiso, J., 2017. Solve Antarctica's sea-ice puzzle. *Nature*, 547, 275-277.

Turner, J., Colwell, S.R., Harangozo, S., 1997. Variability of precipitation over the coastal western Antarctic Peninsula from synoptic observations. *Journal of Geophysical Research-Atmospheres*, 102, 13999-14007.

Turner, J., Lu, H., White, I., King, J.C., Phillips, T., Hosking, J.S., Bracegirdle, T.J., Marshall, G.J., Mulvaney, R., Deb, P., 2016. Absence of 21st century warming on Antarctic Peninsula consistent with natural variability. *Nature*, 535, 411-+.

Turner, J., Maksym, T., Phillips, T., Marshall, G.J., Meredith, M.P., 2013. The impact of changes in sea ice advance on the large winter warming on the western Antarctic Peninsula. *International Journal of Climatology*, 33, 852-861.

Tyson, R.B., Friedlaender, A.S., Nowacek, D.P., 2016. Does optimal foraging theory predict the foraging performance of a large air-breathing marine predator? *Animal Behaviour*, 116, 223-235.

Van Caspel, M., Hellmer, H.H., Mata, M.M., 2018. On the ventilation of Bransfield Strait deep basins. *Deep Sea Research Part II: Topical Studies in Oceanography*, 149, 25-30.

Vaque, D., Boras, J.A., Torrent-Llagostera, F., Agusti, S., Arrieta, J.M., Lara, E., Castillo, Y.M., Duarte, C.M., Sala, M.M., 2017. Viruses and Protists Induced-mortality of Prokaryotes around the Antarctic Peninsula during the Austral Summer. *Frontiers in Microbiology*, 8.

Varela, M., Fernandez, E., Serret, P., 2002. Size-fractionated phytoplankton biomass and primary production in the Gerlache and south Bransfield Straits (Antarctic Peninsula) in Austral summer 1995-1996. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 49, 749-768.

Vaughan, D.G., Marshall, G.J., Connolley, W.M., Parkinson, C., Mulvaney, R., Hodgson, D.A., King, J.C., Pudsey, C.J., Turner, J., 2003. Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change*, 60, 243-274.

Venables, H.J., Meredith, M.P., 2014. Feedbacks between ice cover, ocean stratification, and heat content in Ryder Bay, western Antarctic Peninsula. *Journal of Geophysical Research-Oceans*, 119, 5323-5336.

Venables, H.J., Clarke, A., Meredith, M.P., 2013. Wintertime controls on summer stratification and productivity at the western Antarctic Peninsula. *Limnology and Oceanography*, 58, 1035-1047.

Venables, H.J., Meredith, M.P., Brearley, J.A., 2017. Modification of deep waters in Marguerite Bay, western Antarctic Peninsula, caused by topographic overflows. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 139, 9-17.

Vernet, M., Martinson, D., Iannuzzi, R., Stammerjohn, S., Kozlowski, W., Sines, K., Smith, R., Garibotti, I., 2008. Primary production within the sea-ice zone west of the Antarctic Peninsula: I-Sea ice, summer mixed layer, and irradiance. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 55, 2068-2085.

von Glasow, R., Hughes, C., 2015. Bromine. In G.R.E.i.C. North, John Pyle and Fuquing Zhang (Editors) (Ed.), *Encyclopedia of Atmospheric Sciences, 2nd Edition*, Vol. 1 (pp. 194-200): Elsevier.

Warren, J.D., Santora, J.A., Demer, D.A., 2009. Submesoscale distribution of Antarctic krill and its avian and pinniped predators before and after a near gale. *Marine Biology*, 156, 479-491.

Watson, S.A., Morley, S.A., Peck, L.S., 2017. Latitudinal trends in shell production cost from the tropics to the poles. *Science Advances*, 3.

Webb, A.L., van Leeuwe, M.A., den Os, D., Meredith, M.P., Venables, H., Stefels, J., *in review*. Extreme spikes in DMS flux double estimates of biogenic sulfur export from the Antarctic coastal zone to the atmosphere. *Nature Scientific Reports*.

Webb, D.C., Simonetti, P.J., Jones, C.P., 2001. SLOCUM: An underwater glider propelled by environmental energy. *Ieee Journal of Oceanic Engineering*, 26, 447-452.

Weimerskirch, H., Louzao, M., de Grissac, S., Delord, K., 2012. Changes in Wind Pattern Alter Albatross Distribution and Life-History Traits. *Science*, 335, 211-214.

Weinstein, B.G., Double, M., Gales, N., Johnston, D.W., Friedlaender, A.S., 2017. Identifying overlap between humpback whale foraging grounds and the Antarctic krill fishery. *Biological Conservation*, 210, 184-191.

Weinstein, B.G., Friedlaender, A.S., 2017. Dynamic foraging of a top predator in a seasonal polar marine environment. *Oecologia*, 185, 427-435.

White, B.A., McClintock, J., Amsler, C.D., Mah, C.L., Amsler, M.O., White, S., Quetin, L.B., Ross, R.M., 2012. The abundance and distribution of echinoderms in nearshore hard-bottom habitats near Anvers Island, western Antarctic Peninsula. *Antarctic Science*, 24, 554-560.

Wiencke, C., Amsler, C.D., 2012. Seaweeds and their communities in polar regions. In C. Wiencke, K. Bischof (Eds.), *Seaweed Biology: Novel Insights into Ecophysiology, Ecology and Utilization* (pp. 265-294): Springer-Verlag.

Wilkins, D., van Sebille, E., Rintoul, S.R., Lauro, F.M., Cavicchioli, R., 2013. Advection shapes Southern Ocean microbial assemblages independent of distance and environment effects. *Nature Communications*, 4.

Williams, R., Kelly, N., Boebel, O., Friedlaender, A.S., Herr, H., Kock, K.H., Lehnert, L.S., Maksym, T., Roberts, J., Scheidat, M., Siebert, U., Brierley, A.S., 2014. Counting whales in a challenging, changing environment. *Scientific Reports*, 4.

Williams, T.J., Long, E., Evans, F., DeMaere, M.Z., Lauro, F.M., Raftery, M.J., Ducklow, H., Grzymski, J.J., Murray, A.E., Cavicchioli, R., 2012. A metaproteomic assessment of winter and summer bacterioplankton from Antarctic Peninsula coastal surface waters. *Isme Journal*, 6, 1883-1900.

Williams, T.J., Wilkins, D., Long, E., Evans, F., DeMaere, M.Z., Raftery, M.J., Cavicchioli, R., 2013. The role of planktonic Flavobacteria in processing algal organic matter in coastal East Antarctica revealed using metagenomics and metaproteomics. *Environmental Microbiology*, 15, 1302-1317.

Wing, S.R., McLeod, R.J., Leichter, J.J., Frew, R.D., Lamare, M.D., 2012. Sea ice microbial production supports Ross Sea benthic communities: influence of a small but stable subsidy. *Ecology*, 93, 314-323.

Wu, Y., Gao, K., Riebesell, U., 2010. CO2-induced seawater acidification affects physiological performance of the marine diatom Phaeodactylum tricornutum. *Biogeosciences*, 7, 2915-2923.

Yang, X., Pyle, J.A., Cox, R.A., 2008. Sea salt aerosol production and bromine release: Role of snow on sea ice. *Geophysical Research Letters*, 35.

Yang, X., Pyle, J.A., Cox, R.A., Theys, N., Van Roozendael, M., 2010. Snow-sourced bromine and its implications for polar tropospheric ozone. *Atmospheric Chemistry and Physics*, 10, 7763-7773.

Youngflesh, C., Jenouvrier, S., Li, Y., Ji, R., Ainley, D.G., Ballard, G., Barbraud, C., Delord, K., Dugger, K.M., Emmerson, L.M., Fraser, W.R., Hinke, J.T., Lyver, P.O., Olmastroni, S., Southwell, C.J., Trivelpiece, S.G., Trivelpiece, W.Z., Lynch, H.J., 2017. Circumpolar analysis of the Adelie Penguin reveals the importance of environmental variability in phenological mismatch. *Ecology*, 98, 940-951.

Zemmelink, H.J., Dacey, J.W.H., Houghton, L., Hintsa, E.J., Liss, P.S., 2008a. Dimethylsulfide emissions over the multi-year ice of the western Weddell Sea. *Geophysical Research Letters*, 35.

Zemmelink, H.J., Houghton, L., Dacey, J.W.H., Stefels, J., Koch, B.P., Schroder, M., Wisotzki, A., Scheltz, A., Thomas, D.N., Papadimitriou, S., Kennedy, H., Kuosa, H., Dittmar, T., 2008b. Stratification and the distribution of phytoplankton, nutrients, inorganic carbon, and sulfur in the surface waters of Weddell Sea leads. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 55, 988-999.

Zhou, M., Niiler, P.P., Hu, J.H., 2002. Surface currents in the Bransfield and Gerlache Straits, Antarctica. *Deep-Sea Research Part I-Oceanographic Research Papers*, 49, 267-280.

A Framework for Ocean Observing, 2012. By the Task Team for an Integrated Framework for Sustained Ocean Observing. *UNESCO 2012*, IOC/INF-1284.