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The Marine Ecosystem of the Sub-Antarctic, Prince Edward Islands

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1. Introduction

Straddled between the northern and southern boundaries of the Antarctic Circumpolar Current (ACC), Sub-antarctic islands are typically oceanic; experiencing moist, cool and windy climates. They are classified as regions, in which the terrestrial and marine ecosystems are relatively simple and extremely sensitive to perturbations. One such example are the Prince Edward Islands - the most southerly part of South Africa's official territory. The islands are located in the Indian sector of the Southern Ocean at approximately 46°50'S and 37°50'E (Figure 1). The nearest landfall is the Crozet Island Group 950 km to the east, while South Africa lies over 2 000 km northwest. The islands consist of Marion and Prince Edward Island (Figure 1 - insert), two volcanic outcrops approximately 250 000 years old, but still active. Marion Island covers an area of 270 km^2; whereas Prince Edward Island – 19 km to the north-east – is only about 45 km^2 in extent. The islands rise steeply from a region of complex bottom topography with a shallow saddle, between 40 and 200 m deep, separating Prince Edward from Marion Island. Intensive investigations carried out on the oceanic frontal systems south of Africa (Lutjeharms & Valentine, 1984; Duncombe Rae, 1989 a,b; Belkin & Gordon, 1996) have shown that the Prince Edward Islands lie directly in the path of the ACC, sandwiched between the Sub-antarctic Front (SAF) and the Antarctic Polar Front (APF). As such, these islands provide an ideal ecological laboratory for studying how shifts in atmospheric and oceanic circulation patterns in the Southern Ocean will increase the ease in which these islands, their ecosystems and their ocean surrounds can be invaded by alien species (Smith, 2002).

The Prince Edward Islands, like many other oceanic islands within the Southern Ocean, are seasonally characterised by vast populations of marine organisms and a diversity and abundance of seabirds that use the islands as breeding grounds (Bergstrom & Chown, 1999; Ryan & Bester, 2008). It is estimated that the islands support over 5 million breeding pairs of top predators including flying seabirds, penguins and seals during the peak in breeding season. The energy necessary to sustain these top predators is derived from the surrounding

marine environment. Changes in the marine ecosystem in response to global climate change are therefore, likely to dramatically influence the populations of top predators that seasonally occur on the islands (Ryan & Bester, 2008).

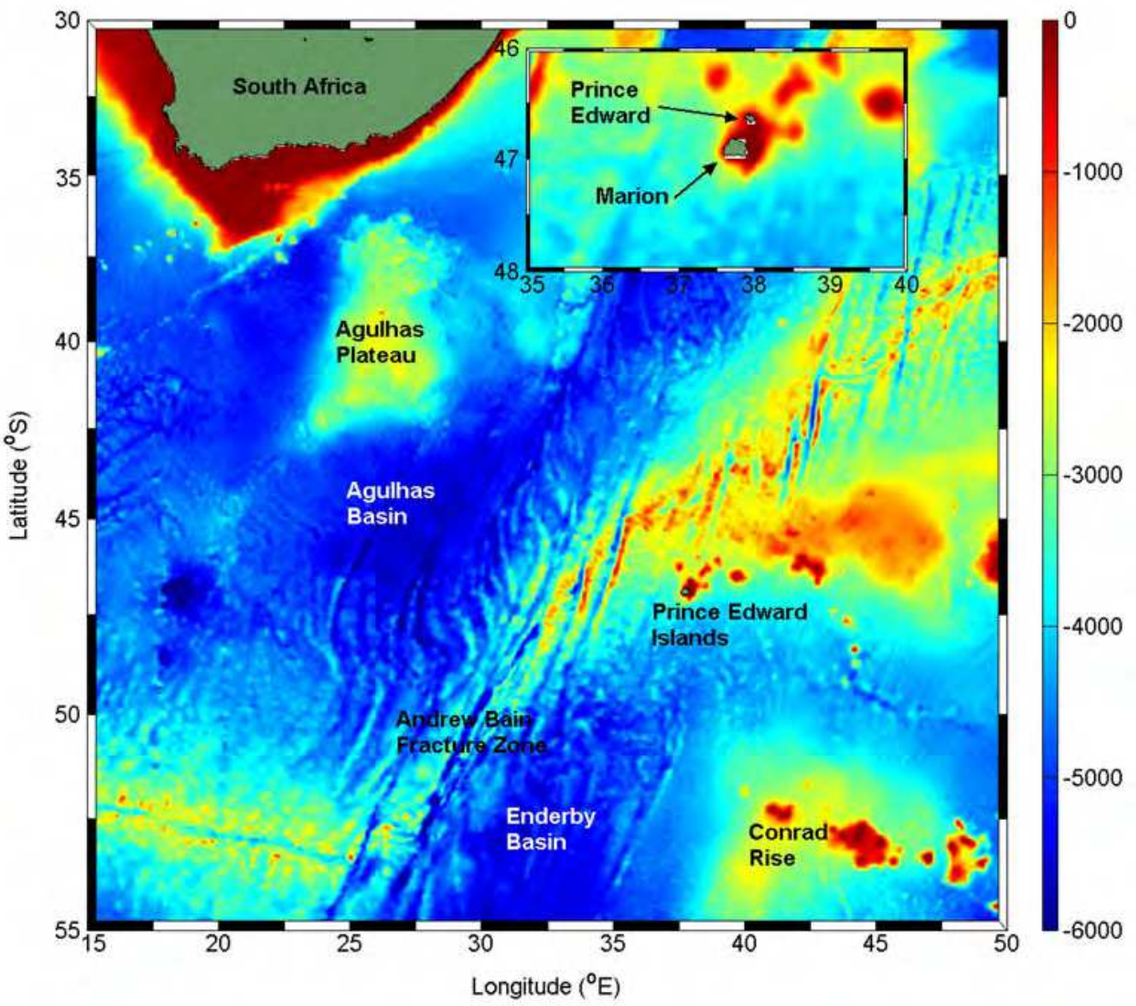


Fig. 1. Map showing the bathymetry for the south-west Indian Ocean from ETOPO2 data. Isobaths are in metres. The insert is a zoom-in of the Prince Edward and Marion Island group and the surrounding bathymetry.

1.1 Historical setting

The terrestrial nature of the islands - geological, biological and meteorological - has been studied since the South African government claimed sovereignty to them in 1947 and when Marion Island became host to a meteorological station. A detailed description of the history of the islands is presented in Cooper (2008). The oceanographic setting of the islands has received attention only since the late 1970s, when pioneering studies on the physical oceanography, primary productivity, plankton, fish and seabirds of the direct ocean environment were carried out by South African and French scientists aboard the French

research vessel *M.S. Marion Dufresne* (Cooper, 2008). The presence of over 5 million birds and seals on the islands raised important questions about their relationship to the physical environment. The nesting success of many birds is critically dependent on food availability suggesting that either the islands create their own enhanced biological ecosystem in their direct vicinity, the so-called 'island mass effect', (Doty & Oguri, 1956) or that biological productivity of the ambient waters is affected by changes in the oceanic environment through frontal dynamics such as eddy generation and meanders. Other suggestions supporting this island support system, through zooplankton species, that upwelling of deep Antarctic water, as a result of predominant north-westerly winds, is the primary mechanism responsible for high productivity in the vicinity of the islands. The upwelling of nutrients in this water would favour increased phytoplankton production. Indeed, Grindley and Lane (1979) reported the presence of a predominantly Antarctic copepod fauna in this region, confirming the presence of water of Antarctic origin during the period of the 1979 cruise. El-Sayed et al., (1979) and Deacon (1983) however, argued against this hypothesis on the basis of low silica concentrations in the surface waters. Miller (1984) suggested that frontal variability may cause foreign water masses from south of the APF to intrude into the vicinity of the Prince Edward Islands. These protrusions may then explain reported appearances of Antarctic planktonic species in what is usually considered a Sub-antarctic environment. There is now growing evidence that the geographical position of the SAF in the proximity of the Prince Edward Islands plays a key role in forming local macro- and mesoscale oceanographic conditions in the region of the islands (Ansorge & Lutjeharms, 2002; Pakhomov et al., 2000).

During the past 15 years as part of the South African National Antarctic Programme (SANAP), two intensive oceanographic programmes – Marion Island Oceanographic Study (MIOS) and Dynamics of Eddy Impacts on Marion's Ecosystem (DEIMEC) have been carried out to establish the nature of the physical and biological environment south of Africa and in particular the environment in which the Prince Edward Islands are embedded. Results indicate an unusually high degree of spatial and temporal variability for this region in contrast to comparable regions of the PFZ elsewhere in the Southern Ocean (Ansorge and Lutjeharms, 2002; Durgadoo et al., 2010). The dynamics associated with this variability have only recently been investigated and described.

2. Physical oceanographic setting

Results from numerous measurements ranging from early ships data (Sultan et al., 2007), numerical model studies (Gille, 1997; Sun & Watts, 2002), remote sensing (Sandwell & Zhang, 1989; Hughes & Ash, 2001), surface drifters (Harris & Stravopoulos, 1978; Hofmann et al., 1985) as well as recent profiling ARGO data (Sokolov & Rintoul, 2009) have shown that the mean eddy kinetic energy associated with the ACC is almost non-existent over the deep ocean basins where topographic constraint is weak. Instead, levels of mesoscale variability surge around prominent topographic features and choke points such as the Drake Passage (Joyce & Patterson, 1977), the Crozet and Kerguelen Plateaux (Gille, 2003) and south of Australia (Phillips & Rintoul, 2000). Past investigations (Park et al., 1997; Pollard & Read, 2001; Kostianoy et al., 2004) have shown that the South-West Indian sector is characterised by explicit regions of extremely high mesoscale variability (Figure 2). To the north, an enhanced band of variability corresponds to the confluence of the warm Agulhas Return Current (Lutjeharms & Ansorge, 2003) and the Subtropical Convergence (Boebel et

al., 2003) forming one of the strongest and fastest flowing (>1.5 ms^{-1}) frontal systems of the world ocean (Park et al., 1993). Directly south of this band, overlying the South-West Indian Ridge and immediately upstream of the Prince Edward Islands, is an isolated region of enhanced sea surface height (SSH) variability. This 'hotspot' seems to coincide with the southward deflection and intensification of the ACC at 30°E (Figure 3).

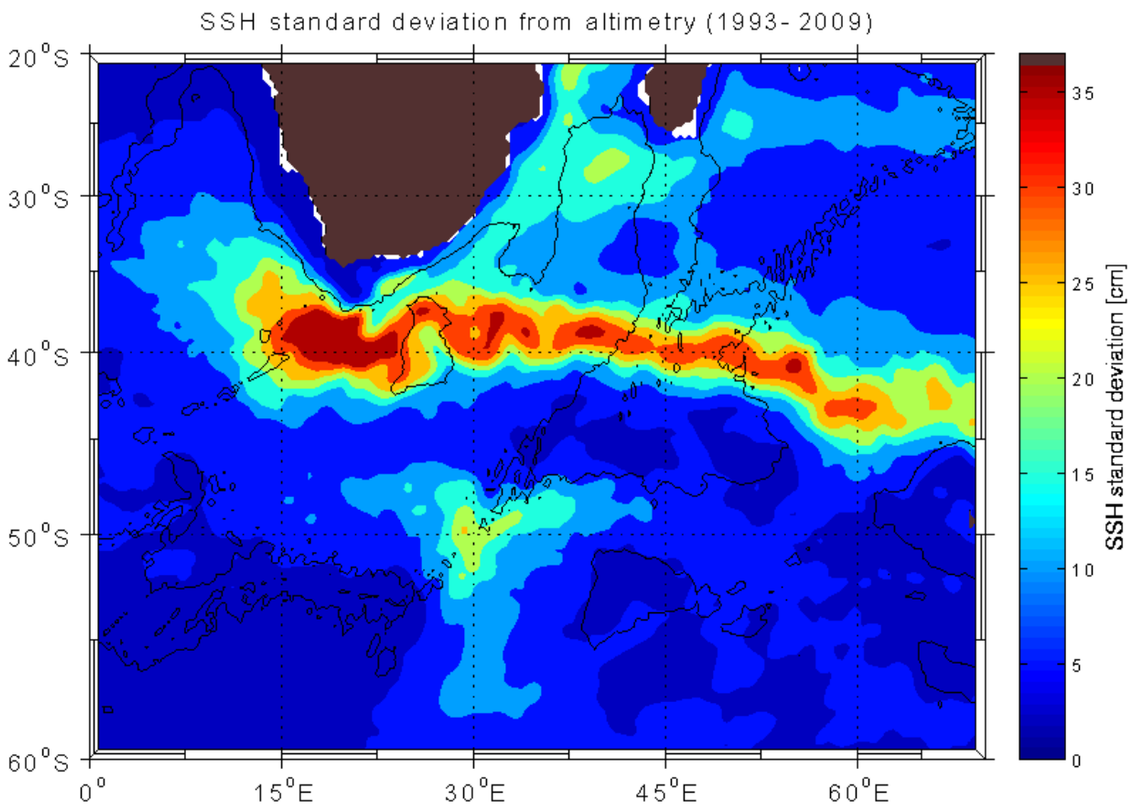


Fig. 2. Map showing the altimetry derived sea surface height variability for the south-west Indian Ocean. The isolated band of variability centred at 50˚S, 30˚E lies directly upstream of the Prince Edward Islands. *(courtesy Samuel Eberenz).*

Hydrographic data collected during the South-West Indian Ocean Experiment (SWINDEX) (Pollard & Read, 2001) have shown that the South-West Indian Ridge exerts a strong influence on the location and dynamics of the ACC and its associated fronts (Moore et al., 1999) resulting in substantial fragmentation of the jets downstream of the ridge. A recent examination of SST (Hughes & Ash, 2001) and SSH gradients (Sokolov & Rintoul, 2009) on either side of the South-West Indian Ridge provide an intricate examination of the ACC's multiple structure (Figure 3), confirming that the ACC narrows to a width of 5˚ of latitude as it is channelled through the ridge region. Downstream (i.e. east of 30˚E) there is a noticeable separation in the two branches of the ACC with the SAF topographically deflected north-eastwards (Belkin & Gordon 1996; Sultan et al., 2007), thus widening the Antarctic Polar Frontal Zone (APFZ) by up to 5˚ of latitude.

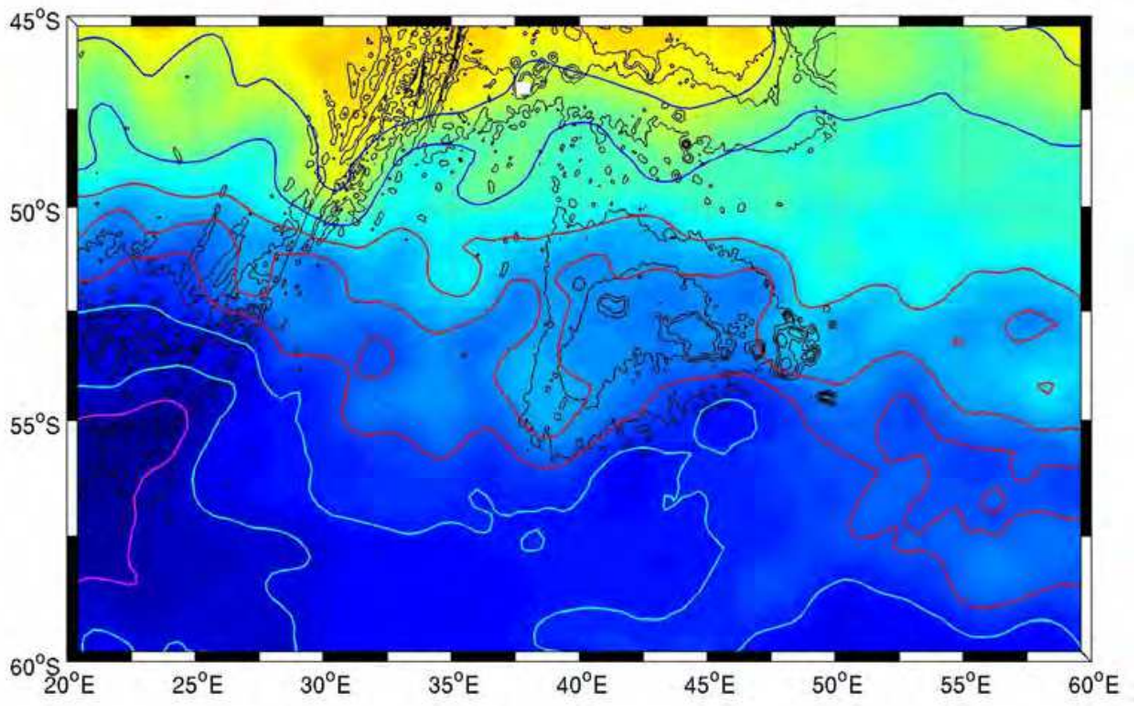


Fig. 3. Map showing the position of the frontal jets associated with the Sub-antarctic Front (blue), Antarctic Polar Front (red), Southern ACC Front (light blue) and Southern Boundary (pink). The positions have been defined from surface gradients obtained from altimetry data. The position of the Prince Edward Islands is denoted by the white square at approximately 47˚S, 38˚E. Isobaths are contoured at 1000 m intervals. *(courtesy Sebastiaan Swart)*

Extensive oceanographic surveys have shown that the Prince Edward Islands are sandwiched between the SAF to the north and the APF to the south (Ansorge & Lutjeharms, 2002). These fronts separate warm Sub-antarctic Surface Water (SASW) from cooler Antarctic Surface Water (AASW), with a zone of transition known as the Antarctic Polar Frontal Zone (APFZ) between the two. The SAF and APF have been shown to demonstrate a high degree of latitudinal variability in this region and it is thought that the complexity of the ACC in the vicinity of these islands (Ansorge & Lutjeharms, 2003) results in an increase in the interchange of Antarctic and Sub-antarctic surface and intermediate water masses (Deacon, 1983). Recent investigations have demonstrated conclusively that an extensive eddy train extends eastwards from the South-West Indian Ridge into the Prince Edward Island vicinity (Ansorge & Lutjeharms, 2003, 2005; Durgadoo et al., 2010, 2011). These eddies have a noticeable biological influence (Pakhomov et al., 2000; Bernard et al. 2007; Ansorge et al., 2010) by transporting physical and biological characteristics typical of the Antarctic northwards into the island vicinity (Figure 4) thus the possibility of providing an important foraging grounds for grey-headed albatrosses (Nel et al., 2001) and elephant seals (de Bruyn et al., 2009).

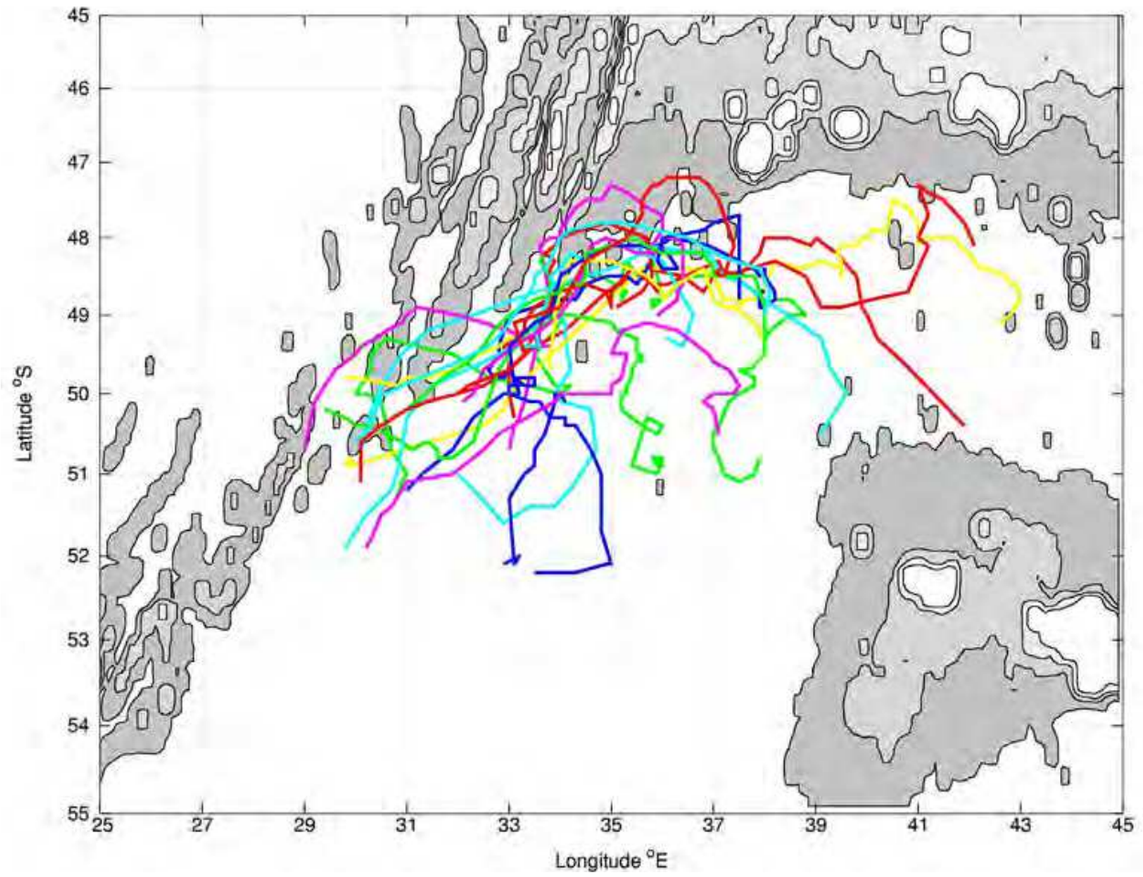


Fig. 4. Map showing the trajectories of 20 eddies tracked over 10 years from their point of generation at the South-west Indian Ridge north-eastwards towards the Prince Edward Island vicinity. Magnitude of f/h contours are shown (0.1 - 0.4 rad/s.m) at 0.1 rad/s.m intervals (Durgadoo et al., 2011).

Based on the geographic distribution of these eddies it has been surmised that their origin is as a direct result of the interaction of the ACC with the South-West Indian Ridge and in particular the series of fractures; notably the Du Toit, Andrew Bain, Marion and Prince Edward, which intersect this ridge between 25° - 35°E and 45° - 55°S and divide the South-West Indian Ridge into two almost equally extensive sections (Sclater et al., 2005). The Andrew Bain Fracture Zone is the largest of these fracture zones with a length of 750 km, and the greatest width (120 km) of any transform fault in the oceans and extends to >6000 m (Fisher & Goodwillie, 1997). It is therefore, not surprising that the highest SSH levels observed in the region (Figure 2) correlate directly to the location of this particular fracture. The clear implication of these findings is that the Prince Edward Island region has an enhanced anomaly presence not so much because of the interaction of the flow with the islands themselves, as has been inferred previously but as a consequence of the fact that they are situated at the north-eastern border of a region of unusually high mesoscale variability in the Southern Ocean (Durgadoo et al., 2010). What effect does this zone of variability – through the generation of transient eddies or latitudinal shifts in the APFZ - have on forming the macro- and mesoscale oceanographic environment of the islands themselves?

3. Biology of the island ecosystem

3.1 Phytoplankton studies

Macronutrient concentrations in the open waters of the APFZ are moderate to low with surface silicate, nitrate and phosphate concentrations ranging from 0.2 to 16.5 mmol m^{-3}, from 9.5 to 97.5 mmol m^{-3} and from 0.1 to 16.6 mmol m^{-3}, respectively (Allanson *et al*. 1985; Balarin, 2000). Shifts in the surface macronutrient concentrations within the open waters of the region generally coincide with the intrusion of warmer Sub-antarctic waters from the north and cooler Antarctic waters from the south. Additionally, eddies generated by the interaction of the ACC with the South-West Indian Ridge may locally also contribute to the spatial and temporal variations in suface concentrations of macronutrients in the open waters of the APFZ.

The total phytoplankton biomass and production within the APFZ is generally < 2.0mg chl-a m^{-3} <300 mg C m^{-2} d^{-1}, and is dominated by small the nano- (2-20µm) and picophytoplankton (< 2.0µm) size fractions (Table 1) (Balarin, 2000; Bernard & Froneman, 2005; McQuaid & Froneman, 2008). The low phytoplankton stocks recorded in the open waters can be attributed to low phytoplankton growth rates conferred by the high wind activity which contributes to deep water mixing (Balarin, 2000). The small nano- and picophytoplankton are better adapted to persist in poor light environments and low macronutrient waters. The contribution of the smaller phytoplankton size classes to the total phytoplankton biomass and production is generally > 90% (Balarin, 2000). Notable exceptions are recorded in the vicinity of the frontal systems that delimit the APFZ which demonstrate increased phytoplankton concentrations (Balarin, 2000; McQuaid & Froneman, 2008). The elevated phytoplankton stocks in the vicinity of the fronts reflect the increased contribution of the larger microphytoplankton (>20µm, mainly diatoms) to the total phytoplankton production and biomass. The shallow shelf waters of the Prince Edward Islands also periodically demonstrate the, 'island mass effect' of increased phytoplankton concentrations (Pakhomov & Froneman, 1999). Here, the phytoplankton biomass and productivity may exceed that of the open waters by 2-3 times (Pakhomov & Froneman, 1999). The elevated phytoplankton stocks periodically recorded in the vicinity of the islands can be ascribed to increased water column stability, macronutrient and trace metal (Fe) concentrations derived from the freshwater runoff from the islands, which are retained on the shallow shelf waters of the islands by anti-cyclonic eddies of the Taylor Cone type (Perrissinotto & Duncombe Rae, 1990). The combination of water column stability and increased macronutrient concentrations generate phytoplankton blooms dominated by large chain forming diatom species, particularly of the genera *Chaetoceros* and *Fragilariopsis*. The presence of the anti-cyclonic eddies in the immediate vicinity of the islands is linked to the geographic position of the SAF (Ansorge et al., 2009). When the SAF lies far to the north of the Prince Edward Islands, current speeds of the ACC are comparatively low resulting in a weak interaction between the islands and the prevailing current (Ansorge & Lutjeharms, 2002). Under these conditions, frictional forces dominate over advective forces resulting in the formation of eddies. Conversely, when the front lies in close proximity of the islands, advective forces prevail resulting in the islands acting as a flow through system. Under these conditions, phytoplankton stocks in the vicinity of the islands are in the range found in the open waters of the APFZ. There are virtually no seasonal studies on phytoplankton biomass and productivity in the region of the Prince Edward Islands (Table 1). It is worth

noting that estimates of total phytoplankton concentration and productivity in APFZ in the other sectors of the Southern Ocean during summer are typically 1-2 times higher than the values recorded in the region of the islands during winter (Laubscher et al., 1993). This would suggest a strong seasonal pattern in the phytoplankton biomass and productivity in the APFZ.

Source	Season	Region	Phytoplankton biomass (mg chl-a m^{-3})	Phytoplankton production (mg C m^{-2} d^{-1})
El-Sayed et al. (1979)	Autumn	Inter-island region	0.09-1.88	211
Allanson et al. (1985)	Autumn	Inter-island region	0.06-0.87	84-2100
Allanson et al. (1985)	Spring	Inter-island region	0.06-0.87	ND
Perissinotto & Duncombe Rae (1990)	Autumn	Inter-island region	0.10-2.80	70-3000
Balarin (2000)	Autumn	Inter-island region	0.20-0.81	119-353
Bernard & Froneman (2005)	Autumn	Open waters	0.15-0.28	ND
Froneman & Balarin (1998)	Autumn	Open waters	0.29-0.52	ND
Bernard (2006)	Autumn	Inter-island region	0.24-0.71	ND
Allan (2011)	Autumn	Inter-island region	0.13-0.29	ND

Table 1. Estimates of total chlorophyll-a concentration and primary production in the open waters and inter-island region of the Prince Edward Islands. ND = no data.

3.2 Zooplankton studies

The zooplankton community structure (>200μm) within the open waters of the APFZ has been described on several occasions. Results of these studies indicate that there is no endemism among the holoplankton of the APFZ and that the region demonstrates extreme variability in the zooplankton species composition (Pakhomov & Froneman, 1999; McQuaid & Froneman, 2008). The variability in the zooplankton can be ascribed to the mesoscale variability in the oceanographic environment including cross frontal mixing, the intrusion of tongues of warm Subtropical water to the north and of cold Antarctic surface water to the south (Bernard & Froneman, 2002; 2003). Additionally, the formation of warm and cold eddies generated by the interaction of the ACC with the South-West Indian Ridge may also contribute to the transport of species from different water masses into the APFZ waters (Bernard et al., 2007). The extreme variability in the oceanographic environment within the APFZ contributes to the zooplankton comprising species with different biogeographic affinities including species which are Subtropical, Sub-antarctic and Antarctic in origin (Bernard & Froneman 2002; 2003; Hunt et al., 2001; McQuaid & Froneman, 2008).

The zooplankton community structure within the APFZ is numerically dominated by mesozooplankton (200-2000µm) comprising mainly copepods (*Oithona, Calanus* and *Metridia* spp.), pteropods (mainly *Limacina retroversa*), amphipods (*Themisto gaudichaudi*) and chaetognaths (*Eukrohnia hamata* and *Sagitta gazellae* (Pakhomov & Froneman, 1999; McQuaid & Froneman, 2008). Estimates of the contribution of the mesozooplankton to the total zooplankton abundance are highly variable and range from 52-88% of the total. The larger macrozooplankton (> 2000µm) may, however, contribute substantially to the total zooplankton biomass within the region (up to 45% of the total) although their contribution to the total zooplankton counts is generally < 15%. Among the macrozooplankton, the most important groups by numbers are the euphuasiids (*Euphausia vallentini*, *Nematoscelis megalopes* and *Thysanoessa* spp.), chaetognaths (*Sagitta gazellae* and *S. maxima*) and tunicates (*Salpa thompsonii*). The contribution of these groups to the total macrozooplankton counts typically demonstrates a high degree of both temporal and spatial variability reflecting the variable oceanographic environment of the APFZ.

Estimates of the total zooplankton abundance and biomass in the region of the Prince Edward Islands are highly variable, and range between 5 and 4850 ind m^{-3} and between 0.6 and 62.7 mg dwt m^{-3}, respectively (Table 2) (McQuaid & Froneman, 2008). Although there are no clear spatial patterns evident in the total zooplankton abundance and biomass within the APFZ, the frontal systems that delimit the APFZ, the SAF to the north, and the APF to the south, typically demonstrate increased zooplankton numbers which can attributed to the increased contribution of the larger macrozooplankton to the total zooplankton biomass (Pakhomov & Froneman, 1999; McQuaid & Froneman, 2008). Additionally, there is some evidence in the literature to suggest that the periodic intrusion of colder Antarctic Surface Waters in the APFZ is associated with elevated zooplankton abundances and biomass values (McQuaid & Froneman, 2008). There are currently limited seasonal data available on the zooplankton community structure available in the region of the Prince Edward Islands. It is worth noting, however, that the estimates of the total zooplankton abundance and biomass within the APFZ water during autumn are nearly an order of magnitude lower that estimates obtained in the APFZ in other sectors of the Southern Ocean during summer. This would suggest a strong seasonal pattern in the total zooplankton abundance and biomass within the region. Nonetheless, the zooplankton species composition appears, however, to be broadly similar between the different seasons.

Source	**Season**	**Abundance (ind.m^{-3})**	**Biomass (mg Dwt m^{-3})**
Grindley & Lane (1979)	Autumn	400-4850	8.7-28.4
Grindley & Lane (1979)	Spring	1575-1854	14.6-34.9
Boden & Parker (1986)	Autumn	22-594	12.9-53.0
Froneman et al. (1998)	Autumn	5-263	0.6-15.7
Ansorge et al. (1999)	Autumn	10-312	2.47-62.70
Bernard & Froneman (2002)	Autumn	49-1512	0.7-25.0
Bernard & Froneman (2003)	Autumn	78-1034	9.8-27.9
Bernard (2006)	Autumn	230-1004	ND

Table 2. Estimates of the total zooplankton abundance and biomass in the open waters of the Polar Frontal Zone and in vicinity of the Prince Edward Islands. ND = no data presented.

3.3 Nekton studies

Only a few nekton studies have been conducted in the region of the Prince Edward Islands. Results of these investigations suggest that the total nekton abundance and biomass in the region are generally low, < 2 ind $1000m^{-3}$ and < 0.1 mg dwt $1000m^{-3}$ (McQuaid & Froneman, 2008). It should be noted, however, that these studies have largely employed sampling gear that would likely underestimate the nekton abundances and biomass values. There appear to be no significant spatial patterns in the nekton abundance and biomass evident although values in the region of the fronts tend to be higher than those in the open waters.

4. Benthic community studies

The shallow waters of the Prince Edward Islands support a diverse (up to 550 species) and biomass rich benthic community which are numerically and by biomass dominated by suspension-feeders comprising mainly polychaetes, bivalves and brachiopods (Branch et al., 1993). The benthic community is thought to be sustained by the mass sedimentation of phytoplankton cells generated by the 'island mass effect' (Perissinotto & McQuaid, 1990; Pakhomov & Froneman, 1999; Allan, 2011). Locally, the kelp, *Durvillea antarctica*, also appears to contribute to the supply of food to the benthic community of the islands (Kaehler et al., 2006; Allan, 2011). A key component of the benthic community is the caridian shrimp, *Nauticaris marionis*, which represents the second most abundant component of the benthos in the vicinity of the islands (Branch et al., 1993). The sub-adults and adult consume mainly benthic and suspension feeders while their larvae feed mainly on phytoplankton (Vumazonke et al., 2003; Allan, 2011). The adult shrimp represent a key component in the diets of a number of top predators, including penguins and flying seabirds, found on the islands and thus serve as a link between the plankton, benthos and land- based predators (Perissinotto & McQuaid, 1990)

5. Terrestrial-marine interactions

The energy necessary to sustain the large numbers of top predators found seasonally on the islands is obtained from both allochthonous and autochthonous sources. The allocthonous source is derived from the advection of zooplankton and nekton towards the islands via the easterly flowing ACC (Pakhomov & Froneman, 1999). The zooplankton and nekton trapped in the shallow island shelf waters are vulnerable to predation by the top predators during the daytime. The depleted stocks are subsequently replenished during the night-time. This mechanism has been termed 'The replenishing hypothesis' by McQuaid and Froneman (2008). The periodic development of dense phytoplankton bloom associated with the so called, 'island mass effect' which sustains the benthic rich community within the shallow shelf waters of the Prince Edward Islands represents the main autochthonous source of energy necessary to sustain the top predators on the islands. Collectively, these two food delivery mechanisms are termed, "*the life support system of the Prince Edward Islands*" (Pakhomov & Froneman, 1999; McQuaid & Froneman, 2008). It is now well understood that the geographical position of the SAF in the proximity of the Prince Edward Islands plays a crucial role in forming local macro- and mesoscale oceanographic conditions (Pakhomov et al., 2000, Ansorge & Lutjeharms, 2002) and that any changes in its position may have dire consequences to the functioning of the island's "*life support system*".

6. Global climate change and the Prince Edward Island ecosystem

Recent studies have shown that since the 1950's, the ACC has strengthened and migrated southwards by 50–70 km (Gille, 2002). Changes in the intensity and geographic position within these frontal systems are likely to coincide with dramatic changes in the distribution of species and total productivity within the Southern Ocean and in particular at the Prince Edward Islands. The impact a southward migration of the ACC will have on the Prince Edward Islands ecosystem over the next century is indeed complex. It has been suggested (Ansorge et al., 2009) that shifts in the ACC may alter the intensity and frequency of eddies spawned at the South-West Indian Ridge while closer to the islands a more southern position of the SAF may result in an increase in the through-flow regime as can be seen from recent investigations (Pakhomov & Chown, 2003; Ansorge et al., 2009). Physical data further confirm that the mean sea surface temperatures at the Prince Edward Islands have increased by >1°C over the past 60 years (Melice et al., 2003). Mirroring this is a decrease of nearly 500 mm in precipitation, an increase of over 200 hours in sunshine and an increase in winds from the warmer sector in the north-west (Melice et al., 2003). The warming of the surface waters in the region of the islands has been coupled with an elevated contribution of warmer Subtropical Zone zooplankton species to the total zooplankton counts over the last three decades (Figure 5). A recent review of their composition around the Prince Edward Islands indicates that over the past two decades the contribution of Antarctic species decreased by ~20%, whereas the number of subtropical species found in the areas had increased from 6% to 26% (Ansorge et al., 2009). This is also supported by the incidental catches of subtropical fish species during the long-line fishery in the proximity of these

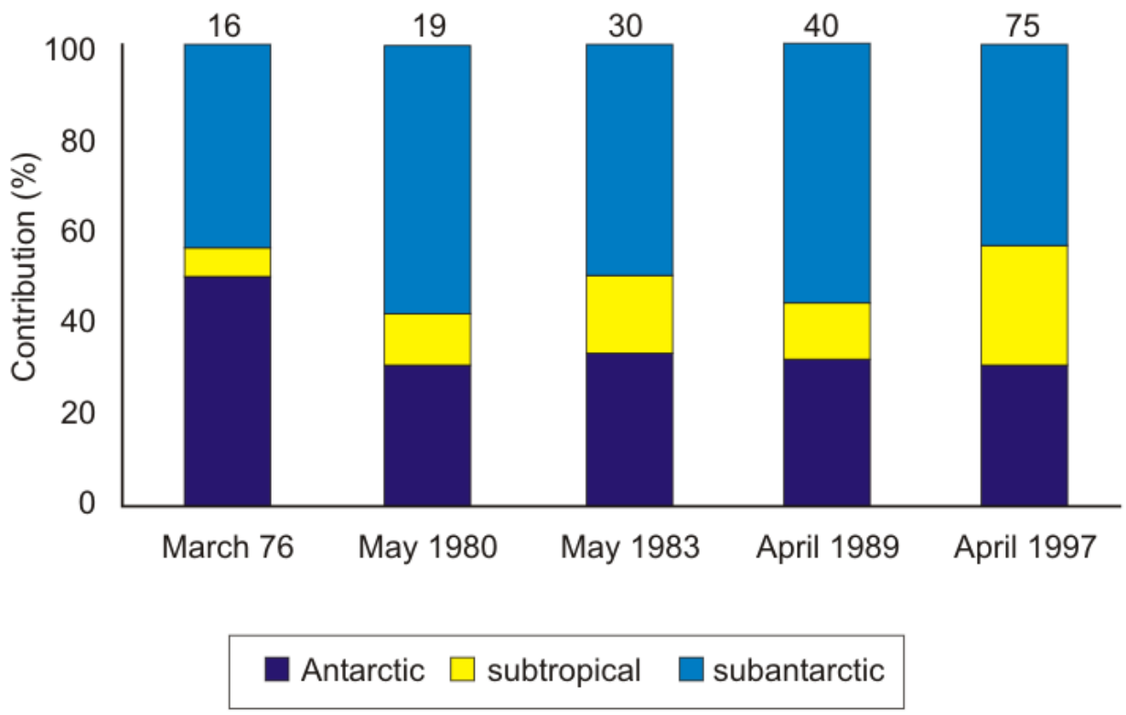


Fig. 5. Long-term changes in the composition of zooplankton species in the vicinity of the Prince Edward Islands since March 1976 (modified from Pakhomov et al., 2000).

islands. Although short-term variability and eddy transport cannot be completely discounted, it may be postulated that warmer water species have intruded into the APFZ more frequently during the past decades (Pakhomov et al., 2004). The most direct effect of a meridional shift in the SAF can be seen from changes within the species composition of the zooplankton.

Most recently, Allan (2011) demonstrated that the isotope ratios (carbon and nitrogen) of the numerically dominant suspension feeders of benthos and the caridian shrimp, *N. marionis*, have become significantly depleted since the 1980's. The observed depletion in isotope signatures was linked to the increased contribution of allochthonous food sources in the diets of these organisms due to the decreased frequency of occurrence of the so called, "island mass effect" (Allan, 2011). Indeed, a decline in stable isotope carbon values of a bottom dwelling shrimp *Nauticaris marionis* tissue indirectly postulates a decrease in the occurrence of bloom conditions in the inter-island region between 1980s and 2000s (Pakhomov et al., 2004). Lastly, a decrease in chlorophyll concentrations near the islands since 1976 provide further support that a variation in the position of the SAF has occurred during the past 30 years (Pakhomov & Chown, 2003).

It is unclear whether this change is expected to continue and at what rate. However, studies using coupled ocean-atmosphere climate models suggest that the westerly wind belt, which drives the ACC, is intensifying (Oke & England, 2004) and shifting polewards (Large & Yeager, 2004) in response to global warming. This shift has been associated with a southward migration of the SAF towards the islands. The decreased contribution of autochthonous production in the diets of the benthos in the region of the islands is therefore, the result of large scale changes in the prevailing oceanographic conditions in the region of the islands in response to global warming. It is likely that global climate change may in the future become associated with the disruption of the "*Life support system of the Prince Edward Islands*"and further investigations are required to understand better what impact these changes will have on the system. Furthermore, the impact of this shift on the top predators found seasonally on the islands remains largely unknown. However, it is worth noting that the populations of top predators that feed predominantly in the vicinity of the islands have decreased over the past two decades, possibly as a result of decreased food availability (Ryan & Bester, 2008). This represents a fundamental shift in the balance between allochthonous and autochthonous trophic pathways within the system and confirms the vulnerability of marine ecosystems to changes in physical conditions. Importantly, this indicates that the more dramatic consequences of climate change may be indirect ones.

7. Acknowledgments

This chapter is dedicated to the memory of the late Professor Emeritus JRE Lutjeharms. Funds for this study were obtained from the University of Cape Town, Rhodes University and the South African National Antarctic Programme (SANAP).

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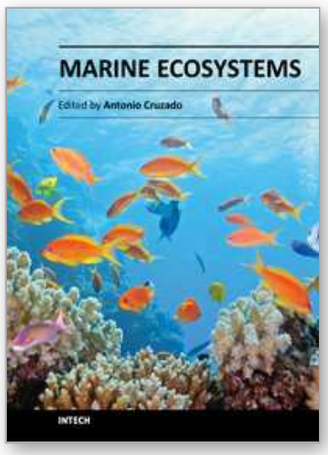
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Marine Ecosystems

Edited by Dr. Antonio Cruzado

ISBN 978-953-51-0176-5
Hard cover, 310 pages
Publisher InTech
Published online 02, March, 2012
Published in print edition March, 2012

Marine ecosystems, a very wide topic, includes many different processes, groups of organisms and geographical peculiarities. The objective of this book is to present various topics of great importance for understanding the marine ecosystems, what they are, how they work and how we can model them in order to forecast their behaviour under changing conditions. They have been thoroughly reviewed and accepted for publication. The chapters cover aspects such as: Threats to ultraoligotrophic marine ecosystems (Ch. 1); Modelling the pelagic ecosystem dynamics: the NW Mediterranean (Ch. 2); The marine ecosystem of the Sub-antarctic, Prince Edward Islands (Ch. 3); Meiofauna as a tool for marine ecosystem biomonitoring (Ch. 4); Chemical interactions in Antarctic marine benthic ecosystems (Ch. 5); An Interdisciplinary Approach on Erosion Mitigation for Coral Reef Protection- A Case Study from the Eastern Caribbean (Ch. 6); A revisit to the evolution and ecophysiology of the Labyrinthulomycetes (Ch. 7); Seabed mapping and marine spatial planning: a case-study from a Swedish marine protected area (Ch. 8); Management strategies to limit the impact of bottom trawling on VMEs in the High Seas of the SW Atlantic (Ch. 9); Hydrocarbon contamination and the swimming behavior of the estuarine copepod Eurytemora affinis (Ch. 10), and Interactions between marine ecosystems and tourism on the Adriatic and Mediterranean (Ch. 11).

How to reference

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I. J. Ansorge, P. W. Froneman and J. V. Durgadoo (2012). The Marine Ecosystem of the Sub-Antarctic, Prince Edward Islands, Marine Ecosystems, Dr. Antonio Cruzado (Ed.), ISBN: 978-953-51-0176-5, InTech, Available from: http://www.intechopen.com/books/marine-ecosystems/the-prince-edward-islands-a-subantarctic-ecosystem

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