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Seabird assemblages observed during the BROKE-West survey of the Antarctic coastline (30°E–80°E), January – March 2006

Eric J Woehler[a,b,*], Ben Raymond[a,c], Adrian Boyle[b], Andrew Stafford[b]

[a] Australian Antarctic Division, Channel Highway, Kingston, Tasmania 7050, Australia
[b] School of Zoology, University of Tasmania, Sandy Bay, Tasmania 7005, Australia
[c] Antarctic Climate & Ecosystem Cooperative Research Centre, University of Tasmania, GPO Box 252C-80 Hobart, Tasmania 7001, Australia

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ABSTRACT

Seabird surveys in January – March 2006 of a poorly known area of the Southern Ocean adjacent to the East Antarctic coast identified six seabird communities, several of which were comparable to seabird communities identified both in adjacent sectors of the Antarctic, and elsewhere in the Southern Ocean. These results support previous proposals that the Southern Ocean seabird community is characterised by an ice-associated assemblage and an open-water assemblage, with the species composition of the assemblages reflecting local (Antarctic-resident) breeding species, and the migratory routes and feeding areas of distant-breeding taxa, respectively. Physical environmental covariates such as sea-ice cover, distance to continental shelf and time of year influenced the distribution and abundance of seabirds observed, but the roles of these factors in the observed spatial and temporal patterns in seabird assemblages was confounded by the duration of the survey. Occurrence of a number of seabird taxa exhibited significant correlations with krill densities at one or two spatial scales, but only three taxa (Arctic tern, snow petrel and dark shearwaters, i.e. sooty and short-tailed shearwaters) showed significant correlations at a range of spatial scales. Dark shearwater abundances showed correlations with krill densities across the range of spatial scales examined.

1. Introduction

Abiotic and biotic oceanographic processes and their interactions influence the distribution and abundance of seabirds at sea in the Southern Ocean. Two seabird communities have been recognised around the Antarctic continent (Ribic and Ainley, 1988/89; Ainley et al., 1992, 1993). One, confined to the Antarctic pack-ice zone, is broadly similar around the Antarctic periphery, mediated by regional breeding species (Woehler et al., 2003), while the open-water community exhibits greater diversity and variability in its composition (Ainley et al., 1994; Woehler, 1995, 1997; Woehler et al., 2003, 2006 and references therein). Seabird community composition reflects the at-sea distributions and ranges of local breeding species, with surveys sampling within the foraging ranges of individuals. These individuals can originate either regionally in breeding colonies, or from more distant temperate localities. These abiotic and biotic oceanographic processes and their interactions influence individual species (e.g. Woehler et al., 2006) and seabird assemblages (Fraser and Ainley, 1986; Ainley et al., 1994; Raymond and Woehler, 2003; Woehler et al., 2003), at a range of spatial scales, from regional to ecosystem-level.

Relationships between Southern Ocean seabird distributions and their prey species are less well understood. Early studies (e.g., Griffiths et al., 1982; Hunt et al., 1990) investigated the relationship between Southern Ocean seabirds at sea with productivity and prey distributions. Studies integrating abiotic and biotic processes are rare (but see Ainley et al., 1986, 1991, 1992, 1993; Rau et al., 1992; Hopkins et al., 1993; Nicol et al., 2000).

This study investigated the distributions and abundances of seabirds at sea in a largely unsurveyed sector of the Southern Ocean adjacent to the Antarctic continent between 30°E and 80°E during January to March 2006. Many of the taxa reported in this paper breed during the summer, coincident with the survey. While some of the study area comprises Prydz Bay (60°E – 90°E), for which detailed analyses have been conducted (e.g., Woehler, 1995, 1997; Woehler et al., 2003), the area west of Prydz Bay has experienced little survey effort and the seabird community present in the area is largely undocumented (but see Griffiths et al., 1982; Ohyama and Naito, 1982; Ryan and Cooper, 1982b). This study also investigated the relationships among abiotic and biotic oceanographic parameters and the observed seabird community in this area, with the aim of comparing with similar studies eastward of the current study area (Woehler et al., 2003; Raymond and Woehler, 2003).

* Corresponding author at: School of Zoology, University of Tasmania, Sandy Bay, Tasmania 7005, Australia.
E-mail address: eric.woehler@utas.edu.au (E.J. Woehler).

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2. Methods

2.1. Seabirds at sea

Details of methodologies used to collect seabird at sea data and concomitant physical oceanographic and environmental data are described elsewhere (Woehler, 1995, 1997). Briefly, observations of the numbers and behaviours of all seabirds present within a 300-m forward quadrant of the ship were recorded continuously while the vessel was underway during daylight hours. Ship-followers were excluded from all analyses following BIOMASS Working Party on Bird Ecology (1982) as these individuals bias abundance estimates and reduce statistical correlations between seabirds and the physical environment (Hyrenbach, 2001 and references therein). Ship-followers typically associate with the vessel for extended periods, either following the vessel at the stern or circling the vessel, or both. Data for prions (*Pachyptila* spp.) and dark shearwaters (*Puffinus griseus* and *P. tenuirostris*) have been pooled as with previous analyses, as these are difficult to separate at sea (Woehler, 1997). All scientific names for seabirds observed in the survey are listed in Appendix 1.

2.2. Physical environment

Physical environmental data collected contemporaneously with seabird observations comprised sea surface temperature (°C), sea state (Beaufort), cloud cover (oktas), precipitation (precipitation types), wind force (Beaufort scale) and air pressure (hPa). Sea ice concentration from daily passive microwave satellite images (Cavalieri et al., 1990, updated 2007) were expressed as 10^{th}s cover. The 1000-m isobath (GEBCO Digital Atlas, British Oceanographic Data Centre 1994) was used to delineate the outer extent of the Antarctic continental shelf. The shelf break is usually considered to be at a depth of approximately 600 m, however, there were insufficient data for the 600 m isobath within the study area. Moreover, the shelf break front lies just seaward of the shelf break and is an important factor affecting bird occurrence (Ainley and Jacobs, 1981; Ainley et al., 1998). The locations of the Antarctic Polar Front (APF) and the Antarctic Divergence (AD, also referred to as the southern boundary of the Antarctic Circumpolar Current) were taken from Orsi et al. (1995). Estimates of surface chlorophyll-*a* concentrations were obtained from merged SeaWiFS/MODIS data (http://oceancolor.gsfc.nasa.gov/). These data were averaged over 8-day periods to reduce the effects of missing data due to cloud cover and satellite orbit paths. These estimates were used in favour of underway measurements of surface chlorophyll-*a*, as the latter samples were not coordinated with seabird observations and were only available at designated CTD stations.

2.3. Statistical analyses

Sightings were combined into 3-hour composite records, and physical environmental data were averaged for each composite record. The distance of each composite record to the ice pack was calculated as the minimum distance to any area of 15% or greater sea-ice concentration. The date of melt of each sea-ice pixel was calculated as the last day on which the sea-ice concentration was at least 15%, and the time since melt was collated for each composite record. The surface chlorophyll-*a* concentration was calculated as the mean value in a 0.2° by 0.2° bin (approximately 9 km in longitude and 22 km in latitude at 65°S), centred on the mean position of each composite record.

Species sighted on fewer than 10 occasions were excluded from analyses — these were white-headed petrel (6 sightings), wandering albatross (8), chinstrap penguin (1), Sabine's gull (1), black-browed albatross (1) and subantarctic skua (1).

The continuous seabird observations were partitioned into discrete records, each spanning three hours, giving a total of 167 records. Species' abundances were $\log_{10}(x+1)$ transformed. Pairwise dissimilarities among all survey records were calculated using the Bray-Curtis coefficient (Bray and Curtis, 1957), which gives a robust estimate of ecological distance (Faith et al. 1987). Survey records were clustered into discrete community groups using unweighted pair-group method with arithmetic mean (UPGMA). The UPGMA algorithm is a hierarchical, agglomerative method, and so yields a dendrogram that shows the order in which the groups were merged during the clustering process. This dendrogram is cut at an appropriate point to give a final set of groups. We chose a cut point at a natural break in the dendrogram (i.e. where subsequent groupings were separated by a relatively large dissimilarity) that also gave an ecologically meaningful grouping. Non-metric multidimensional scaling was used to assist in this process but the results of these analyses are not presented here. Community groups comprising fewer than five survey records were identified and treated as a single "outlier" group for the purposes of discussion. These groups tended to be comprised of records with unusual (in comparison to the remainder of the surveys) species compositions that were merged with larger groups in the clustering procedure at relatively high dissimilarity values. There were nine such groups, of sizes one (four groups), two, three, and four (two groups) surveys; which were merged with their parent group at a mean dissimilarity value of 0.87. A total of 17 composite records was identified via this mechanism to form the "outlier" group.

2.4. Seabirds and potential prey taxa

The relationships between seabirds and their potential prey were examined using Antarctic krill (*Euphausia superba*) densities from acoustic estimates in the depth range 18–24 m (Jarvis et al., 2010), and zooplankton densities from net hauls (Swadling et al., 2010). The net-based zooplankton data were only available at discrete haul station locations, and so each net sample was compared with seabird sightings in a 0.5° bin surrounding the haul location. The seabirds were not necessarily feeding on krill, as they may have been feeding on krill predators (Ainley et al., 1992). However, the present study was assessing only the abundance of krill, and therefore, krill abundance was a proxy for overall prey availability.

Continuous acoustic krill density estimates were available along the entire voyage track. The Spearman rank correlation between seabird abundance and krill density was calculated for each seabird taxon. Each correlation was calculated across a range of spatial scales, by averaging the bird abundances and krill densities in spatial bins (ranging in size from 0.125° to 5°). A randomisation test was used to test for correlation coefficients significantly higher than would be expected for random associations of seabirds with krill. Two sets of correlations were calculated for each seabird taxon. The first used a temporal subset of the surveys starting from the day on which a taxon was first observed through to the day on which it was last observed (including surveys in which the taxon in question was absent). This temporal subsetting was important for seabird taxa that were observed only during a discrete portion of the study (particularly dark shearwaters, which were only observed on the eastern transects). The second set of correlations used only those survey data for which the taxon in question was present. If seabirds congregate in feeding flocks, then one might reasonably expect to see larger flocks where prey is more abundant; but one would not necessarily see flocks at all locations where prey is present.