Oecologia Australis
15(1): 51-58, Março 2011
doi:10.4257/oeco.2011.1501.05

ON THE RELATION OF ANTARCTIC AND SUBANTARCTIC SEABIRDS WITH ABIOTIC VARIABLES OF SOUTH AND SOUTHEAST BRAZIL

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ABSTRACT

The distribution of wintering seabirds is influenced by biotic and abiotic oceanic processes. Ocean productivity is a main parameter at small and large scales, but the role of abiotic parameters at large scales may be explored further. Thus, we conducted bird surveys between Rio Grande and Rio de Janeiro (Brazil) onboard NApOc Ary Rongel from April 11st to 13th of 2009. The samples comprised 10 minutes each hour, from sunrise until sunset. Abiotic data were collected by NApOc Ary Rongel equipment. Data were analysed through CDA, PCA of species and CDA functions, and Multiple Regressions of CDA functions with sum of the abundances of all Antarctic and Subantarctic species observed, and the sum of all tropical and subtropical species' abundances. We verified through PCA that *Thalassarche chlororhynchos* and *T. chrysostoma* are associated with greater wind speeds and air temperatures, *Calonectris diomedea* and *Puffinus gravis* are associated with greater depths, sea surface temperatures and atmospheric pressures. As a group, Antarctic / Subantarctic species are associated with higher wind speeds, higher air temperatures, lower atmospheric pressures and shallower depths. Tropical / subtropical birds did not respond to any CDA functions. At small scales (<10km), seabirds tend to respond to local gradients in productivity, chlorophyll concentrations, depth and salinity. Nonetheless at larger scales (>100km), seabirds' distributions and abundances may be mainly driven by wind, associated with low pressures zones. At larger scales, the ability of disperse over greater distances may play a fundamental role.
Keywords: Seabirds at sea; association; bathymetry; dispersal; hydrography; migration; open ocean; winter.

RESUMO

RELAÇÃO DAS AVES MARINHAS ANTÁRTICAS E SUBANTÁRTICAS COM VARIÁVEIS ABIÓTICAS NO SUL E SUDESTE DO BRASIL A distribuição de aves marinhas migratórias é influenciada por processos oceânicos bióticos e abióticos. A produtividade oceânica é o principal parâmetro em pequena e larga escalas. No entanto, o papel dos parâmetros abióticos em grande escala pode ser investigado. Dessa forma, foram realizadas contagens de aves entre o Rio Grande e o Rio de Janeiro (Brasil) a bordo do NApOc Ary Rongel de 11 a 13 de abril de 2009. Cada amostragem se deu durante 10 minutos de cada hora, do amanhecer ao entardecer. Os dados abióticos foram coletados por meio dos equipamentos instalados no NApOc Ary Rongel. Os dados foram analisados por meio de CDA, PCA das espécies e funções de CDA e regressão múltipla das funções de CDA com a soma de todas as abundâncias das espécies originárias da Antártica e Subantártica, bem como a soma das abundâncias das espécies oriundas da região tropical e subtropical. Verificou-se por meio da PCA que *Thalassarche chlororhynchos* e *T. chrysostoma* encontram-se associados com maior velocidade do vento e temperatura do ar, enquanto que *Calonectris diomedea* e *Puffinus gravis* ocorrem associados a maiores profundidades, temperatura marinha e pressão atmosférica. Como grupo, as espécies Antárticas / Subantárticas ocorrem associadas a maior velocidade do vento, maior temperatura aérea, pressão atmosférica mais baixa e menor profundidade. As aves Tropicais / Subtropicais não apresentaram respostas a quaisquer das funções

de CDA. Em escala pequena (<10km), as aves marinhas tendem a responder a gradientes de produtividade, concentração de clorofila, profundidade e salinidade. Em grande escala (>100km), contudo, a distribuição e abundância das aves marinhas podem estar relacionadas principalmente ao vento associado a zonas de baixa pressão. Ainda em grande escala, a habilidade de dispersão por grandes distâncias pode desempenhar papel fundamental.
Palavras-Chave: Aves marinhas no mar; associação; batimetria; dispersão; hidrografia; migração; oceano aberto; inverno.

RESUMEN

RELACIONES DE AVES MARINAS ANTÁRTICAS Y SUBANTARTICAS CON VARIABLES ABIOTICAS DEL SUR Y SURESTE DE BRASIL. La distribución de las aves marinas migratorias está influenciada por procesos oceánicos bióticos y abióticos. La productividad oceánica es un parámetro principal a pequeña y gran escala, no obstante el rol de los parámetros abióticos a grandes escalas debe continuar siendo investigado. De esta manera, realizamos censos de aves entre Río grande y Río de Janeiro (Brasil) a bordo de NApOc Ary Rongel, desde el 11 al 13 de Abril de 2009. Cada registro comprendió 10 minutos cada hora, desde el amanecer hasta el atardecer. Los datos abióticos fueron colectados por los equipamientos electrónicos instalados en NApOc Ary Rongel. Los datos fueron analizados por medio de CDA, PCA de especies y funciones de CDA y regresión múltiple de funciones de CDA con la suma de todas las abundancias de especies de Antártida y Subantártida observadas y la suma de las abundancias de especies tropicales y subtropicales. Verificamos a través de PCA que Thalassarche chlororhynchos y T. chrysostoma están asociados con mayor velocidad del viento y temperatura del aire, mientras que Calonectris diomedea y Puffinus gravis están asociados a mayores profundidades, temperatura superficial del mar y presión atmosférica. Las especies antárticas/subantárticas, tomadas como un grupo, están asociadas con mayor velocidad del viento, mayor temperatura del aire, menor presión atmosférica y menor profundidad. Las aves del grupo Tropical/subtropical no respondieron a ninguna función de CDA. A menor escala (< 10 km), las aves marinas tienden a responder a gradientes locales de productividad, concentración de clorofila, profundidad y salinidad. Sin embargo, a mayor escala (> 100 km), la distribución y abundancia de las aves marinas pueden estar principalmente influenciadas por el viento, asociado con zonas de baja presión. A mayores escalas, la habilidad de dispersión a mayores distancias puede desempeñar un rol fundamental.
Palabras clave: Aves marinas en el mar; asociación; batimetría, dispersión; hidrografía; migración; océano abierto; invierno.

INTRODUCTION

The distribution of seabirds at sea is influenced by a number of biotic and abiotic factors, such as hydrography, productivity, fisheries and colony placing (Garthe 1997, Weichler *et al.* 2004, Ribic *et al.* 2005). The local productivity and fisheries are the main factors ruling the seabird's movements during the breeding season, as seabirds are central-place foragers during this period (Ollason *et al.* 1997, Ainley 1980, Ainley *et al.* 1982, Woehler & Croxall, 1997, Woehler *et al.* 2001, Woehler 2006). In the non-breeding period the seabirds are also influenced by productivity, but they typically search for their food over greater areas of open ocean, no longer under constraints imposed by chick attendance. During the breeding the required energetic inputs are greater, and birds may associate with different environmental cues for dealing with prey searching (Barret *et al.* 2007).

The South and Southeastern coast of Brazil is a key wintering area for seabirds as a result of the Falklands and Brazilian Oceanic Currents confluence that results in high local productivity (Borzone *et al.* 1999, Fernandes & Brandini 1999). The area is used by many seabird species from many continents (Vooren & Brusque 1999). Thus, one may question the role of abiotic (hydrographic and atmospheric) conditions in determining seabird movements during their non-breeding period. Particularly interesting is to compare such responses between breeding and non-breeding grounds. The present study examines the influence of abiotic factors on the distribution of seabirds of the South and Southeast Brazil coast, paying special attention to Antarctic and Subantarctic species in their non-breeding, winter period.

METHODS

The study was conducted onboard NApOc Ary Rongel, a ship that supports the Brazilian Antarctic Program. Data were collected during the return of the ship to Brazil, in the route from Rio Grande and Rio de Janeiro (Figure 1), between 11st and 13th of April in 2009. The samples comprised 10 minutes periods each hour, by the continuous method, taking in account all birds within 300-m from the ship board, from sunrise until sunset between 6 am and 6 pm. (Tasker *et al*. 1984). Thus, our time effort was 360 minutes. We sampled the birds in the 180º around the ship, but birds flying behind or around the ship (ship-attending birds) were excluded from analysis. No fishing vessels where registered during the samples. Abiotic data were collected by NApOc Ary Rongel onboard equipment.

The abiotic factors were analysed by latitude through Canonical Discriminant Analysis (CDA) by enter method and measured by Square Euclidian Distance. The regression scores from discriminating functions were saved and used in a Principal Component Analysis (PCA) to examine the relationships among species and abiotic gradients. For such analyses, we used the species registered at least in two samples. Species were grouped by their breeding in two categories: Antarctic/Subantarctic and Tropical/Subtropical. Abundances of both groups were used in multiple regressions to look for effect of discriminating scores. All analysis were conducted on SPSS 18.0.

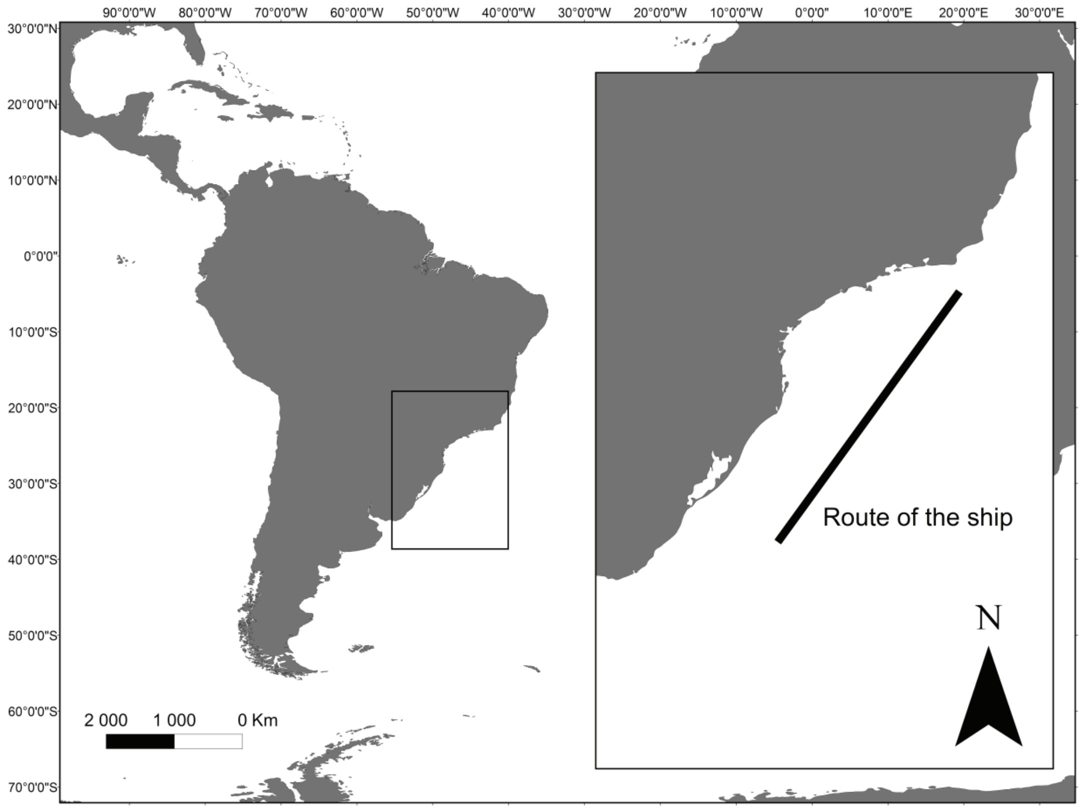

Figure 1. Sampled area in the continental shelf of South America (left) and the detail (right) of the route of the ship between Rio Grande and Rio de Janeiro.

RESULTS

103 birds were counted, belonging to eight species and one genus of seabirds. We grouped three species and *Procellaria* genus as Antarctic/ Subantarctic taxa, four species as Tropical/ Subtropical seabirds and one species (*Puffinus puffinus*) as a Northern Hemisphere Migrant (Table 1). *P. puffinus* was excluded from analyses, as only one individual was recorded. CDA resulted in four functions that explained 100% of the data variation (Table 2). Abiotic conditions varied as a function of latitude during the survey. Depth, sea surface temperatures, atmospheric pressures and air temperatures tending to be lower between 31°S and 28°S, and higher between 27°S and 23°S (Function 1, Figure 2 and Table 3). Wind direction and velocity increased between 23°S and 28°S, but tended to decrease north of 31°S (Function 2, Figure 2 and Table 3). These patterns can be explained by the passage of a cold front during the survey. Depth is associated with the ship position on the cruise track; the greatest distances from the coast coincided with the intermediary latitudes. PCA resulted in four components (axes) explaining 63.71% of variation. Combined, axes one and two explained 40% of the variation. The two *Thalassarche* species associated with CDA Function 4, *C. diomedea* and *P. gravis* associated with CDA Function 1, *S. leucogaster* associated with CDA Function 3, and *P. incerta* tended to associate with Function 2 (Figure 3).

The multiple regressions resulted in three models, from which the model 3 (R^2=0.28) explained most of variation (Table 4). The model shows that the Antarctic species are related to deeper water, higher atmospheric pressures, greater wind velocities, and lower atmospheric and sea surface temperatures (Y=0.57 - 0.38*SCORE3 + 0.23*SCORE4). Tropical species, despite two other models were shown to be significant, were not significantly related to abiotic factors in this study as neither R^2 was above 0.10, so the Functions could not explain the abundances of tropical species observed in this study as a group (Table 5). Possibly the absence of response by the tropical seabirds is explained by the short survey period, but this can not be assured.

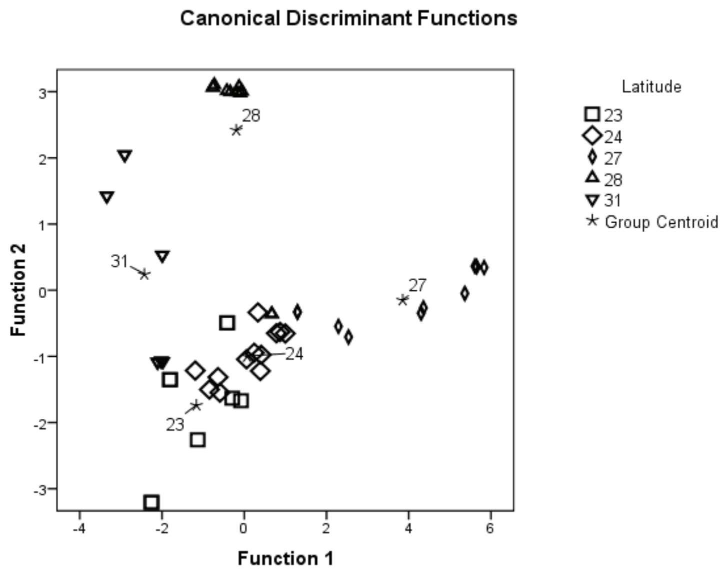

Figure 01. Canonical Discriminant Analysis Biplot. Associated variables see Table 3.

Table 1. Species registered in the NApOc Ary Rongel cruise between Rio Grande and Rio de Janeiro, and species grouping

Species	Group
Procellaria aequinoctialis	Antarctic / Subantarctic
Procellaria sp.	Antarctic / Subantarctic
Thalassarche chlororhynchos	Tropical / Subtropical
Puffinus puffinus	North Migrant
Thalassarche chrysostoma	Antarctic / Subantarctic
Puffinus gravis	Antarctic / Subantarctic
Pterodroma incerta	Tropical / Subtropical
Calonectris diomedea	Tropical / Subtropical
Sula leucogaster	Tropical / Subtropical

Table 2. Functions of Canonical Discriminant Analysis (CDA), variance explained by function and Canonical Correlation Coefficients (CCC) between Functions and variables.

Functions	Eigenvalues	% of variance	% cumulative of variance	CCC
1	4.708	56.6	56.6	0.908
2	2.177	26.2	82.8	0.828
3	1.276	15.3	98.1	0.749
4	0.157	1.9	100	0.369

Table 3. Correlations between abiotic variables and the standardized functions of the Canonical Discriminant Analysis (CDA). Variables ordered by greater correlation with any function.

Variables	Function 1	Function 2	Function 3	Function 4
Depth (m)	0.793*	0.059	-0.518	0.048
Sea Temp. (°C)	0.434*	0.049	0.221	0.428
Pressure (mmHg)	0.244*	-0.02	-0.226	0.002
Wind Direction (º)	-0.255	0.818*	0.039	-0.211
Wind Speed (knots)	-0.218	0.25	-0.324	0.874*
Air Temp. (°C)	0.531	-0.212	0.463	0.661*

* Greater absolute correlation between variable and function.

Table 4. Multiple regression models between CDA Scores and Abundance of Antarctic/Subantarctic species.

Model	R	Adjusted R²	F	P
1	0.560[a]	0.256	5.47	0.001
2	0.560[b]	0.271	7.447	<0.001
3	0.552[c]	0.277	10.954	<0.001

a. Predictors: (Constant), Score4, Score3, Score2, core1

b. Predictors: (Constant), Score4, Score3, Score1

c. Predictors: (Constant), Score4, Score3

Table 5. Multiple Regression models between CDA Scores and abundance of Tropical / Subtropical species.

Model	R	Adjusted R^2	F	P
1	0.389[a]	0.08	2.13	0.91
2	0.389[b]	0.099	2.91	0.04
3	0.375[c]	0.106	4.09	0.02

a. Predictors: (Constant), Score4, Score3, Score2, Score1

b. Predictors: (Constant), Score4, Score3, Score2

c. Predictors: (Constant), Score4, Score3

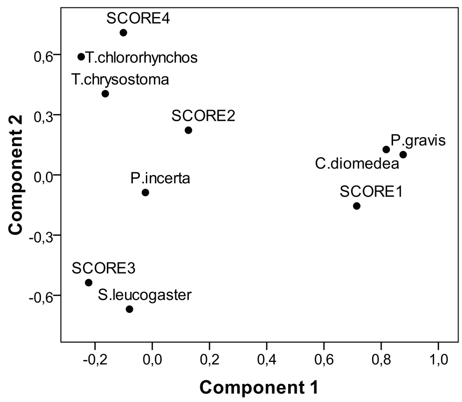

Figure 02. Principal Component Analysis (PCA) between species and the CDA Function Scores.

DISCUSSION

Species that breed at higher latitudes have the tendency to associate during the winter, non-breeding season with areas in accordance to sea bottom, water column and surface current (Skov & Durinck 2000, Chapman *et al.* 2004, Ribic *et al.* 2008). However, different species' strategies will result in different species' associations and relationships with abiotic conditions (Woehler et al. 2010). At the species level, we verified that most pelagic seabirds tend to occur were the water is deeper, and with greater atmospheric pressures (*C. diomedea* and *P. gravis*) and strong winds (*Thalassarche*). Strong winds and higher air pressures can indicate associations with atmospheric fronts (eg Amorim *et al.* 2008, Bost *et al.* 2009). The movement of air masses from high to low pressure zones and higher speed wind fronts provide a less expensive way of traveling for seabirds (Adams & Flora 2010), and they may rapidly cross larger differently-characterized water masses in the process. Ribic *et al.* (2008) showed that the depth is the most important factor affecting three seabird species distribution at Antarctica in the winter. Those birds are related with deeper waters such as migrating Antarctic / Subantarctic birds (present study). Amorim *et al.* (2008) found a negative relation between shearwaters and depth, in contrast to our results. Amorim *et al.* (2008) sampled during the breeding period and near colonies, while we sampled in the winter and relatively distant from the colonies. Our analysis showed that shearwaters may respond differently to that specific variable, assuming different strategies throughout the year. Zones of shallower depth near the colonies may provide more productive waters as consequence of nutrients upwelling inshore, but the confluence in Brazilian offshore waters also provides relatively high productivity. Productivity may be a secondary (but also important) factor for some species, what varies year to year (Ribic *et al.* 2008).

The responses to sea surface temperatures vary among species and between seasons, being positive during fall and negative during summer (O'Hara *et al.* 2006). Our results also showed this positive association with sea surface and air temperatures (Table 3 and 4) during the winter survey. During summer, seabirds search for the cooler conditions (cold water fronts and confluences are more productive) while they may seek higher sea surface temperatures in the winter. At the group level, Antarctic and Subantarctic seabirds are also associated with higher sea surface and air temperatures, but tended to be present at the front of air masses dislodgements, in the low pressures zones, using far more efficient the air currents for their traveling. Low pressure zone (= rising air in the Southern Hemisphere), provides lift. However our evaluation could not examine the role of confluences, and their characteristics of productivity and temperatures that also favours seabirds typical of higher latitudes during breeding (Merket *et al.* 2002, Weichler *et al.* 2004, Ohara *et al.* 2006, Woehler 2006, Hyrenbach *et al.* 2006), but may be a secondary factor during the winter (Ribic *et al.* 2008). Instead, a model that includes biotic factors such as productivity, chlorophyll and tracking of seabirds may furnish explanation to the data variation not explained by our analyses.

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Submetido em 27/08/2010
Aceito em 10/03/2011