

Abundance and breeding of the Antarctic Tern *Sterna vittata* at the James Ross and Seymour Islands, NE Antarctic Peninsula

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Abstract The Antarctic Peninsula (AP) is experiencing rapid environmental change associated with warming and sea ice retreat, which is likely to affect locally breeding birds. Yet, contrary to the knowledge of bird biology along the maritime West coasts of the AP, there is a remarkable lack of data from the more continental East coast. We report on the distribution, abundance, and breeding of the Antarctic Tern at the James Ross and Seymour islands, the two largest snow-free areas in the NE part of the AP, where this species breeds under harsh climate conditions probably close to its limits. Terns were found breeding in most ice-free areas, with nests located up to 2.9 km from coastlines at altitudes up to 180 m a.s.l. While the large-scale density was relatively low (c. 450 pairs per 127 km² of surveyed ice-free area), the local density (total colony area: 3 nests per ha; nest clusters: 100–140 nests per ha) was as high as elsewhere. Mean clutch size (1.21, $n = 196$) was smaller than in the west AP or in the maritime Antarctic. Daily nest survival rate during incubation varied between years and locations (mean = 0.977; 95 % CI: 0.966–0.985). While both predation and weather-caused mortality were locally important, the impact of skua predation might be lower in areas with alternative prey (penguin colonies). We suggest that the Antarctic Tern deserves attention as a species potentially suitable for monitoring of environmental impacts upon bird populations around the AP.

Keywords Antarctica · Birds · *Sterna* · Breeding density · Nest success · Colonies

Introduction

The Antarctic Tern *Sterna vittata* is a circumpolar species breeding on sub-Antarctic islands and the Antarctic Peninsula, in colonies containing from a few to hundreds of pairs. Both eggs and chicks suffer from heavy avian predation and weather-caused mortality (Jablonski 1995; Higgins and Davis 1996). Breeding Terns avoid far inland areas and, as typical inshore foragers (Casaux et al. 2008), are confined to the close vicinity of nesting sites during the breeding season. The distribution at the southern border of their breeding range is thus constrained by the availability of open sea adjacent to snow-free coastal breeding areas.

The Antarctic Peninsula (AP) has undergone rapid environmental change associated with regional warming and sea ice retreat over the past decades (Morris and Vaughan 2003; Stastna 2010). Breeding ranges of several sub-Antarctic penguin species have already moved southward along the west AP (WAP) (Forcada and Trathan 2009). The East AP (EAP) is possibly experiencing even faster environmental change since the break-up of the Prince Gustav Ice Shelf, as reflected in the establishment of new penguin colonies (McClintock et al. 2010). Continued environmental change is likely to affect all birds, in particular those species that occur here at the southern border of their range. Among the few flying bird species breeding along the EAP, Antarctic Terns may benefit most from a further retreat of sea ice in this area.

Here, we report on the distribution, abundance, and breeding of the Antarctic Tern at the James Ross and Seymour islands, the two largest snow-free areas in the NE

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part of AP. The EAP is colder, drier, and icebound (Morris and Vaughan 2003; Stastna 2010) and also supports less vegetation and wildlife compared with the WAP at similar latitudes (Quintana et al. 2000; Nelson et al. 2008; Fretwell et al. 2011). Given the comparatively low attractiveness of this area to ornithologists and birdwatchers (Shirihai 2007), data on the local distribution and abundance of most bird species are scarce (Coria and Montalti 1993; Montalti and Soave 2002; Pavel and Weidinger, in press), while data on breeding performance are almost lacking. Antarctic Terns here (c. 64°S) probably breed close to their limits, under a climate that is even colder (Stastna 2010) than in the more southerly breeding grounds (to 68°S) along the WAP. We asked how the abundance and breeding parameters of local Antarctic Tern populations fit into the current knowledge of the species' biology along the environmental gradient from the WAP (Parmelee 1992), across the tip of the AP (Cordier et al. 1983), to the South Shetland Islands (Jablonski 1995). These new data should contribute to an understanding of this species' natural history across a full range of ecological conditions and provide a regional baseline for future assessments of environmental impacts upon local bird populations.

Materials and methods

The study was conducted at the James Ross Island (JRI; Johan Gregor Mendel Station: 63°48'02"S, 57°52'57"W) and the Seymour Island (SI; Marambio Station: 64°14'27"S, 56°37'31"W) during two austral summers 2008/2009 and 2010/2011 (see Online Source 1 and 2 for the duration of field work). On JRI, we mapped the distribution of all breeding birds over c. 117 km² (length of coastline c. 45 km) of ice-free area on the Ulu Peninsula (Fig. 1). The area is characterized by diverse topography, comprising extensive plains of sedimentary substrates, bordered by volcanic mesas (up to c 400 m a.s.l.); vegetation of mosses, lichens, and algae is abundant along streams and lakes (see also Láska et al. 2011). Our work on SI was restricted to c. 9.5 km² of inland ice-free area comprising the top plateau (c 200 m a.s.l.) and slopes around the Marambio Station (Fig. 1). The area is formed by sedimentary rocks eroded into fine substrate, with very sparse vegetation (see Montalti and Soave 2002).

Because many breeding attempts were already finished and some colonies were abandoned by the date of our arrival to the study area (Online Source 1), we carefully searched for signs of nesting in all sites deemed suitable for placing nests. Current year empty nests could be distinguished from older ones based on the absence/low erosion of the nest scrape and the presence of feces/feathers. The positions of all discovered nests, both active and abandoned, as well as chicks found away from a nest, were recorded by GPS; position of each active nest was marked by 2–3 stacked stones placed >1 m

away from it. Numbers of adult birds and their activity indicative of breeding (defense, food carrying, landing at fixed sites) were recorded throughout the fieldwork.

Terns are characterized as colonial or solitary breeders, typically forming loose colonies (Higgins and Davis 1996). This breeding dispersion makes any quantification of colony sizes and breeding density difficult, because the definition of colony and its area is somewhat arbitrary in this case (cf. fractal nature of nest dispersion; Jovani and Tella 2007). We estimated the total abundance (in pairs) at JRI as the mean of the minimum number ($=0.5 \times$ the total number of counted adult birds in colonies) and maximum number ($=$ the total number of counted nests; re-nesting rate was unknown). Because of the short study period and incomplete survey of potential breeding sites at SI, we estimated the minimum abundance at SI as the number of simultaneously active nests. We estimated breeding density as the number of pairs per total surveyed area (pairs km⁻²). To estimate the overall nesting density (nests ha⁻¹), we divided the total number of recorded nests by the total area occupied by nesting colonies. We delimited the area of each colony by the position of the outer nests, extended to the adjacent area actively defended by adult Terns, with regard to local topography. The colony area was thus not necessarily a minimum convex polygon (MCP) if located, for instance, along a curved valley. To estimate the maximal local nest density within colonies (nests ha⁻¹), we divided the number of nests forming well-defined clusters by the area of MCP delimited by the outer nests.

Active nests were inspected in 2–10-day intervals depending on site accessibility and weather conditions. As our study period covered neither the entire breeding season nor the entire incubation period of most discovered nests, we could not derive an unbiased seasonal distribution of laying/hatching dates. The mean clutch size was calculated separately for completed, abandoned, and all nests found. As completed, we considered those clutches that had been incubated on two consecutive nest checks ≥ 2 days apart. An active nest was classified as successful (hatched) when a chick was found in or close to the nest or when feces around the nest and aggressive adult behavior (at isolated nests) indicated the presence of a chick(s). A nest was considered as depredated if the eggs disappeared before the expected date of hatching or if we did not find any signs of chick presence. We modeled nest survival in terms of daily survival rates (DSR). We used the logistic-exposure method (Shaffer 2004) implemented in the PROC GENMOD (SAS Inc.), which is an extension of the logistic regression allowing for variable exposure time. Each interval between successive nest visits was treated as one observation, and the fate of the nest during the interval was the binary response variable (survived/failed); intervals of uncertain fate were excluded from the analysis. To allow comparison with published values, we approximated an overall nest-hatching success as DSR raised

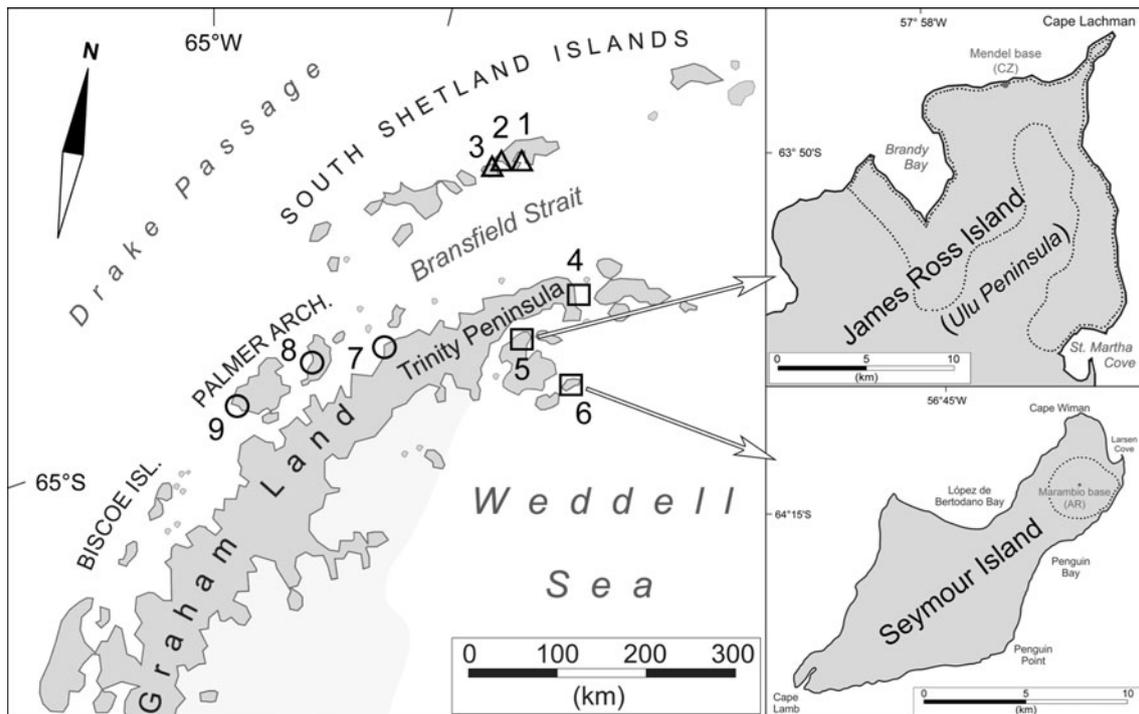


Fig. 1 Location of the studies reporting data on clutch size of the Antarctic Tern at the South Shetland Islands (*triangles*) and along the East (*squares*) and West (*circles*) coast of the Antarctic Peninsula (see Fig. 2). Locations are numbered according to an increasing latitude within the three respective areas: (1) Admiralty Bay, King George Island (Jablonski 1995); (2) Fildes Peninsula, KGI (Peter et al. 1988); (3) Nelson I. (Lumpe and Weidinger 2000); (4) Esperanza Bay

(Cordier et al. 1983); (5) James Ross I. (this study); (6) Seymour I. (this study); (7) Cierva Point (Novatti 1978 after Cordier et al. 1983); (8) Brabant I. (Parmelee and Rimmer 1985 after Jablonski 1995); (9) Anvers I. (Parmelee and Maxson 1974). The inset maps show areas of the James Ross and Seymour islands surveyed in this study (delimited by *dotted line*)

to the mean length of incubation period (24 days). We did not have adequate data to evaluate chick mortality.

Antarctic Terns are claimed to be generally sensitive to anthropogenic disturbance (Kaiser et al. 1988; Higgins and Davis 1996; Silva et al. 1998; Peter et al. 2008). While this may be certainly true in the case of heavy and long-standing disturbances (e.g. logistical and tourist activities around polar bases), which may lead to the abandonment of nests/colonies, we have no evidence that non-invasive research (short visits to check nest status) led to increased nest abandonment or predation on temporarily unattended eggs. During both study seasons, a subset of incubated nests was monitored by mini video cameras to obtain continuous records of incubation behavior (unpublished data). As a side product, the video records showed that Terns resumed incubation soon (<3 min) after being flushed by observers and that the recorded predation events (all by skuas) were not temporally associated with preceding observer visits.

Results and discussion

The Antarctic Tern was by far the most abundant breeding bird species in the surveyed area of JRI (Table 1) where it

outnumbered the other regular breeders (South Polar Skua *Catharacta maccormicki*, 38 and 54 pairs in the two study seasons; Kelp Gull *Larus dominicanus*, 31 and 24 pairs; unpublished data). Size of the mapped Tern colonies (mean = 15–30 nests, max = 69; Online Source 1) roughly corresponds to data from elsewhere (Jablonski 1995; Higgins and Davis 1996). Yet, in agreement with Parmelee (1992) we did not record large colonies encompassing hundreds of pairs as are known from South Shetland Islands (Jablonski 1995; Peter et al. 2008). Large-scale density was lower at JRI (c. 258–344 pairs per 117 km², ~2.2–2.9 pairs km⁻²; Table 1) than on the Fildes Peninsula (c. 100–900 pairs per c. 29 km², ~3–31 pairs km⁻², Peter et al. 2008) and Admiralty Bay (c. 650–1830 pairs per 19 km², ~34–96 pairs per km⁻², Jablonski 1995) of King George Island (KGI), South Shetland Islands. Yet, abundance calculated for the length of coastline was only marginally lower at JRI (5–8 pairs km⁻¹; Table 1) than at KGI (~2.5–22 pairs km⁻¹, Peter et al. 2008; 7–20 pairs km⁻¹, Jablonski 1995). Of note is the fact that we found nests as far as 2.9 km inland and that about 29 % (13/45) of all colonies mapped at JRI were located >1 km from the sea coast (Table 1, Online Source 1). Our estimates of nest density per total colony area were surprisingly consistent for both seasons and study areas (2.7–3.2 nests ha⁻¹; Table 1).

Table 1 Breeding density and colony characteristics in the Antarctic Tern at the James Ross and Seymour islands, NE Antarctic Peninsula

Variable	James Ross Island		Seymour Island
	2008/2009	2010/2011	2010/2011
Number of nests/colonies	481/20	372/25	120/4
Number of pairs ^a	344 (206–481)	258 (144–372)	120
Altitude (m) ^b	69 (5–180)	77 (10–180)	98 (35–170)
Distance to sea (m) ^b	923 (100–2600)	863 (80–2900)	877 (330–1390)
Colony area (ha) ^c	7.1 (0.3–37)	5.5 (0.1–30)	10.9 (0.01–24)
Nests per colony ^c	24 (2–69)	15 (2–52)	30 (4–65)
Density per colony (nests ha ⁻¹) ^c	9.1 (0.4–34)	7.2 (1.1–40)	102 (2.4–400) ^e
Density per total colony area (nests ha ⁻¹) ^d	3.2	2.7	2.7
Density per total ice-free area (pairs km ⁻²) ^d	2.9	2.2	12.6
Density per length of coastline (pairs km ⁻¹) ^d	7.6	5.7	21.8

See Online Source 1 for data on individual colonies

^a *JRI*: total abundance estimated as the mean from the minimum ($0.5 \times$ total number of counted adult birds) and the maximum (total number of counted nests), the min–max values are shown in parentheses; *SI*: minimum abundance estimated as the number of simultaneously active nests

^b Unweighted mean (min–max) calculated from the mid-values for individual colonies (min–max values for individual colonies shown in Online Source 1)

^c Unweighted mean (min–max) calculated from values for individual colonies (see Online Source 1)

^d Calculated from the total values

^e The mean is strongly influenced by a single small colony of four nests (see Online Source 1)

Similarly, the largest clusters of nests found within colonies at JRI (16 nests/0.16 ha, 21/0.15, 56/0.51, 59/0.42) suggested a rather stable upper limit of local nest density (100–140 nest ha⁻¹). The closest active nests were only c. 1 m apart; solitary nests were no more than c. 200 m away from their nearest neighbors. Although the total number of colonies, total colony area and general distribution across the surveyed area of JRI remained rather stable between 2008/2009 and 2010/2011, the exact location and extent of individual colonies shifted (Online Source 1). The reoccupation rate between the two study seasons was 70 % (14 of 20 colonies) and 16 % (23 of 141 ha) in terms of colony number and total colony area, respectively. Any comparison of abundance/distribution data among studies is potentially confounded by the high inter-annual fluctuations in Tern breeding numbers (e.g. by a factor of 9 \times ; Peter et al. 2008). Yet, our data suggest that Antarctic Terns might be more abundant in this area than it was thought. Although our results represent minimal estimates, we found 120 simultaneously active nests on c. 12 % of the area of SI, while the only previous census of this area counted 107 breeding pairs on the entire island (Montalti and Soave 2002).

Antarctic Terns laid smaller clutches at JRI and SI (mean = 1.21 eggs, $n = 196$ [155 \times 1 egg, 41 \times 2 eggs]; Online Source 2) than elsewhere in the maritime Antarctic or WAP (Fig. 2). Although this could be partly an artifact of increased proportion of late/replacement clutches in our data set, the seasonal decline of mean clutch size seems to be generally less pronounced in this species (Jablonski

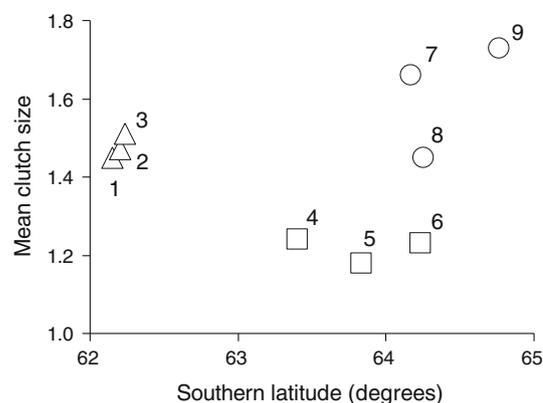


Fig. 2 Geographical variation of mean clutch size in the Antarctic Tern: South Shetland Islands (*triangles*), East Antarctic Peninsula (*squares*), West Antarctic Peninsula (*circles*). Numbers refer to the location shown in a map and to the source of data (see Fig. 1)

1995; Kaiser 1996), while a similarly small mean clutch size was reported by a full-season study from the geographically close location at the tip of the AP (1.24 eggs; Cordier et al. 1983). An extrapolation of the mean DSR over a 24-day incubation period yielded nest-hatching success ranging from 33 to 85 % (Online Source 2). These values should be considered maximum estimates, because while our limited observation period accounted for predation losses, it did not include events of catastrophic mortality due to inclement weather (Johnson and Shaffer 1990). The number of clutches found already abandoned suggests that massive non-predation mortality had occurred

already before the study period. Abandonment of these clutches cannot be attributed to human disturbances (as humans were not present) or partial predation (Terns even accept foster eggs after loss of their own eggs; Parmelee and Maxson 1974). Nevertheless, the abandoned clutches were smaller on average than incubated clutches (mean = 1.09 eggs, $n = 23$ [21×1 egg, 2×2 eggs]; Online Source 2). This suggests that either parents laying smaller clutches are more prone to abandon them in case of adverse conditions during incubation, or that most of these clutches were abandoned soon after laying the first egg, that is, before clutch completion (see also Parmelee and Maxson 1974). Although we cannot quantify the relative importance of predation and weather-caused mortality over the entire breeding season, the counts of failed nests (Online Source 2) suggest that both these mortality factors are locally important. Egg losses ascribed to predation were much lower at SI (Online Source 2), where Brown Skuas *Catharacta antarctica* and South Polar Skuas are about equally abundant (Montalti and Soave 2002), compared with JRI, where only South Polar Skuas were breeding during the study period. Presumably because both skua species are opportunistic foragers (Higgins and Davis 1996; Malzof and Quintana 2008), Terns at SI benefit from the presence of a large penguin colony (>7 km from the study area)—a major prey source that attracts locally breeding skuas (Montalti and Soave 2002; also Jablonski 1995). In contrast, with the absence of penguin colonies at JRI, Tern eggs and chicks were the main terrestrial prey for local skuas, whose nests were dispersed over much of the study area: a minimum distance between active nests of these two species was 74 m. Nest success, causes of nesting failure, and overall breeding productivity in the Antarctic Tern show remarkable variation among geographical locations, years, as well as colonies within a year (Kaiser et al. 1988; Parmelee 1992; Jablonski 1995; Kaiser 1996; Higgins and Davis 1996; Peter et al. 1997; Tree and Klages 2004; Casaux et al. 2008). Yet, the utility of published data for comparative purposes is strongly limited by the mostly incomplete coverage of breeding seasons and/or by inconsistent methods used for nest survival analysis.

Conclusions

1. The available data suggest that the Antarctic Tern is the most abundant flying bird species in the NE part of the AP with local nesting densities as high as in maritime Antarctic. The estimated minimal total abundance (c. 450 pairs per 127 km² of surveyed ice-free area) represents c. 30 % of the total breeding population (1500 pairs) previously estimated for the entire AP (Higgins and Davis 1996; Tree and Klages 2004).

2. Mean clutch size was smaller in the NE part of the AP compared with the WAP and maritime Antarctic. This pattern, if real, might indicate limited marine food availability (Hahn et al. 2007) and/or higher energetic costs of incubation (Thomson et al. 1998) in this area. Nest-hatching success and rate of skua predation varied between years as well as between colonies, suggesting no obvious geographical pattern.
3. We propose that the Antarctic Tern deserves attention as a species potentially suitable for monitoring of environmental impacts upon local bird populations—the species is currently abundant and widely distributed in ice-free areas across the AP, and it is likely to respond to continued deglaciation of coastal areas and retreat of sea ice.

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