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SHORT NOTE

Migration front of post-moult emperor penguins

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Abstract The moult is arguably the most critical period in the life of emperor penguins (*Aptenodytes forsteri*). Birds from western Ross Sea colonies travel yearly to and from the pack ice of the eastern Ross Sea to moult. Despite the suspected large numbers of penguins involved, this migration had never been directly observed. Here, we provide the first description of a migratory front of penguins travelling east to west between their moulting habitat and to the breeding colonies. Early autumn ship-bound visual surveys showed density of birds increased significantly as we approached the eastern Ross Sea and was not related to ice type, per cent ice cover or primary productivity. This supports the hypothesis of a dense "source" of post-moult birds in the eastern Ross Sea migrating in near-synchrony and gradually dispersing towards breeding colonies in the southwest and northwest Ross Sea. Emperor penguins travelled alone or in small groups of up to 8 individuals, concentrating around narrow leads or isolated water holes, and were occasionally seen far from open water, suggesting they move primarily by swimming, complemented by tobogganing. Their new coats indicated they had completed the moult. Aggregations of birds and guano stains suggested they were feeding while migrating.

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Introduction

Emperor penguins remain within the bounds of Antarctica's Seas and adjust well to the continent's extreme winter conditions (Wilson 1907; Prévost 1963). The yearly moult is perhaps the most dangerous and least understood period of their lifecycle. Lasting ~35 days, it takes place during the warmer months of January and February (Kooyman et al. 2000), when sea ice is receding around the continental coast (Cavalieri and Parkinson 2008). Due to their reduced thermal insulation and waterproofing, birds do not enter the water to forage; the ensuing fast can cause the loss of up to half of their pre-moult body mass (Groscolas 1978). The need to stay dry makes them dependent on floes that remain intact for at least one month, precluding most areas near breeding colonies in the western Ross Sea (WRS) as these become ice-free during summer. When finished moulting, the penguins, weakened from starvation, must resume feeding. Abundant prey in the immediate vicinity of the moult area is key to their survival (Kooyman et al. 2004).

The Ross Sea harbours seven emperor penguin colonies, six of which lie on its western shores (Fig. 1). Satellite telemetry showed that birds from four WRS colonies travel at least 1,200 km to moult in dense pack ice in the eastern Ross Sea (ERS; Kooyman et al. 2000). Kooyman et al. (2004) later confirmed post-moult penguins tagged in the ERS went back to WRS colonies (Fig. 1). This highlights the importance of the consistent heavy pack ice field of the ERS and Amundsen Sea as moulting habitat for emperor penguins.

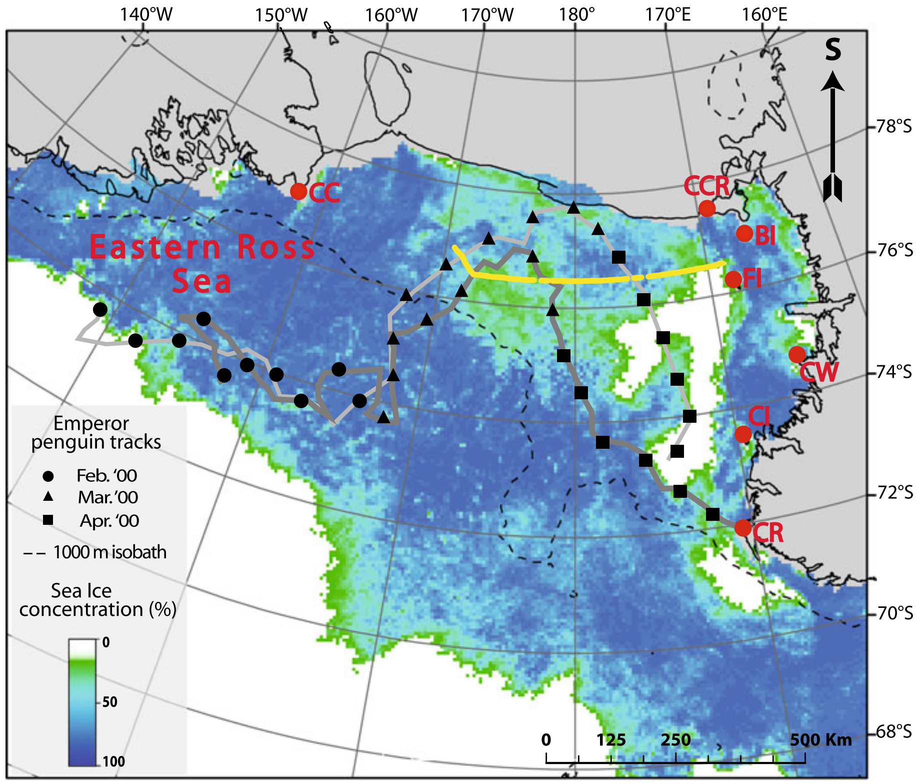

Fig. 1 Transect of the 2013 NBP cruise (*yellow*) and migratory routes (*grey*) of two penguins satellite-tracked in 2000 (data: Kooyman et al. 2004). Migratory routes coincide in space and time with the observed migration front. Sea ice concentration on March, 8th, 2013 (AMSR2, 6.25-km grid; Spreen et al. 2008) shows extensive pack ice coverage of the Ross Sea, including the transit section with only a few open areas in the WRS. Breeding colonies: *CR* Cape Roget, *CI* Coulman Isl., *CW* Cape Washington, *FI* Franklin Isl., *BI* Beaufort Isl., *CCR* Cape Crozier, *CC* Cape Colbeck. (Color figure online)

Arrival synchrony at breeding sites, a known trait in pygoscelid and emperor penguins (Prévost 1963; Lynch et al. 2012), implies concurrent departure and travel from the moulting areas (Battley 2006). This phenomenon has never been observed for emperor penguins in the ERS, despite the presence of large numbers of moulting birds (Kooyman et al. 2004), as it occurs at a time when most researchers have left Antarctica. Here, we report what we believe is the first sighting of a migration front of penguins travelling from ERS moulting floes back to their breeding colonies.

Materials and methods

Visual surveys were carried out aboard the icebreaker N.B Palmer during an early autumn cruise throughout the Ross Sea. This period corresponds to the end of the moulting season when birds in the ERS are travelling back to their colonies through reforming ice. The surveys consisted in uninterrupted daytime ("on-effort") counts of emperor penguins along a 450-km-long straight-line transect. This transect consisted in three on-effort sections following the 76.5°S parallel from 168°E to 171°W (Fig. 2), representing a longitudinal gradient from the breeding colonies to the ERS pack ice. The transect was characterized by a uniform seascape, precluding any edge effects on animal distribution (Buckland et al. 2001), and was within the known migration corridor of satellite-tracked penguins (Fig. 1). Transect width was 1000 m, beyond which penguins could not reliably be identified. An ipad 2 (Apple, Inc., Cupertino, CA, USA) with Bento (Filemaker, Inc., Santa Clara, CA, USA), a database application with an automatic geo-referencing function, was used to record data. GPS data were fed into Bento by a BadElf Pro GPS unit (BadElf, West Hartford, CT, USA) with accuracy of 2.5 m. Each observation was referenced with a location and UTC time. Data on ice type and per cent ice cover (following the classification given by Smith 2007), sea state and weather were recorded when they changed. Information on behaviour (prior to the animals being flushed by the ship), life stage (juvenile/adult) and physiology (moulting/not moulting) was added whenever possible. Count data from on-effort sections were pooled a posteriori into 10-km bins to enable spatial comparisons and compute the mean density of penguins (sightings/kilometre along the transect, or the number of sightings in each bin divided by ten). Count data were analysed using stepwise generalized linear modelling (GLM) in R (R Development Core Team 2010), with "sightings/bin" as dependent variable and a quasi-Poisson model to account for overdispersion and excess zeroes. Location (latitude/longitude), ice type and percent ice cover, whose effect on the distribution of Antarctic birds is well documented (Ainley et al. 1984; Ballard et al. 2012), and chlorophyll-a (measured by underway fluorometry) were factored in the GLM as explanatory variables. QAIC

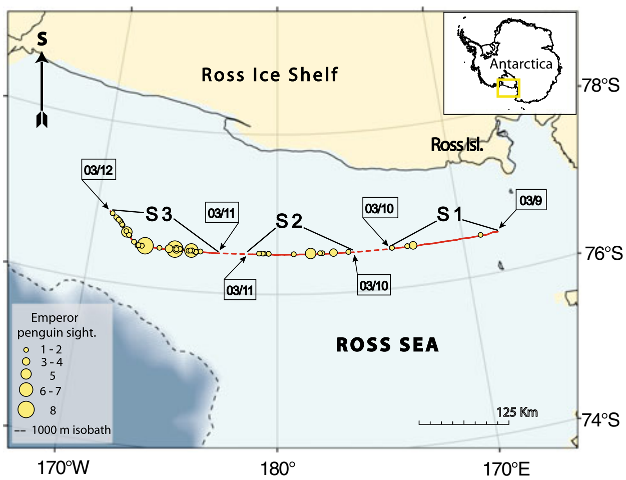

Fig. 2 West- to eastern Ross Sea transect along the 76.5°S parallel. "On" and "off-effort" (daytime and nighttime) portions given by the *solid* and *dashed red line*, respectively, with sects. 1–3 (S1–S3) totaling 450 km of on-effort surveys. Emperor penguin sightings (*yellow circles*) increase from west to east, suggesting birds are migrating back to breeding colonies. (Color figure online)

Fig. 3 Group of 8 emperor penguins aggregated around a water hole at 76.5°S, 171.5°E

was used to select the best model (Richards 2008). Results are presented as mean ± standard error.

Results

From March 9 to 12, 2013, after completing the scientific agenda of other teams aboard the ship, the N.B Palmer transited from the WRS to ERS through a landscape of new ice (<25 cm thick) interspersed with small floes and 90–100 % ice cover. A total of 90 emperor penguins were observed, all of which had new coats, suggesting they had completed the moult. Chlorophyll-a concentration ranged from 0.04 to 1.44 mg m^3.

In Sect. 1 (164°W–173°W; Fig. 2), eight penguins (0.047 birds km^{-1}, ±0.024) were observed. Birds were standing upright or hauled out next to small leads or holes in the ice. They were either alone ($n = 2$) or clustered in 2 groups of 3 individuals. Most of this section was through new ice.

The density in Sect. 2 (March 10–11th) was 0.13 birds km^{-1} (±0.05), significantly higher than in Sect. 1 (Wilcoxon rank-sum test (WRSP), $P = 0.036$). From a total of 12 birds, one lone individual was seen standing with no open water in sight; the remaining birds were along narrow leads or next to isolated open water holes. Penguins were standing upright or hauled out on new ice or small floes in slightly larger groups of up to 5 individuals.

As the ship progressed along the 76.5°S line in Sect. 3 (March 11–12th), these aggregations became larger, with clusters of up to 8 birds (Fig. 3). The density of penguins along Sect. 3 was 0.38 birds km^{-1} (±0.1); three times that of Sect. 2 (WRSP, $P = 0.021$). All 70 penguins counted in this section were standing or hauled out next to leads and water holes. Large, dark-coloured guano stains were frequently observed, especially along leads.

The most parsimonious GLM model included only *longitude*, a proxy for distance to the ERS pack ice (Table 1).

Discussion

The environmental constraints of finding an area of stable pack ice with abundant food may force emperor penguins to travel yearly to the same region in the ERS. As 6 of the 7 breeding colonies of the Ross Sea are located on its western shores, the conditions are met for a synchronous flux of a large number of birds entering and leaving the ERS pack ice through a relatively narrow corridor. The return routes of two post-moult penguins satellite-tracked in 2000 were south of 75.5°S during the months of February and March (Kooyman et al. 2004), roughly the same latitudinal section and timeline as our cruise (Fig. 1).

One of the striking aspects of our surveys (confirmed by the most parsimonious GLM model, which included only the covariate *longitude*) was the gradual increase in the number of penguins as the ship approached the ERS: from a lone individual 40 km SE of Franklin Island, the location of a breeding colony, the sightings of small groups of birds became more frequent as the ship travelled eastward. As it was not possible to survey during the night, the gaps between 173.5°E–176.0°E and 178.6°W–176.6°W were not filled (Fig. 2). However, this trend of increasing density of penguins is likely to hold true for the entire transect, with the highest concentrations of birds close to the source (ERS pack ice, Fig. 1), and a gradual decrease towards the West as birds had yet to reach the most western areas, then

Table 1 The most parsimonious GLM model (in *bold*) for density of emperor penguins (number of birds.km^{-1} along the transect line), given as *count*, was obtained by stepwise selection. Δ QAIC shows the performance of other GLMs relative to the best model. Abbreviations: EV=explanatory variables; r.d=residual deviance, df=degrees of freedom, φ=dispersion parameter.

GLM (count ~ $EV_1 + EV_2 + \ldots + EV_n$, family: quasi-Poisson)

EV	r.d	df	Δ QAIC	ϕ
longitude	**123**	**44**	**0**	**3.13**
latitude, *longitude*, *ice type*	122.7	42	7.11	3.19
latitude	156	44	11.74	4.54

diverging to their respective colonies of the NW and SW Ross Sea (Fig. 1).

Swells open up the pack ice in the central Ross Sea even during winter, so the observed scarcity in leads may have been due to a period of calm weather (Langhorne et al. 1998). Not surprisingly, in a seascape covered by a uniform sheet of new ice, most sightings were of individuals standing or hauled out next to isolated holes or narrow leads. During such days of reduced access to open water, penguins may toboggan and swim from lead to lead.

In contrast to Adélie penguins (*Pygoscelis adeliae*), which also winter in Antarctica but don't breed until spring, emperors need to gain a maximum weight before the breeding fast (Le Maho 1977). Because of the thin ice, it was not possible to weigh birds or attach transmitters. Thus, from their aggregated position around leads and holes as well as from the presence of guano, we conclude they were feeding while travelling, possibly on *Pleuragramma antarcticum*, a common prey above the continental shelf (Kooyman et al. 2004). This behaviour was also apparent in the zigzagging trajectories of the birds tracked by Kooyman et al. (2004) and consistent with the body mass of over 30 kg of 20 individuals we weighed shortly after this survey at and around Cape Colbeck (Fig. 1). The gradual increase in the number of birds when approaching the ERS, as well the direction of travel of the post-moult birds tracked by Kooyman et al. (2004; Fig. 1), suggests the birds observed during the surveys were travelling from east to west.

GLM modeling showed that *ice type,* per cent *ice cover* and *chlorophyll-a* were non-significant predictors of penguin counts. The lack of variability in ice characteristics along the survey transect is the likely cause of this result. However, it does not rule out the possibility that birds may initially have migrated along a route through open water (low percent ice cover), favourable to travel and feeding, but due to sudden changes in weather they found themselves encased in new ice, biasing our observations and subsequent analysis. The absence of relationship between chlorophyll-a concentration and emperor penguin density in our best model is in line with Ballard et al. (2012), who found that among a suite of environmental covariates, chlorophyll concentration has the weakest predictive power for emperor penguin distribution. Again, the time frame and environmental conditions under which our survey was made make comparisons with other studies, carried out mostly during the austral summer, tentative.

This report sheds light on behavioural aspects of the post-moult migration of emperor penguins, a life stage that had hitherto never been directly observed. It includes: (1) the formation of a migratory front composed of small clusters of birds moving west, (2) the aggregation of penguins around ice holes maintained by bird activity, allowing them access to food and (3) the occasional sighting of birds far from open water suggesting they travel over-ice to distant leads.

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