RESEARCH ARTICLE

Penguins are attracted to dimethyl sulphide at sea

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SUMMARY

Breeding *Spheniscus* penguins are central place foragers that feed primarily on schooling pelagic fish. They are visual hunters, but it is unclear how they locate prey patches on a coarse scale. Many petrels and storm petrels (Procellariiformes), the penguins' closest relatives, use olfactory cues to locate prey concentrations at sea, but this has not been demonstrated for penguins. Procellariiforms are attracted to a variety of olfactory cues, including dimethyl sulphide (DMS), an organosulphur compound released when phytoplankton is grazed, as well as fish odorants such as cod liver oil. A recent study found that African penguins *Spheniscus demersus* react to DMS on land. We confirm this result and show that African penguins are also attracted by DMS at sea. DMS-scented oil slicks attracted 2–3 times more penguins than control slicks, whereas penguins showed no response to slicks containing cod liver oil. The number of penguins attracted to DMS increased for at least 30 min, suggesting penguins could travel up to 2 km to reach scent cues. Repeats of land-based trials confirmed previous results showing DMS sensitivity of penguins on land. Our results also support the hypothesis that African penguins use DMS as an olfactory cue to locate prey patches at sea from a distance, which is particularly important given their slow commuting speed relative to that of flying seabirds.

Key words: olfaction, DMS, prey location, orientation cue, Spheniscidae.

INTRODUCTION

Penguins (Spheniscidae) are visual predators that capture live prey by underwater pursuit diving (Williams, 1995; Wilson et al., 1993). During the breeding season, penguins rely on locating sufficent prey to feed their chicks within a restricted range of their colonies. Prey aggregations tend to be patchily and randomly distributed (Hunt et al., 1999), and little is known about how breeding penguins locate prey patches on a coarse scale (Wilson and Wilson, 1995). Many procellariiforms, the closest relatives to penguins (Hackett et al., 2008), are attracted to odours associated with their prey, including fish oils, krill pyrazines and trimethylamine, and organosulphur compounds associated with phytoplankton (reviewed by Nevitt, 2008). Dimethyl sulphide (DMS) is released when phytoplankton is grazed (Dacey and Wakeham, 1986), indicating areas of high productivity and associated grazers such as Antarctic krill *Euphausia superba* and planktivorous fish (Nevitt, 2000). By detecting odours related to their prey, procellariiforms are able to find small, ephemeral prey patches in a seemingly featureless ocean environment (Nevitt, 1999; Nevitt, 2000). Such ability would be valuable for penguins, especially given their slow commuting speed relative to that of flying seabirds.

Cunningham and colleagues demonstrated through a series of land-based experiments that African penguins *Spheniscus demersus* Linnaeus respond to DMS at concentrations typical of those found in their natural foraging environment (Cunningham et al., 2008). The use of DMS for detecting prey patches has also been suggested for Humboldt penguins *S. humboldti* (Culik, 2001; Culik et al., 2000). However, at sea, experiments to demonstrate the reaction of penguins to odorants have not been attempted. Here, we repeated land-based experiments to confirm previous findings of DMS sensitivity (Cunningham et al., 2008) and tested whether African penguins respond to DMS and a fish odorant (cod liver oil) at sea using trials similar to those demonstrating the importance of olfactory cues among procellariiforms (Nevitt et al., 2004).

MATERIALS AND METHODS
Land-based trials

All trials were conducted in Nelson Mandela Bay, South Africa (Fig. 1A) during April–June 2010, the peak chick-rearing period of African penguins (Hockey et al., 2005). Land-based trials were conducted from 3 to 7 May on St Croix Island (33°48′S, 25°46′E). The methodology repeated that used for African penguins at Robben Island, South Africa, by Cunningham and colleagues (Cunningham et al., 2008). A $1\,\mu mol\,l^{-1}$ solution of DMS dissolved in 25 ml distilled water or a control of distilled water only was placed in a Petri dish along a penguin walk-way (paths between the birds' nests and the shore). Marker poles were erected 1.5 m on either side of the sample dish and randomly selected penguins were observed to see how long they spent within the 3 m demarcated area. The observer sat >100 m away, hidden from the birds, and was unaware which sample was deployed. Each trial lasted 35 min with both a control and a scented trial conducted every morning after sunrise (06:30 h–08:00 h, N=8) and every evening before sunset (16:30 h–18:00 h, N=8). Wind strength varied from light to moderate (approximately 5–40 km h⁻¹) and was from a range of directions. Only penguins heading out to sea in the mornings and returning to their nests in the evenings were sampled, so it is unlikely that any individual was sampled twice during a trial period. It was assumed that if the penguins responded to the DMS deployments, they would spend more time within the test area.
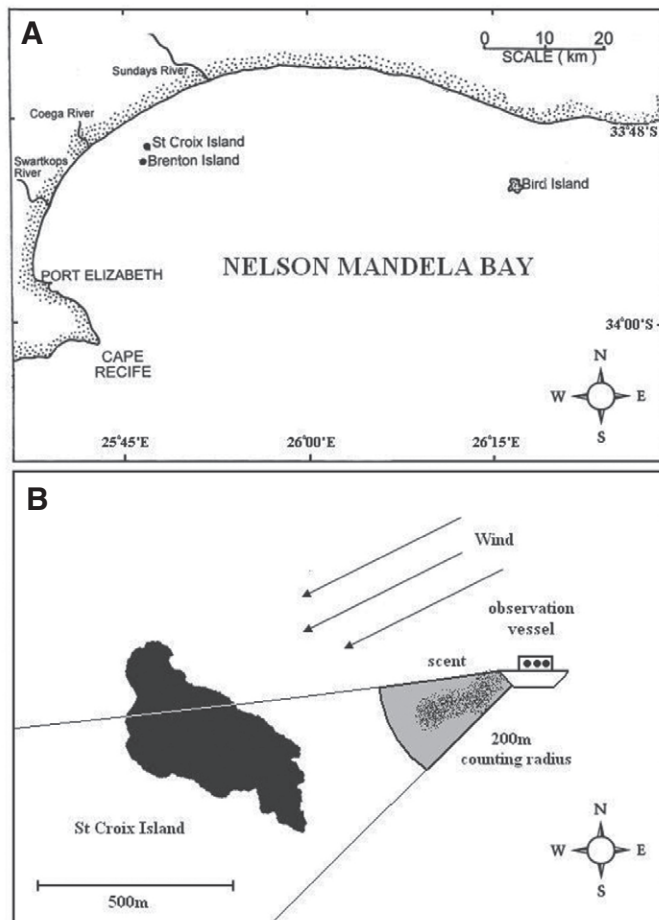
Fig. 1. Study sites (A) and schematic of experimental protocol at sea showing the count area (shaded) and expected odour plume dispersal (dots) (B).

Sea-based trials

At-sea trials followed the method used previously for procellariiforms (Nevitt et al., 1995; Nevitt et al., 2004), comparing the number of birds attracted to scented and control treatments. Oil slicks were released off the stern of a boat approximately 500 m upwind of either St Croix or Bird Island (33°50′S, 26°17′E) between 09:00 h and 14:00 h (Fig. 1B). This close proximity was chosen as too few penguins were recorded for adequate statistical power during initial trials conducted 5 km from the islands (penguin density decreases exponentially with distance from colonies). Slicks were scented with DMS (0.2 mol l^{-1} DMS concentration in 2.5 l of vegetable oil, N=10) or cod liver oil (380 ml added to 2.12 l of vegetable oil, N=6), with control slicks consisting of vegetable oil only (2.5 l). Paired experimental and control slicks were released in succession from the same location (determined by GPS). The order was randomised and the observer was not aware which slick was deployed. Slicks drifted away from the release point during trials because of strong near-shore currents and dissipated within 30 min (Nevitt et al., 1995; Nevitt et al., 2004). Presentations were separated by 45–60 min to ensure roughly similar conditions within slick pairs but without cross-contamination. Trials were conducted at wind speeds of <20 km h^{-1} with swells <2 m. The boat stayed upwind of the slick and the number of penguins within a 200 m radius was counted every minute from 2 min before slick release until 30 min after. Given the relatively small number of penguins in the count area and their slow swimming speed, it was possible to track individual penguins in most trials, to give an estimate of the total number of individuals present. This was compared with the total number of penguins counted to assess whether birds remained longer in the count area during experimental or control trials.

Data analysis

For the land-based trials, the time penguins spent between the flags was compared between morning and evening as well as experimental and control trials. We used Mann–Whitney U-tests (one-tailed) as the data were not normally distributed and variances were significantly different. For the sea-based trials, paired t-tests (one-tailed) were used to compare the total number of penguins counted after slick release as well as the maximum single count between experimental and control slicks. To assess the degree of attraction of experimental slicks, the mean number of penguins counted in each 5 min interval was divided by the respective mean count during control deployments.

RESULTS

In the land-based trials, the time spent in the test area by returning birds in the evening was significantly greater for DMS trials (mean ± s.e.m. 18.6±0.84 s, N=129) than for control trials (14.7±1.13 s, N=144; U=7329, P=0.003), but there was less of a difference in the morning (13.7±0.76 s, N=152 vs 11.7±0.81 s, N=128; U=8009, P=0.051). Overall, penguins spent significantly longer between flags in the evenings than in the mornings (U=27252, P<0.001).

In the experiments at sea, the number of penguins varied considerably between trials, but the number attending DMS-scented slicks was consistently greater than that for control slicks whereas there was no pattern among trials with cod liver oil (Fig. 2). Overall, three times more penguins were counted at DMS slicks (N=1079) than at control slicks (N=360), and the maximum number of penguins was greater at DMS slicks than at control slicks (mean ± s.e.m. for DMS 11.1±2.6; control 5.0±1.2; paired t=3.50, d.f.=9, P=0.003). There was no difference between the maximum number attending cod liver oil (5.3±1.9) and control slicks (5.2±1.9; paired t=0.04, d.f.=5, P>0.5). The difference between the number of
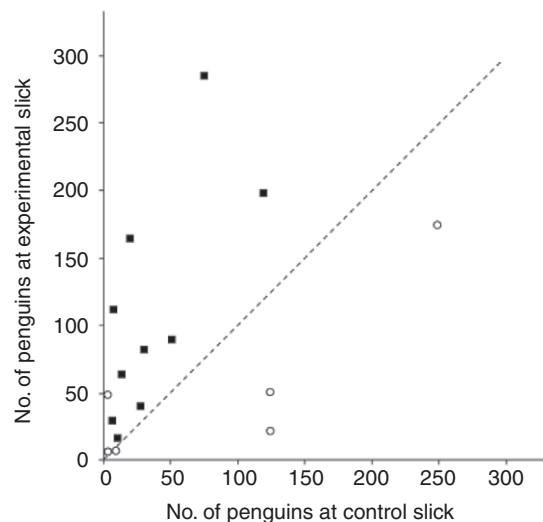

Fig. 2. Biplot of the total number of penguins counted over 30 min at experimentally scented and control slicks. Solid squares, dimethyl sulphide (DMS); open circles, cod liver oil.
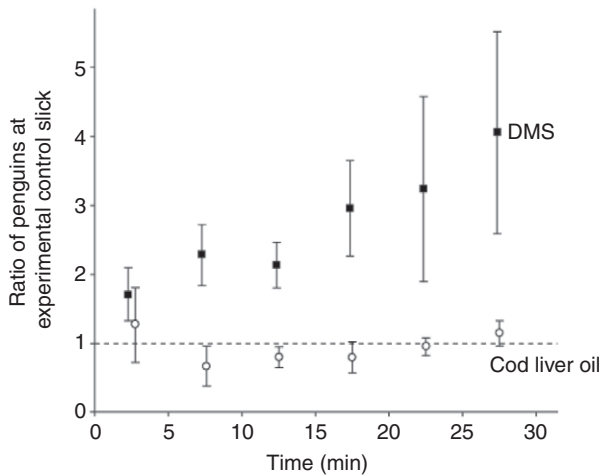
Fig. 3. The ratio (mean ± s.e.m.) between the mean number of penguins attending experimental (scented) and control (unscented) oil slicks, showing the consistent increase in penguins at DMS-scented slicks (N=10) and no response to cod liver oil-scented slicks (N=6).

penguins attending DMS deployments and control slicks increased with time (Fig. 3), although peak numbers were recorded roughly 20 min after slick release (median, 19.5 min). Comparing estimates of the number of individual penguins suggests that penguins remained in the count area slightly longer during DMS deployments; in the seven DMS trials when birds were tracked, 190 individuals were counted at DMS slicks compared with 78 at control slicks (ratio 2.44:1, compared with 3.36:1 for the total number counted at these trials).

DISCUSSION

Our study confirms that African penguins react to DMS on land (Cunningham et al., 2008) and we have demonstrated for the first time that penguins are attracted to DMS at sea. In the previous land-based experiments conducted at Robben Island, only penguins returning from the sea in the evening responded to DMS (Cunningham et al., 2008), but we found a signal in the morning too (albeit less marked than in the evening). Cunningham and colleagues argued that the failure to detect a reaction to DMS in the morning may have been due to the wind blowing consistently offshore at Robben Island, preventing penguins from smelling the DMS in the trial area (Cunningham et al., 2008). In our study, wind direction and strength were more varied, perhaps explaining our result. However, it is intriguing why penguins heading out to forage appear to be less responsive than those returning to the island.

At sea, the DMS-scented slicks attracted 2–3 times more birds than control slicks. This is comparable to levels of attraction recorded among petrels (Nevitt et al., 1995). By comparison, there was no evidence that penguins responded to fish oil. This result might be expected given that penguins, unlike many procellariiforms, do not scavenge dead or damaged fish (Williams, 1995). Fish oils are released when fish are macerated and damaged (Nevitt et al., 2004), and most seabirds swallow their prey whole (Kvitek and Bretz, 2005), limiting the amount of oil released. The number of penguins attending DMS-scented slicks peaked 20–30 min after slick release.

Assuming that African penguins commute at $1.2\,\mathrm{m\,s^{-1}}$ (Petersen et al., 2006), birds were attracted from distances of up to 2 km.

Our study suggests that African penguins use increased atmospheric levels of DMS as an olfactory cue to locate and navigate to areas where zooplankton or fish are grazing. DMS sensitivity is probably an important component of the African penguin's foraging strategy. African penguins are visual hunters on a fine scale (Wilson, 1985; Wilson et al., 1993; Wilson and Wilson, 1995; Ryan et al., 2007), but it is not known how they locate prey on a coarser scale. Relying on random searching would be inefficient given the patchiness of their prey (Wilson, 1985; Weimerskirch, 2007). It is likely that DMS is one of a suite of cues used by African penguins to locate favourable foraging areas. DMS sensitivity should be assessed for other penguin genera to establish how widespread the ability is. It would also be interesting to see whether species targeting other prey respond to different olfactory cues (e.g. if *Pygoscelis* penguins are attracted by krill-scented compounds).

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