Polar Science 9 (2015) 393–400

Contents lists available at ScienceDirect

Polar Science

journal homepage: http://ees.elsevier.com/polar/

Chinstrap penguin foraging area associated with a seamount in Bransfield Strait, Antarctica

Nobuo Kokubun [a, b, *], Won Young Lee [c], Jeong-Hoon Kim [c], Akinori Takahashi [a, b]

[a] National Institute of Polar Research, Japan, 10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan
[b] Department of Polar Science, School of Multidisciplinary Sciences, SOKENDAI (The Graduate University for Advanced Studies), 10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan
[c] Korea Polar Research Institute, 26 Songdomirae-ro, Yeonsu-gu, Incheon 406-840, Republic of Korea

A R T I C L E I N F O

Article history:
Received 28 April 2015
Received in revised form
25 September 2015
Accepted 5 October 2015
Available online 9 October 2015

Keywords:
Foraging habitat
Bathymetry
Bransfield current
Antarctic krill
Upwelling

A B S T R A C T

Identifying marine features that support high foraging performance of predators is useful to determine areas of ecological importance. This study aimed to identify marine features that are important for foraging of chinstrap penguins (*Pygoscelis antarcticus*), an abundant upper-trophic level predator in the Antarctic Peninsula region. We investigated the foraging locations of penguins breeding on King George Island using GPS-depth loggers. Tracking data from 18 birds (4232 dives), 11 birds (2095 dives), and 19 birds (3947 dives) were obtained in 2007, 2010, and 2015, respectively. In all three years, penguins frequently visited an area near a seamount (Orca Seamount) in Bransfield Strait. The percentage of dives (27.8% in 2007, 36.1% in 2010, and 19.1% in 2015) and depth wiggles (27.1% in 2007, 37.2% in 2010, and 22.3% in 2015) performed in this area was higher than that expected from the size of the area and distance from the colony (8.4% for 2007, 14.7% for 2010, and 6.3% for 2015). Stomach content analysis showed that the penguins fed mainly on Antarctic krill. These results suggest that the seamount provided a favorable foraging area for breeding chinstrap penguins, with high availability of Antarctic krill, possibly related to local upwelling.

1. Introduction

When studying the marine environment, it is important to identify and quantify environmental factors that affect the foraging behavior of top predators. This research is useful to determine areas of high ecological significance and to address conservation concerns (Block et al., 2002; Hindell et al., 2011). Foraging hotspots are defined as areas associated with particular marine features that result in high foraging performance (Hastie et al., 2006; Seminoff et al., 2014). Understanding the underlying physical and biological processes that create foraging hotspots is key to ecological monitoring, conservation, and marine spatial planning (Hazen et al., 2013). Several types of marine features are associated with foraging hotspots. These include persistent hydrographic features such as oceanic fronts (Biuw et al., 2007; Bost et al., 2009); ephemeral hydrographic features such as mesoscale eddies (Cotté et al., 2007); and static bathymetric features such as continental shelves (Clarke et al., 2006; Costa et al., 2008), submarine canyons (Santora and Reiss, 2011), and seamounts and banks (Barlow and Croxall, 2002; Lea et al., 2008; Hindell et al., 2011). Static foraging hotspots driven by bathymetric features are especially important for marine predators, because of their high predictability (Hazen et al., 2013).

Chinstrap penguins (*Pygoscelis antarcticus*) are one of the most abundant top predators in the Antarctic Peninsula region (Brooke, 2004). During the breeding season, they are land-based, central place foragers, and their foraging efforts are concentrated in near-shore areas within 100 km from the colony (Lynnes et al., 2002). Their ecological niche is less ice-dependent compared to that of congeneric Adélie penguins (*P. adeliae*; Lynnes et al., 2002; Forcada et al., 2006) and more pelagic compared to that of gentoo penguins (*P. papua*; Kokubun et al., 2010; Miller et al., 2010). Populations of chinstrap penguins have declined in the Antarctic Peninsula region in recent decades, and this has been attributed to both climate-driven and fisheries-related changes in the availability of Antarctic krill (Trivelpiece et al., 2011). However, relatively little is known about the local marine features that affect the foraging behavior of

* Corresponding author. National Institute of Polar Research, Japan, 10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan.
E-mail address: kokubun@nipr.ac.jp (N. Kokubun).

http://dx.doi.org/10.1016/j.polar.2015.10.001
1873-9652/

this species (but see Takahashi et al., 2003; Ichii et al., 2007). With GPS-depth loggers it is possible to record the foraging locations of marine predators at high resolution and to relate their foraging performance to the marine environment at spatial scales of <1 km (Ryan et al., 2004). Previous studies using GPS-depth loggers have shown that penguin foraging behaviors are closely related to fine-scale (about 1 km) bathymetric features. For example, yellow-eyed penguins (*Megadyptes antipodes*) follow the same movement paths across multiple trips, possibly using bottom topography as a landmark (Mattern et al., 2007). Gentoo penguins frequently visit particular coastal areas with shallow depths and perform benthic dives (Kokubun et al., 2010). Investigations into foraging locations of top predators using GPS-depth loggers are key to marine spatial planning in terms of conservation and ecosystem-based management.

The aim of this study was to investigate whether the foraging behavior of chinstrap penguins is associated with particular marine habitats characterized by bathymetric features, such as small-scale seamounts. In addition, we discuss the possible factors driving the patterns of habitat use in chinstrap penguins.

2. Materials and methods

2.1. Study site

The field study was conducted in a colony on Barton Peninsula (62°14.3′S, 58°46.5′W), King George Island, Antarctica, where 2961 pairs of chinstrap penguins and 1719 pairs of gentoo penguins bred in the 2006/2007 season. The study colony is located in the Antarctic Specially Protected Area (ASPA) #171 Narębski Point (ATCM, 2009). The study was conducted for three austral summers, from 25 December 2006 to 28 January 2007 (hereafter described as 2007), 30 December 2009 to 23 January 2010 (hereafter described as 2010), and 29 December 2014 to 19 January 2015 (hereafter described as 2015). The study periods corresponded to the chick-guarding period of chinstrap penguins.

2.2. Environmental setting

The sea around the study colony is characterized by two important bathymetric features (Fig. 1): Maxwell Bay, a 6–14 km wide bay surrounded by King George Island and Nelson Island, which features a U-shaped submarine valley with a maximum depth of 550 m (Khim and Yoon, 2003); and Bransfield Strait, a 110 km wide strait between the Antarctic Peninsula and the South Shetland Islands, with a maximum depth of 2000 m (Schreider et al., 2014). Maxwell Bay and the northern part of Bransfield Strait can be subdivided into shelf (≤200 m in depth) and offshelf, offshore (>200 m in depth) areas. In the offshore area of Bransfield Strait, there is a seamount of volcanic origin, called Orca Seamount (62°26′S, 58°24′W). The summit of this seamount is 700 m below the sea surface, and its relative elevation from the ocean floor of Bransfield Strait is 550 m. The approximate diameter is 20 km (Schreider et al., 2014). This is the only seamount within the penguin foraging range from the study colony.

We classified the penguin foraging areas into five zones based on bathymetry (Fig. 1): 1) the King George Island shelf zone, defined by bottom depth ≤200 m along the King George Island coast; 2) the Nelson Island shelf zone, defined by bottom depth ≤200 m along the Nelson Island coast; 3) the Maxwell Bay zone, defined by bottom depth >200 m and within 10 km from Narębski Point; 4) the Bransfield Strait slope zone, defined by bottom depth >200 m and >10 km from Narębski Point, excluding the Seamount zone; and 5) the Seamount zone, defined as the area within a circle of 10 km radius from the center of the Orca Seamount.

We analyzed the chlorophyll *a* concentration around the study area during the study period using satellite imagery, because it is an environmental factor potentially reflect local marine productivity. We used monthly-averaged chlorophyll *a* concentration data for January of 2007, 2010, and 2015, acquired from the Chlorophyll *a*, Aqua MODIS, NPP, L3SMI, Global, Science Quality, (Monthly Composite) dataset available at the National Oceanic and Atmospheric Administration Earth Research Division's Data Access Program (ERDDAP) webpage, http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMH1chlamday.graph?chlorophyll. The chlorophyll *a* data with a 2.5′ × 2.5′ resolution were extracted for the colored area shown in Fig. 1, which covers the maximum foraging range of the penguins. Next, the chlorophyll *a* concentration was compared among the five zones or the 3 study years using generalized linear models (GLMs). We used the likelihood ratio test (LRT) to investigate the effect of zones or years and a gamma error distribution in the GLMs, because the errors are not normally distributed. We used R ® 3.1.1 software (R Development Core Team, 2014) to conduct the GLMs.

2.3. Deployment of data loggers

To collect location and dive data, three types of GPS-depth loggers were deployed on 20, 17, and 20 chick-guarding chinstrap penguins in 2007, 2010, and 2015, respectively. The GPS-depth loggers used in 2007, 2010 and 2015, were GPL380-DT and GPS-TD log, GPL380-DT, and GPL400-D3GT, respectively. The details of the GPS-depth loggers used are as follows: the GPL380-DT (Little Leonardo, Tokyo, Japan), a rectangular container (58 mm in length × 28 mm in width × 20 mm in height) with a cylindrical battery section (20 mm in diameter and 47 mm in length) and a mass in air of 92 g; the GPS-TD logger (Earth and Ocean Technologies, Kiel, Germany), a stream-lined fiber-composite container unit, 96 mm in length × 36 mm in width × 27 mm in height, with a mass in air of 86 g; and the GPL400-D3GT (Little Leonardo), a cylindrical unit 20 mm in diameter and 113 mm in length, with a mass in air of 55 g. We instrumented only one bird per breeding pair. The weight of these loggers represented 1.1–2.7% of the body mass of the study birds. The loggers were attached on the lower medial portion of the back using tesa® tape, plastic cable ties, and instant glue (Loctite 401®; Loctite Corporation). The loggers were set to record dive depth, water temperature, and location every second. The loggers were attached to the penguins before their departure for a foraging trip, and were removed upon return to the colony.

2.4. Foraging parameters

Foraging trip duration was defined as the time between the start of the first dive (deeper than 1 m) after departure from the colony and the end of the last dive before arriving back at the colony. Only dives deeper than 1 m were included because of possible measurement error in the instruments (Takahashi et al., 2003). Maximum distance from the colony during the foraging trips was defined as the distance between the colony and the most distant point of each trip. Dives deeper than 5 m were considered to be potentially related to foraging. The majority of dives were shallower than 5 m (43.9 ± 18.1%, 46.3 ± 13.0%, and 49.0 ± 14.6% for 2007, 2010, and 2015, respectively), but these dives accounted for only a small portion of the total dive duration (7.0 ± 4.4%, 10.9 ± 8.2%, and 9.6 ± 6.2% for 2007, 2010, and 2015, respectively). Therefore, these shallow dives (<5 m) are likely to constitute traveling dives, as noted in previous studies (Takahashi et al., 2003; Kokubun et al., 2010). Hereafter “dives” refers to the potential foraging dives deeper than 5 m unless stated otherwise.

The last location just prior to a dive was used as the location of