J Ethol (2017) 35:131–135
DOI 10.1007/s10164-016-0500-x

ARTICLE

Breeding records of kelp gulls in areas newly exposed by glacier retreat on King George Island, Antarctica

Won Young Lee[1] · Hyun-Cheol Kim[2] · Yeong-Deok Han[1,3] · Chang-Uk Hyun[2] · Seongseop Park[1,4] · Jin-Woo Jung[1] · Jeong-Hoon Kim[1]

Received: 24 June 2016 / Accepted: 3 October 2016 / Published online: 15 October 2016
© Japan Ethological Society and Springer Japan 2016

Abstract In recent decades, the glaciers on the Antarctic Peninsula have been rapidly retreating. Using satellite images taken during the austral summer from 1989 to 2016, we estimated the glacier pattern on King George Island in the Antarctic Peninsula, Antarctica, and found that glacier boundaries have gradually retreated. We have recorded the kelp gull nest sites in this glacier-retreat region during four breeding seasons (from 2012–2013 to 2015–2016). Satellite images and newly established kelp gull nests suggest that glacier retreat could lead to an enlarged breeding habitat for kelp gulls.

Keywords Antarctic Peninsula · Climate warming · Climate change · Nesting site · Breeding habitat

Electronic supplementary material The online version of this article (doi:10.1007/s10164-016-0500-x) contains supplementary material, which is available to authorized users.

✉ Jeong-Hoon Kim
jhkim94@kopri.re.kr

[1] Division of Polar Life Sciences, Korea Polar Research Institute, Incheon 21990, Republic of Korea

[2] Division of Polar Ocean Environment, Korea Polar Research Institute, Incheon 21990, Republic of Korea

[3] Department of Biological Sciences, College of Natural Sciences, Inha University, Incheon 22212, Republic of Korea

[4] Division of Life Sciences, Incheon National University, Incheon 22012, Republic of Korea

Introduction

In recent decades, the glaciers on the Antarctic Peninsula have been rapidly retreating (Cook et al. 2005). Specifically, changes caused by intensified glacier melt due to recent climate change have been observed on King George Island (KGI), the South Shetland Islands, and in the northern part of the Antarctic Peninsula (Rückamp et al. 2011). Croxall (2004) expected that Antarctic birds would be greatly influenced by marine environmental changes related to global climate processes. In the Antarctic Peninsula, populations of chinstrap penguin (*Pygoscelis antarctica*) and Adélie penguin (*Pygoscelis adeliae*), which are sea ice-dependent species, have decreased, which is possibly related to the reduced availability of Antarctic krill (*Euphausia superba*) due to climate warming, while the gentoo penguin (*Pygoscelis papua*), a sea ice-independent species, has expanded its range and population (Clucas et al. 2014). This implies that species which favor ice-free areas may have more chances to expand their habitats following glacier retreat in the Antarctic Peninsula (Parnikoza et al. 2008).

The kelp gull (*Larus dominicanus*) is a widespread seabird in the Southern Hemisphere, including sub-Antarctic islands and the Antarctic Peninsula (Harrison 2003). Breeding nests of kelp gulls have been continuously recorded in ice-free areas on KGI since the 1970s (Aguirre 1995; Lumpe and Weidinger 2000; Sander et al. 2006). In the Antarctic Peninsula, kelp gulls are highly dependent on Antarctic limpets (*Nacella concinna*) on shores (Favero et al. 1997), and their nest sites are found in coastal habitats where rocks and food sources are abundant (Quintana and Travaini 2000).

Here, we examined glacial retreat on the Barton Peninsula of KGI, and kelp gull nest distribution in recently exposed areas. While surveying Antarctic birds' breeding sites on KGI, we found newly exposed areas with many

moraines where we observed kelp gull nests. Although long-term studies of kelp gull nests were recently conducted on KGI (Sander et al. 2006; Branco et al. 2009), the glacial retreat and its possible correlation with nest distribution were not considered in previous studies. We thus analyzed satellite images from 1989 to 2016 to observe glacier patterns, and recorded kelp gull nest locations in newly exposed areas.

Materials and methods

Our study was conducted in the eastern part of the Barton Peninsula, KGI, South Shetland Islands, Antarctica (62°13′35–55″S, 58°42′15″–43′00″W; Fig. 1), which shares a boundary with the Fourcade glacier. We selected eight satellite images that were clear enough to determine glacier boundaries during the austral summer (December–March) 1989–2016 (for the images and spatial resolution, see Fig. S1; the images were taken on 28 January 1989 from Landsat-4 TM, US Geological Survey; 31 December 1999 and 26 March 2005 from Google Earth; 6 December 2006 from Quickbird-2, DigitalGlobe; 21 March 2011 and 21 February 2013 from Google Earth; and 3 February 2015 and 18 January 2016 from Korea Multi-Purpose Satellite-3, Korea Aerospace Research Institute). Due to the low resolution (30 m) in 1989, we additionally considered the high contrast of brightness values between glacier-covered regions and non-glacier regions in red, green and blue color space, to decide the indistinct boundaries in that low-resolution satellite image. For each satellite image, we performed geometric correction to adjust geometrical errors of the image using the digital topographic map (1:5000) of the Barton Peninsular, KGI (Kim et al. 2013). From the glacier boundaries and the coastline, we determined an ice-free area newly exposed since 1989 (Fig. 1).

To determine clutch size, kelp gull nests were visited twice in mid-December during four consecutive breeding seasons from 2012–2013 to 2015–2016. Nest site locations were recorded using a global positioning system (Geo7x handheld; Trimble GeoExplorer, Sunnyvale, CA). Nest area was measured with polygons drawn in Google Earth (version 7.1.5.1557; Google, Mountain View, CA). We compared clutch size among 4 breeding years using one-way ANOVA with Tukey's post hoc test in SPSS version 18.0 (SPSS, Chicago, IL).

Results and discussion

According to 1989–2016 satellite images, glacier boundaries have gradually changed in our study site (Fig. 1). Over these 27 years, glaciers have retreated approximately 200–300 m from the coast, heading inland and leaving behind newly exposed areas. The ice-free area newly exposed since 1989 is approximately 96,000 m^2 at present (January 2016; Fig. 1). We observed 30 kelp gull nests in the 2012–2013 breeding season, 32 in 2013–2014, 34 in 2014–2015 and 21 in 2015–2016 in two habitats (habitats A and B; Fig. 1 and Table 1). Other seabird nests were not observed in this newly exposed area. From the satellite images, habitat A was covered with the glacier until at least 1989, and was exposed before 1999, while habitat B was exposed between 1989 and 2006 (Fig. 1). Although we did not determine the geological details, it seemed that there were geological differences between the two habitats, such as the degree of slope and the frequency of rocks, which can affect the kelp gull's nest-site selection. Habitat A comprises a hillside area with steeper slopes, while habitat B is located on a gentle slope near the sea with more rocks. In terms of the number of nests, habitat B was approximately two to three times more preferred than A (nine, ten, eight, and seven nests in A; 21, 22, 26 and 24 nests in B, from 2012–2013 to 2015–2016, respectively; Table 1), despite the fact that A was exposed earlier than B (Fig. 1). Clutch size, nest density and nest areas in the two habitats are provided in Table 2. Clutch size varied among 4 years (average values 1.85–2.47; $F_{3,79} = 4.36$, $P = 0.007$; one-way ANOVA; Table 2). Clutch size in the 2012–2013 season was significantly higher than in 2014–2015 and 2015–2016 (2012–2013 vs. 2014–2015, $P = 0.019$; 2012–2013 vs. 2015–2016, $P = 0.024$; Tukey's post hoc test). Clutch size in our study population appeared to be lower than that of a kelp gull population at Nelson Island on KGI [on average 2.6 eggs (Lumpe and Weidinger 2000)]. Compared with a neighboring kelp gull population at Admiralty Bay, nest density in our study site seemed to be relatively high [1.2–300 nests/km^2 (Sander et al. 2006); 10.5–14.9 nests/km^2 (Branco et al. 2009); 218.8–354.2 nests/km^2 (this study; Table 2)]. Considering that avian clutch size may reduce in high-density habitats (Dhondt et al. 1992; Both et al. 2000), we expect that the high nest density in our study site could be responsible for the low clutch size, through intraspecific competition for nest sites.

Our results indicate that kelp gulls have been breeding in newly exposed areas on KGI for the last few decades. The glacial retreat has exposed many moraine surfaces, formed from glacial debris of soil and rock. Why did kelp gulls colonize this habitat? One possibility is that rocks in the scattered moraines, which protect the birds and offspring against strong winds, could attract kelp gulls to this place for nesting (Suárez et al. 2010). Specifically, the harsh Antarctic winds on the coastal slopes where kelp gulls breed may be stressful for breeding birds. As expected, we observed that all kelp gull nests in our study site were surrounded by several rocks (nests were approximately 40–50 cm away from rocks).

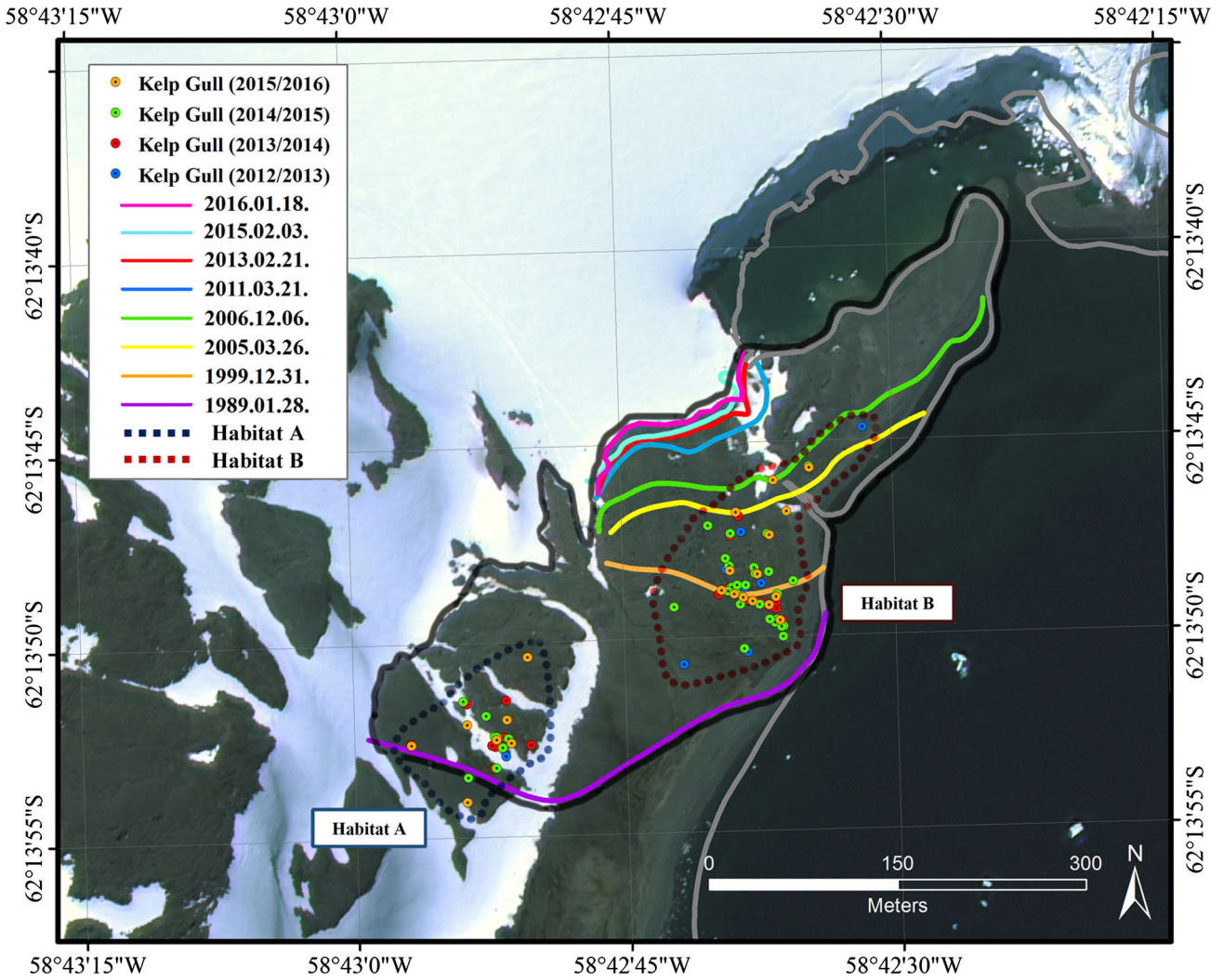

Fig. 1 Changes in glacier boundaries 1989–2016 determined by satellite image analyses, and records of kelp gull nest distributions in two habitats [*Habitat A* (*blue dotted line*) and *Habitat B* (*red dotted line*)] during four breeding seasons (2012–2013, 2013–2014, 2014–2015 and 2015–2016) on the eastern coast of the Barton Peninsula, King George Island, South Shetlands, Antarctica (62°13′35–55″S, 58°42′15″–43′00″W). *Grey solid line* indicates the coastline from the digital topographic map (1:5000) in 2011, *black solid line* indicates the ice-free area newly exposed since 1989

Table 1 Number of total nests, number of nests with eggs and number of reused nests from previous years for four breeding seasons from 2012–2013 to 2015–2016

Breeding season	No. of nests (total)		No. of nests (with eggs)		No. of reused nests	
	A	B	A	B	A	B
2012–2013	9	21	5	11	–	–
2013–2014	10	22	10	22	4	13
2014–2015	8	26	4	9	2	10
2015–2016	7	14	7	14	2	6

Habitat selection in birds is a decision-making process in restricted environmental conditions (Block and Brennan 1993). Based on our observations on breeding records for the newly exposed areas, we suggest that kelp gulls selected this habitat for its favorable nesting conditions, such as moraines and vegetation, after glacier retreat. Previous studies also suggested that kelp gulls select nest sites in favorable habitats in areas with rocks and vegetation cover, not in random sites (Burger and Gochfeld 1981; Borboroglu and Yorio 2004).

In which case, where did the breeding kelp gulls originate? One of the most promising candidates is a

Table 2 Clutch size (mean ± SD), nest density, and areas in two habitats (habitats A and B; Fig. 1) for four breeding seasons from 2012–2013 to 2015–2016

Breeding season	Clutch size (mean ± SD)	Density[a] (no. of total nests/km^2)	Area (m^2; in habitat A/habitat B)
2012–2013	2.25 ± 0.68 (n = 16)	312.5	1,687/8,807
2013–2014	2.47 ± 0.62 (n = 32)	333.3	3,160/6,251
2014–2015	1.85 ± 0.55 (n = 13)	354.2	1,333/9,315
2015–2016	1.95 ± 0.67 (n = 21)	218.8	3,785/4,679

[a] Calculated as the total number of nests divided by the ice-free area newly exposed since 1989 (0.096 km^2; see Fig. 1)

neighboring kelp gull population at Potter Peninsula, approximately 2–3 km away from the glacier retreat region. In this area, 200–400 kelp gulls, including 44–49 breeding pairs and non-breeders, were observed in the mid 1990s (Aguirre 1995; Favero et al. 1997). Other candidates are a population on the Nelson Islands [10–20 km away, ten breeding pairs in 1990–1992 (Lumpe and Weidinger 2000)] and a population at Admiralty Bay [20–30 km away, 105–144 breeding pairs from 1978–1979 to 2004–2005 (Sander et al. 2006)]. Although the kelp gull breeding populations on KGI have remained stable for the last few decades (Sander et al. 2006; Branco et al. 2009), the continuous expansion of ice-free areas on the Barton Peninsula on KGI could provide a new breeding site to kelp gulls and lead to a population increase, possibly via immigration of kelp gull adults from neighboring sites.

Satellite images and records of newly established kelp gull nests in our study site suggest that kelp gulls breed in the area newly exposed by recent glacier retreat. Considering that glacial retreat is continuing in a north-westerly direction, we predict that larger areas will be exposed in the near future, providing more breeding sites for kelp gulls. Future surveys in broader regions of the Antarctic Peninsular would reveal how kelp gull populations have changed with glacier retreat. Furthermore, it would be worth trying to investigate the relationship between kelp gull nest-site selection and nest microclimates in areas newly exposed by glacier retreat.

Acknowledgments We thank all staff at King Sejong Station for logistic help.

Compliance with ethical standards

Funding This research was supported by the Long-Term Ecological Researches on King George Island to Predict Ecosystem Responses to Climate Change (PE14020) and Satellite Remote Sensing on the West Antarctic Ocean Research (PE14040) funded by the Korea Polar Research Institute. This work was partly supported by the Basic Science Research Program through the National Research Foundation of Korea, funded by the Ministry of Education, Science and Technology (NRF-2014 R1A6A3A01008495).

Conflict of interest The authors declare no conflict of interest.

Ethical approval All the procedures performed in the studies involving animals were in accordance with the ethical standards of the institution or practice in which the studies were conducted.

References

Aguirre A (1995) Distribution and abundance of birds at Potter Peninsula, 25 de Mayo (King George) Island, South Shetland Islands, Antarctica. Mar Ornithol 23:23–31

Block WM, Brennan LA (1993) The habitat concept in ornithology: theory and applications. Curr Ornithol 11:35–91

Borboroglu PG, Yorio P (2004) Habitat requirements and selection by kelp gulls (*Larus dominicanus*) in central and northern Patagonia, Argentina. Auk 121:243–252

Both C, Tinbergen JM, Visser ME (2000) Adaptive density dependence of avian clutch size. Ecology 81:3391–3403

Branco JO, Costa ES, Araujo J, Durigon E, Alves MAS (2009) Kelp gulls, *Larus dominicanus* (Aves: Laridae), breeding in Keller Peninsula, King George Island, Antarctic Peninsula. Zoologia 26:562–566

Burger J, Gochfeld M (1981) Colony and habitat selection of six kelp gull *Larus dominicanus* colonies in South Africa. Ibis 123:298–310

Clucas GV, Dunn MJ, Dyke G, Emslie SD, Levy H, Naveen R, Polito MJ, Pybus OG, Rogers AD, Hart T (2014) A reversal of fortunes: climate change 'winners' and 'losers' in Antarctic Peninsula penguins. Sci Rep 4:5024

Cook AJ, Fox AJ, Vaughan DG, Ferrigno JG (2005) Retreating glacier fronts on the Antarctic Peninsula over the past half-century. Science 308:541–544

Croxall JP (2004) The potential effects of marine habitat change on Antarctic seabirds. Ibis 146:90–91

Dhondt AA, Kempenaers B, Adriaensen F (1992) Density-dependent clutch size caused by habitat heterogeneity. J Anim Ecol 61:643–648

Favero M, Silva P, Ferreyra G (1997) Trophic relationships between the kelp gull and the Antarctic limpet at King George Island (South Shetland Islands, Antarctica) during the breeding season. Polar Biol 17:431–436

Harrison P (2003) Seabirds of the world: a photographic guide. Princeton University, NJ

Kim SI, Kim HC, Shin JI, Hong SG (2013) Land-cover classification of Barton Peninsular around King Sejong station located in the Antarctic using KOMPSAT-2 satellite imagery. Korean J Remote Sens 29:537–544

Lumpe P, Weidinger K (2000) Distribution, numbers and breeding of birds at the northern ice-free areas of Nelson Island, South Shetland Islands, Antarctica, 1990-1992. Mar Ornithol 28:41–46

Parnikoza I, Inozemtseva DM, Tyschenko OV, Mustafa O, Kozeretska IA (2008) Antarctic herb tundra colonization zones in the context of ecological gradient of glacial retreat. Ukrainian Bot J 65:504–511

Quintana RD, Travaini A (2000) Characteristics of nest sites of skuas and kelp gull in the Antarctic Peninsula. J Field Ornithol 71:236–249

Rückamp M, Braun M, Suckro S, Blindow N (2011) Observed glacial changes on the King George Island ice cap, Antarctica, in the last decade. Glob Planet Chang 79:99–109

Sander M, Carneiro APB, Mascarello NE, Santos CR, Costa ES, Balbão TC (2006) Distribution and status of the kelp gull, *Larus dominicanus Lichtenstein* (1823), at Admiralty Bay, King George Island, South Shetland, Antarctica. Polar Biol 29:902–904

Suárez N, Pozzi L, Yorio P (2010) Nest site selection of the Kelp gull (*Larus dominicanus*) in the Beagle Channel, Tierra del Fuego, Argentina. Polar Biol 33:215–221