Site Selection and Nest Survival of the Bar-headed Goose (*Anser indicus*) on the Mongolian Plateau

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Abstract.—Waterbirds breeding on the Mongolian Plateau in Central Asia must find suitable wetland areas for nesting in a semiarid region characterized by highly variable water conditions. The first systematic nesting study of a waterbird dependent on this region for breeding was conducted on the Bar-headed Goose (*Anser indicus*). The purpose of this study was to document Bar-headed Goose nesting locations, characterize nests and nesting strategies, and estimate daily nest survival ($n = 235$ nests) from eight areas of west-central Mongolia across three summers (2009-2011) using a modified Mayfield estimator. Bar-headed Goose daily nest survival ranged from 0.94 to 0.98, with a 3-year average nest success of 42.6% during incubation. Bar-headed Geese were found to primarily nest on isolated pond and lake islands as previously reported, but were also documented regularly, though less frequently, along rocky cliffs in several regions of west-central Mongolia. Daily nest survival was higher for cliff nests than for island nests. Information-theoretic models indicated that nest survival decreased with nest age and varied annually with changing environmental conditions. Results of this study suggest that while Bar-headed Geese primarily rely on nesting island sites these sites may be more susceptible to anthropogenic disturbance and predation events influenced by seasonal variation in environmental conditions, and that higher daily nest survival values documented for the less frequent cliff nest strategy may provide an important alternative strategy during poor island nest success years. Thus, conservation efforts for this and other waterbird species in the semiarid region should be focused on conserving nesting islands and protecting them from disturbance in areas of high livestock densities experiencing a rapidly warming climate. *Received 1 November 2013, accepted 12 July 2014.*

Key words.—*Anser indicus*, Bar-headed Goose, breeding biology, daily nest survival, daily survival rate, depredation, nest ecology, reproduction, semiarid grassland, waterfowl.

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The Mongolian Plateau is an extensive area located in eastern Central Asia and stretches from the Gobi Desert in the south to the Siberian Taiga Forest in the north. The landscape is dominated by grassland ecosystems that receive little summer precipitation and frequently experience drought (Batima and Dagvadorj 1998). In this semiarid region, breeding waterbirds must search for suitable nesting areas constrained by highly variable water conditions. Wetlands in the Mongolian Plateau support nesting by many species including several ducks, three cranes, two swans and three true geese (tribe Anserini). The Bar-headed Goose (*Anser indicus*) and Swan Goose (*A. cygnoides*) are species of conservation concern that nest in this region (BirdLife International 2009). Their populations are threatened by rapid climate change in their steppe breeding grounds and by habitat conversion in their migration and wintering areas (Batbayar *et al.* 2011; Murray and Fuller 2012; Iwamura *et al.* 2013).

Most true geese migrate several thousand kilometers from southern wintering areas to northern latitudes for breeding. The Bar-headed Goose is unique in that it winters on the Indian subcontinent, crossing the Himalaya during a long distance physiologically demanding migration, or in southwestern China with a series of short distance migration movements on the way to northern breeding grounds (Bishop *et* *al.* 1997; Takekawa *et al.* 2009; Hawkes *et al.* 2011). Bar-headed Goose primary breeding areas are in high altitude wetlands of the Qinghai-Tibetan Plateau in western China and western Mongolia, but they also nest in small numbers in southeastern Kazakhstan, southern Kyrgyzstan, Pakistan, and northern India (Del Hoyo *et al.* 2001; Prins and Wieren 2004; Köppen *et al.* 2010). The global population is estimated at < 60,000 individuals (Wetlands International 2006).

Although the population has a decreasing trend attributed to land use change, hunting, egg collection, and habitat loss, this species is not considered threatened by the International Union for Conservation of Nature (IUCN) because it has an extensive breeding range and meets the threshold for breeding adults (BirdLife International 2009). However, there are several new and emerging threats related to this species. In 2005, more than 3,000 Bar-headed Geese were found dead at Qinghai Lake in western China, the largest known breeding colony for this species, due to infection of highly pathogenic avian influenza H5N1 virus (Chen *et al.* 2005). This disease remains endemic in the region, although dispersal probability is thought to be relatively low (Liu *et al.* 2005; Gaidet *et al.* 2011; Iverson *et al.* 2011; although see Prosser *et al.* 2011). In addition, Bar-headed Geese have suffered extensive loss of breeding habitats because the species nests in semiarid temperate regions subject to decreased rainfall and loss of wetlands with rapid global warming since the beginning of the 20th century (Xu *et al.* 2009). Concomitant melting of glaciers in the Himalaya has affected the extent of wetland nesting areas in China and India (Xu *et al.* 2009). Furthermore, land use change in India (Contina *et al.* 2013) and the southeast Tibetan Plateau (Batima and Dagvadorj 1998) are dramatically changing their wintering habitats.

The objective of this study was to document the breeding biology of the Bar-headed Goose on the Mongolian Plateau, including the examination of spatial requirements of its nesting habitats, estimating nest success and assessing potential threats or risks that may adversely affect reproduction. This region is thought to support a significant proportion of the global population of Bar-headed Geese. However, little has been reported in the literature about the breeding biology and nesting ecology of Bar-headed Geese nesting in semiarid regions of Mongolia, and published breeding data for this species are very limited in general.

METHODS

Study Area

Bar-headed Geese breeding habitats in central, north and west Mongolia, hereafter referred to as west-central Mongolia, are restricted to lakes and river valleys in mountainous areas (Fomin and Bold 1991; Gombobaatar and Monks 2011). Our study was conducted at eight sites located in the northern part of Khangai Mountain Range (hereafter Khangai region) extending between Arkhangai and Zavkhan provinces in west-central Mongolia (Fig. 1). Geographically, much of Mongolia is located in the temperate semiarid zone of the Eastern Palearctic. The study area is located between 1,800 and 3,900 m above sea level, and the region is characterized by forested mountains with short grass steppe distributed at lower elevations in the river valleys between the mountains with well-developed river and lake systems. Several of Mongolia's largest rivers originate in the Khangai Mountains, and numerous large freshwater lakes are found in this region, including Terkhiin Tsagaan (6,100 ha), Sangiin Dalai (16,500 ha), Telmen (19,400 ha), and Khar (8,450 ha) Lakes. However, most other lakes are small in size and are characterized by mesotrophic saline or low mineralized water quality (Tserensodnom 2000).

The main climate of the Khangai region is continental semiarid. The region has long and cold winters, short summers, and large annual and seasonal air temperature fluctuations. The average annual precipitation is > 350 mm, which falls within the highest precipitation levels of this semiarid region (Tsegmid 1968). In some wet years, precipitation reaches 400-500 mm. January is the coldest month, and average air temperatures range between -20 °C to -24 °C. The warmest month is July, and average air temperatures range from 10 °C to 15 °C. In the spring and summer, average daily air temperature is usually lower compared to adjacent geographical regions, and rapid air temperature drops in the summer are observed annually (Jambaajamts 1989; Dagvadorj *et al.* 2009). Conditions with cold winds occur on a daily basis, and occasional light snow and hail events have been recorded in May and June.

The primary land use in the Khangai region is livestock herding; the region is in a relatively undeveloped area without large agricultural fields, mines, or major cities or towns. The human population of the nearest towns numbered approximately 600, otherwise the

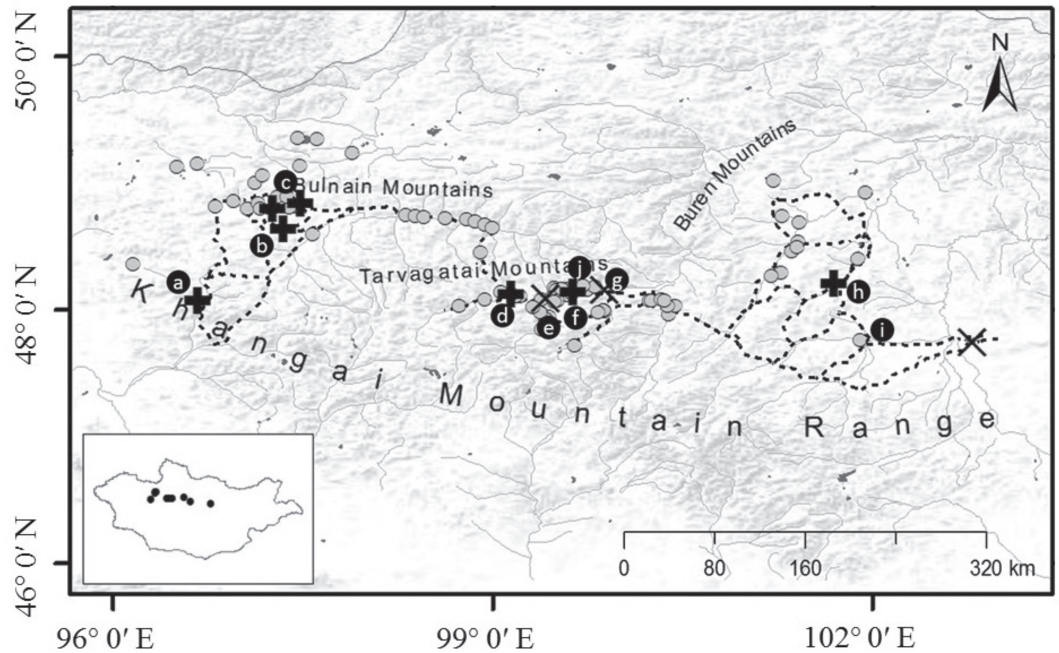

Figure 1. Map of the study area in west-central Mongolia. Numbered circles show locations of Bar-headed Geese (*Anser indicus*) observed during spring and summer surveys. Bold (+) symbols show locations of island nests, and "X" symbols indicate nest locations on cliffs. Dashed lines indicate the survey route used during the study period. The inset map shows the location of the study areas (black circles) in west-central Mongolia.

landscape was sparsely inhabited by nomadic livestock-herding families, and their activities are the major source of human-related disturbances.

Field Observations

Fieldwork was conducted during 2009 (11 May to 11 June), 2010 (20 May to 10 June) and 2011 (23 May to 11 June). Because available descriptions of Bar-headed Goose breeding ecology indicated the species typically selected islands within lakes for nesting, we initially focused efforts toward searching lakes in the region. However, during the first field season, while in transit between visited lakes, several Bar-headed Geese were unexpectedly encountered nesting on cliffs, which required the search description to be broadened within the study area.

To estimate nest success and assess potential threats or risks to the nests, we recorded GPS location, clutch size, incubation stage, weight, width and length of each egg, nest site habitat, number of livestock and distance to closest herder-families. Nests were revisited one to three times during the incubation period at approximately 7-day intervals to determine their fate until the nest failed or the eggs hatched. Eggs were marked with black permanent marker to facilitate the checks made during subsequent visits. The incubation stage of each egg was evaluated by standard candling techniques, which allowed assessment of embryo development to standardize and adjust nest age comparisons for exposure days (see 'Modeling Nest Survival' below). The method and criteria for determination of the development stage were adapted from standard protocols (Weller 1956; Klett *et al.* 1986; Reiter and Andersen 2008).

After each visit, nests were covered with nesting material to avoid the exposure of eggs to avian predators and wind-chill. Precautions were taken to minimize time spent at the nest site to avoid attracting nest predators. We took notes on the evidence of egg and nest failure by recording information on broken eggshells and the number of Mongolian Gulls (*Larus mongolicus*) and Common Ravens (*Corvus corvax*) present on the island and near the nest site as an indicator of potential avian predation risk. In addition, we recorded the presence of fresh footprints of known mammalian nest predators, including corsac fox (*Vulpes corsac*), red fox (*Vulpes vulpes*), gray wolf (*Canis lupus*), and domestic dogs (*Canis lupus familiaris*). The presence of cattle (*Bos primigenius*) tracks or dung was used as evidence of potential cattle trampling or habitat disturbance on nesting islands.

Statistical Analysis

Differences among means were tested with one-way analysis of variance tests. Differences were analyzed with protected *t*-tests (Zar 1999). Differences in nest initiation time and clutch size across 3 years were examined with a non-parametric Kruskal-Wallis test. We used the year as a group variable and standardized nest initiation date and clutch size as the measurement variables. Two-way analysis of variance was used to examine differences in the mean clutch size among years and habitat types. Test statistics were reported as significant when $P < 0.05$. All analyses were performed using the R statistical package (R Development Core Team 2013).

Modeling Nest Survival

Due to the geographic scope of this study, Bar-headed Goose nests were found at various ages upon first encounter. In addition, because competing hypotheses of influence on daily nest survival had been identified, commonly used logistic regression models (Aebischer 1999) and apparent nest success estimators (Mayfield 1975) were deemed inappropriate for calculating nesting success. Instead, we used the daily nest survival (DNS) module in Program MARK (White and Burnham 1999) to examine variations in DNS rates and estimate overall nest survival (Dinsmore and Dinsmore 2007). The assumptions of the DNS model were that: 1) nests were correctly aged when they were first found; 2) nest fates were correctly determined; 3) nest visits did not influence the survival of nests; 3) fates were independent; and 4) nest survival rate was homogenous (Rotella *et al.* 2004; Dinsmore and Dinsmore 2007). To use the DNS model, at each nest we recorded: 1) *k*, the day the nest was found; 2) *l*, the last day the nest was checked alive; 3) *m*, the last check date; 4) the fate of the nest where 0 = successful or 1 = failed; and 5) number of nests with the same encounter history (Dinsmore *et al.* 2002; Rotella *et al.* 2004; Dinsmore and Dinsmore 2007).

We used an information-theoretic approach for model selection (Burnham and Anderson 2002) to investigate additive and interactive effects of year, habitat, avian or mammalian predation, and accessibility levels on DNS. Model selection was based on rankings by Akaike's Information Criterion corrected for small sample size (AIC_c), and the model with the lowest AIC_c value was considered the best fit model and compared to a suite of competitive models including the intercept only model (Burnham and Anderson 1998). Models with less than or equal to two AIC_c values were considered competitive models, and Akaike's weights (ω) were used to examine the relative strength of the competing models (Dinsmore and Dinsmore 2007), and model averaged coefficients calculated to assess relationships between models receiving support (Burnham and Anderson 1998). We obtained the probability of the nest success estimate by raising the estimated daily survival rate (DSR) to a power equal to the incubation period (Dinsmore and Dinsmore 2007).We initially calculated overall DNS for the model without any explanatory variables. Separate DNS rates were calculated between sites with high and low gull predation, accessible and inaccessible nests, and island and cliff-nesting areas using model averaged coefficients. Then, variation in DNS rates were examined across years. Observer associated data were not collected; therefore, we did not address observer effects on Bar-headed Goose nests directly, but instead assumed any potential observers affected nest visitation sites similarly.

We considered a nest successful if at least one egg successfully hatched as determined by eggs observed pipping, goslings heard vocalizing inside the eggs, or eggshells remained that had large intact pieces of inner membranes that were detached from the shell (Klett *et al.* 1986). We used 28 days as the incubation period based on averaging the incubation period of eight eggs with known history ($n = 8$, $\bar{x} = 28.4$ days, Range = 28-29 days). Nests without repeated visits were not included for the DNS analysis as fates could not be assigned to these nests. We standardized 11 May as Day 1, based on phenology across the 3 years of study, and numbered all nest check dates sequentially thereafter. Nest age was determined by adding the average incubation stage of eggs in the nest to the number of eggs in the nest because many members of Anserini do not start incubation until the clutch is complete (Black *et al.* 2007). The nest age was used to estimate the nest initiation and hatch dates. All calendar dates (e.g., 5 May 2009) were converted to day of the year (e.g., 125) and used for calculations (Klett *et al.* 1986).

The number of Mongolian Gulls, breeding and non-breeding status, at or near each nest site was used as an indication of potential nest predation risk. If no Mongolian Gull was nesting on the same nest site or the number of nests was < 10, the effect of gull predation on nest survival was coded as 0, whereas nests with adjacent nesting Mongolian Gulls and > 10 individuals were coded 1. If we found evidence of nest failure due to mammalian predators, based on the presence and identification of fresh tracks or scat, or suspected nest site trampling by livestock crossing channels separating islands from the shoreline, as indicated by the presence of tracks or fresh cattle dung, the nest site also was coded 1. If no evidence of disturbance was present, the nest site was given a code of 0.

RESULTS

Bar-headed Geese nested in small colonies (Range = 2-81 nests across all years) on islands of freshwater and saline lakes or they nested alone or in small colonies on rocky cliffs (Range = 1-14 nests). Two island colonies had the largest numbers of nesting pairs across all years: Angirt Lake (66-81) and Khunt Lake (19-56). At Khanan Khad Cliff, the number of nesting pairs significantly increased over the 3 years from one pair in 2009 to 14 pairs in 2011. We monitored a total of 345 nests found at 10 different locations in the Khangai region during the 3 years of study: 323 nests were found on islands and 22 were located on cliffs. Site names and nest numbers are as follows: (a) Khag Lake ($n = 29$); (b) Angirt Lake ($n = 152$); (c) Telmen Lake ($n = 34$); (d) Shivert Lake ($n = 31$); (e) Khanan Khad Cliff ($n = 21$); (f) Kholboo Lake ($n = 2$); (g) north of Tariat town ($n = 1$); and (h) Khunt Lake (*n*

= 75). Nests at two additional sites (cliff nest at (i) Ogii Lake and nests on the island at (j) Terkhiin Tsagaan Lake) were not included in the DNS analysis because they were checked only once.

Nests of Bar-headed Geese on islands were composed primarily of goose down placed in shallow depressions in dirt and sand. Nests on cliffs were placed on rock ledges or in nests previously built by Upland Buzzards (*Buteo hemilasius*) or Common Ravens. Nests were 10-40 cm in width ($\bar{x}$ = 20.0 ± 5.2 cm, *n* = 173) and 4-15 cm in depth ($\bar{x}$ = 7.6 ± 1.6 cm, *n* = 171). Egg length averaged 81.3 mm and ranged from 70.1 to 91.2 mm (*n* = 670). Egg width averaged 54.6 mm and varied from 50.4 to 58.8 mm (*n* = 667) (Table 1). Weight of the eggs ranged from 83 g to 162 g (*n* = 1,016), and the mean weight decreased gradually toward the hatch date (Fig. 2). Clutch size ranged from one to eight eggs incubated for 28-29 days. The mean clutch size was 3.2 eggs (SD ± 1.6), but nests with 2-4 eggs were most common (*n* = 328; Table 2, Fig. 3). Two nests were encountered with more than 10 eggs (11 and 14, respectively) which are likely examples of intraspecific brood parasitism; these nests were excluded from further analyses.

Mean clutch size across years ($F_{2,326}$ = 8.5, $P < 0.0001$) and between cliff and island habitat types ($F_{1,326}$ = 14.6, $P < 0.004$) were significantly different. Clutch size of nests located on rock cliffs was 3.9 eggs (*n* = 20) on average, whereas island nests averaged 2.9 eggs (*n* = 306; Table 2). Average clutch size was 3.4 eggs (*n* = 155) in 2009, 2.6 eggs (*n* = 65) in 2010, and 2.6 eggs (*n* = 106) in 2011.

The earliest nest initiation date was 22 April (observed only in 2009) and the latest date was 5 June (Table 3). The observed mean nest initiation date was 9 May (SD ± 10.3 days) in 2009, 19 May (SD ± 8.6 days) in 2010, and 17 May (SD ± 8.5 days) in 2011. The observed mean nest initiation date across the 3 years was 13 May (SD ± 10.5 days), and the mean nest initiation date was significantly different across the 3 years (H = 39.0, df = 2, $P < 0.001$). We found no differences in nest initiation date between island and cliff nests ($F_{1,279}$ = 0.11, $P > 0.74$) in the Khangai region.

The best-supported model to explain daily nest survival contained a term for nest age (Table 4), indicating that the DNS varied with nest age during the incubation period. There was no support for the null model that assumed constant survival throughout the incubation period. The best-supported model to explain daily survival rate indicated that DSR decreased with nest age; a negative slope estimate ($\beta_{NestAge}$ = -0.052, SE - 0.01, 95% LCI = -0.073, 95% UCI = -0.031; Fig. 4). The second-best model indicated that the DNS decreased with nest age and varied by study year (Table 4). In general, all top models with $\Delta AIC_c < 2$ included nest age and indicated that nests were more vulnerable as their hatch date approached. Also, all models that included a constant DNS rate varying by habitat type were not supported, and the ΔAIC_c for these models received no model weights compared to the top model (*wi* = 0).

Nest survival during the incubation period was estimated on the basis of 235 nests with known fates and at least one exposure period. The overall DNS rate for the incubation period was 0.97 (CI: 0.96-0.98) with the lowest rate in 2010 (0.94, CI: 0.88-0.97) compared to 2009 (0.98, CI: 0.97-0.98) and 2011 (0.97, CI: 0.95-0.98). For the 3 years combined, the estimated probability of nest survival during incubation period was 44.4% (*n* = 235). Nest survival did vary among years (χ^2 = 10.31, *P*

Table 1. Measurements of eggs and nests of Bar-headed Geese (*Anser indicus*) in west-central Mongolia.

Variables	*n*	Mean	SD	Median	Min	Max
Egg length (mm)	670	81.3	3.3	81.4	70.1	91.2
Egg width (mm)	667	54.6	1.6	54.5	50.4	58.8
Egg weight (g)	1,016	125.1	12.2	125.0	83.0	162.0
Nest diameter (cm)	403	13.7	8.3	14.0	0.0	40.0
Nest depth (cm)	173	15.6	8.0	18.0	4.0	31.0
Nest height (cm)	82	19.8	2.6	19.8	14.0	26.0

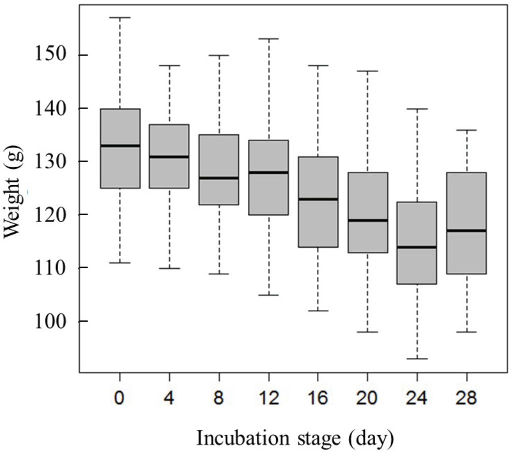

Figure 2. Decreasing egg weights for Bar-headed Geese (*Anser indicus*) during the incubation period.

= 0.006) which was 56.8% in 2009, 17.7% in 2010, and 42.6% in 2011 (Fig. 5).

There was a difference in nest survival between the island and cliff-nesting geese (χ^2 = 3.71, df = 1, *P* = 0.05), and it was consistent across years. However, we found no significant differences in DNS between the accessible and inaccessible nests (χ^2 = 0.14, df = 1, *P* = 0.706) and between nests with low and high avian predation risk (χ^2 = 0.05, df = 1, *P* = 0.823). The pattern of differences between habitat types, predation levels, and accessibility was consistent across years (Fig. 6).

DISCUSSION

We documented Bar-headed Goose nesting ecology and breeding biology on the Mongolian Plateau with specific focus on nest site selection and nest success. Bar-headed Goose nests were found on lake islands and cliff faces. It is common to observe small colonies of Bar-headed Geese nesting on relatively small barren islands in India, China, and Russia (Gole 1982; Baranov 1991; Ma and Cai 1997). The largest island known to have a large colony of Bar-headed Geese was reported at the Qinghai Lake National Nature Reserve on the Qinghai-Tibetan Plateau, China (Cui *et al.* 2011). The smallest nesting island observed being used by Bar-headed Geese in Mongolia was about 22-m long and 5-m wide (0.011 ha) (N. Batbayar, unpubl. data) and was shared with > 100 Mongolian Gulls and approximately 20 Great Cormorants (*Phalacrocorax carbo*). Cliff nests were solitary or in small aggregate and were few in number, similar to descriptions reported for a few cases in northern India (Gole 1982) and southern Russia (Baranov 1991). In addition, we found two adjacent Bar-headed Goose nests in trees during 2009 in central Mongolia. These trees were elm (*Ulmus* spp.) approximately 7 m tall located 3.7 km from the nearest river with no lakes present in the area. Both nests were known to be previously used by Saker Falcons (*Falco cherrug*), Upland Buzzards, and Common Ravens interchangeably. Tree nesting by Bar-headed Geese was previously reported from the Tuva region in southern Russia (Baranov 1991).

Availability of suitable, protected nest locations may be one of the main limiting factors for this species in west-central Mon-

Table 2. Clutch size nest frequency of Bar-headed Geese nesting on islands and cliffs in west-central Mongolia.

	2009		2010		2011		Total	
Clutch Size	Island	Cliff	Island	Cliff	Island	Cliff	Island	Cliff
1	15		19		19	1	53	1
2	34	4	11	1	35	2	80	4
3	38		16		20	4	74	3
4	36		10	2	15	4	61	5
5	17		3	3	4	2	24	5
6	9				1	1	10	1
7	3						3	
8	1	1					1	1
Total	153	2	59	6	94	14	306	20

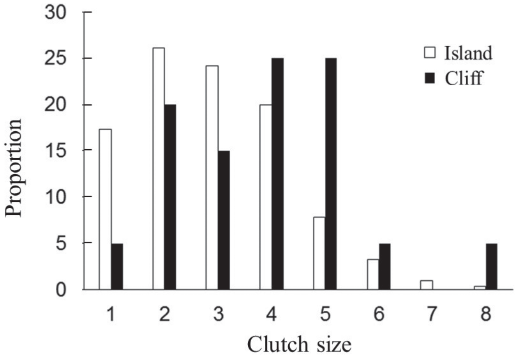

Figure 3. Proportions of Bar-headed Goose (*Anser indicus*) nests with different clutch sizes at island and cliff sites.

golia. In the Khangai region, most lakes lacked suitable islands where Bar-headed Geese could nest. Several lakes formerly had islands depicted on maps, but they were not present during our study due to insufficient precipitation in recent years. Also, we found Bar-headed Geese nesting on temporally exposed sand bars among Mongolian Gull nests. In a few cases, we found their eggs in nests being incubated by Mongolian Gulls which might have been indicative of a shortage of suitable nest sites. Possible intraspecific brood parasitism previously had been documented in Bayinbuluke Lake in northern China (Ma and Cai 1997) and in the Tuva region of southern Russia (Baranov 1991), but the total numbers of nests in these areas were not reported.

Bar-headed Goose nest survival was best explained by nest age and year. DNS was not constant during the incubation period with survival decreasing in older nests; the top three explanatory models included nest age and predation. In general, waterfowl produce more eggs when environmental and safety conditions are better, and the environmental conditions during early stages of nesting control the size of clutches (Haywood and Perrins 1992). Egg laying dates in many goose species are influenced by several factors (e.g., lack of nesting sites, fitness cost associated with early nesting, limited food resources en route to the breeding grounds) (Black *et al.* 2007). In general, the Bar-headed Goose lays eggs between the last week of April and the last week of May (Jensen *et al.* 2008). Ming and Dai (1999) reported that they start nesting at the end of April and early May right after returning from spring migration through Xinjiang, China. Bar-headed Geese started laying eggs during the first week of May in India's Ladakh region (Gole 1982; Prins and Wieren 2004), while in Tuva, southern Russia, the first eggs were observed on 26 April (Baranov 1991). Nest initiation and egg laying dates observed in Mongolia were very similar to the above-mentioned reports. All of these records suggest that this species has asynchronous nest initiation and hatching dates that can span up to 1 month throughout their geographical range. Bar-headed Goose nest initiation dates are 7-21 days earlier compared with Arctic nesting geese (Roweling 1978). We speculate that this difference may be related to the disparity in vegetation green-up timing (Cargill and Jefferies 1984; MacInnes and Dunn 1988; Madsen *et al.* 1989) and possibly spring temperature (MacInnes and Dunn 1988) in different parts of this semiarid region along a latitudinal gradient.

The range of clutch sizes was consistent with the numbers reported elsewhere for this species (Lamprecht 1986; Baranov 1991;

Table 3. Nest initiation date of Bar-headed Geese (*Anser indicus*) in west-central Mongolia in 2009-2011.

	2009		2010		2011		Summary	
Values	*n* = 136	Date	*n* = 18	Date	*n* = 81	Date	*n* = 235	Date
Average ± SD	17 ± 10.3	9-May	27 ± 8.6	19-May	25 ± 8.5	17-May	21 ± 10.5	13-May
Earliest	0	22-Apr	8	30-Apr	11	3-May	0	22-Apr
Latest	41	2-Jun	34	26-May	37	29-May	41	26-May
Mode	7	29-Apr	33	25-May	16	8-May	16	8-May
Median	16	8-May	32	24-May	25	17-May	18	10-May

Table 4. Akaike Information Criterion model selection results for Bar-headed Goose (*Anser indicus*) nesting in west-central Mongolia from 2009-2011. The top five models, plus the null model, are presented out of a 17 candidate model set. Models are ordered according to ascending ΔAIC_c values.

Model	ΔAIC_c	*w*	Model Likelihood	*K*	Deviance
Nest Age	0.00	0.25	1.00	2	249.95
Nest Age + Year	1.13	0.14	0.57	4	247.06
Nest Age + Predation	1.45	0.12	0.48	3	249.40
Nest Age + Accessibility	1.52	0.12	0.47	3	249.46
Nest Age + Habitat	2.01	0.09	0.37	3	249.95
Constant	23.36	0.00	0.00	1	275.32

Ma and Cai 1997; Prins and Wieren 2004). The frequency of clutch sizes for nests in the Khangai region of Mongolia and the Bayinbuluke Lake of the Tianshan Mountains in northwestern China (Ma and Cai 1997) was similar; however, the average clutch size for Bar-headed Geese was smaller (3.2 ± 1.6 eggs), and smaller clutches of one to four eggs were more frequent in comparison. In contrast, the average clutch size at Bayinbuluke Lake was 4.5 ± 2.2 and nests with 3-5 eggs were more frequent (Ma and Cai 1997). In southern Russia, the average clutch size was 3.6 eggs (Baranov 1991). The lower clutch size observed in our study may be related to higher predation pressure and nest site limitations in Mongolia compared to geese breeding in northwestern China and Russia. The clutch size of Bar-headed Geese at cliff sites was greater than clutch sizes at island sites, and geese at cliff sites consistently had higher DNS rates than at island sites. This result suggests that either cliff sites provided better protection from inclement weather and predation, or island sites were

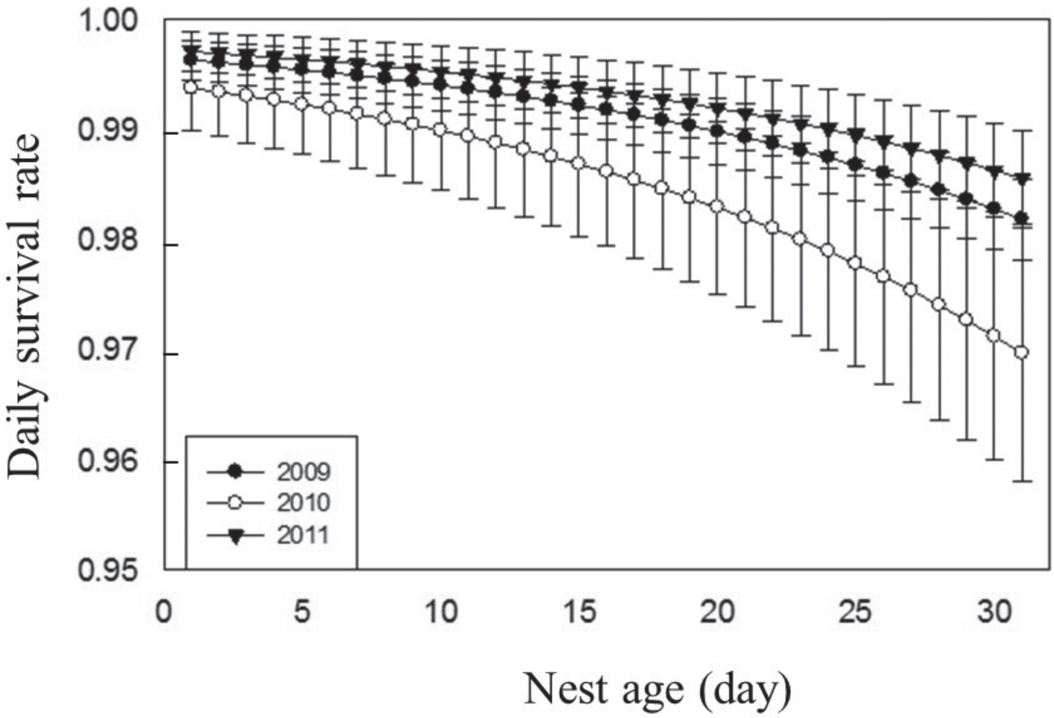

Figure 4. Daily survival rate (DSR) of Bar-headed Goose (*Anser indicus*) nests in relation to nest age (days since egg laying) in west-central Mongolia from 2009-2011. The logistic-exposure model curve and 95% confidence limits are shown. Estimates derived from model-averaged coefficients of top competitive models ($\Delta AIC_c < 2.0$).

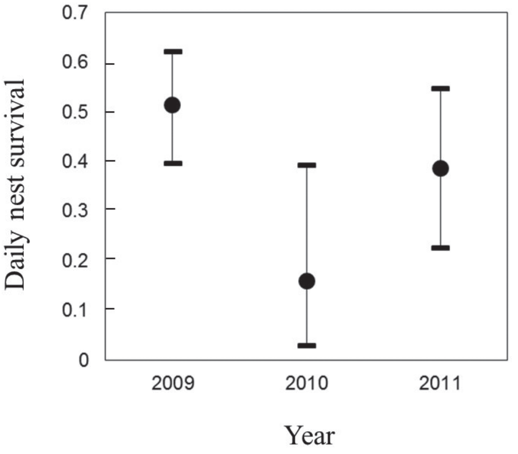

Figure 5. Bar-headed Geese (*Anser indicus*) daily nest survival (DNS) with 95% confidence intervals from west-central Mongolia in 2009, 2010, and 2011. Estimates derived from model-averaged coefficients of top competitive models ($\Delta AIC_c < 2.0$).

in lakes often frozen until June and were not available for early nesting compared with cliff sites in the Khangai region.

Furthermore, we observed a general negative relationship between egg laying date and clutch size ($R^2 = -0.39$), which suggests that the early nesting birds may have laid more eggs, but that relationship could be affected by yearly variation in nest initiation dates. That pattern is similar to what has been reported for Canada Geese (*Branta canadensis*), Barnacle Geese (*B. leucopsis*) and Black Brant (*B. bernicla nigricans*) that nest at northern latitudes (Roweling 1978; Sedinger and Raveling 1986; Lindholm *et al.* 1994; Black *et al.* 2007).

Annual variation in nesting success of waterfowl has often been related to onset of snow melt on the breeding grounds, weather condition, predation, and competition for food during brood rearing (Black *et al.* 2007). Earlier nest initiation in 2009 was probably related to warmer temperatures in the spring and less snow. The warmest year of our study was in 2009, and lakes were clear of ice by the middle of May. The spring of 2011 was colder compared to 2009 and 2010. Lake ice was still partially present until the beginning of June in 2010 and 2011.

During nest searching, we noticed that Bar-headed Geese had the tendency to avoid lakes with full or partial ice coverage. They generally preferred completely ice-free lakes. However, our nest monitoring data indicated that many Bar-headed Geese may have started laying eggs when the lakes still were ice-covered. It is likely that most geese wait to lay eggs until the ice becomes very thin or fragile and it is risky for ground predators to approach nesting islands. The delay between arrival and initiation of egg laying date may cause reduced clutch sizes in Canada Geese nesting in Arctic regions (MacInnes and Dunn 1988). Therefore, the year effect could be a reflection of the delay in nest initiation because of lower air temperatures; 2010 and 2011 were colder years than 2009.

Many nests in our study sites were depredated by Mongolian Gulls, Common Ravens, and domestic dogs, or trampled by livestock.

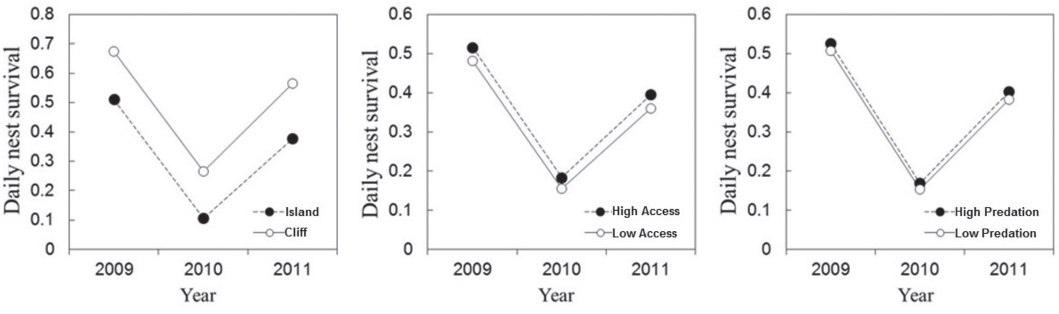

Figure 6. Variation in Bar-headed Geese (*Anser indicus*) daily nest survival (DNS) between different habitat types (island, cliff), accessibility (low, high), and predation levels (low, high) from 2009-2011. Estimates derived from model-averaged coefficients of top competitive models ($\Delta AIC_c < 2.0$).

Many of the lakes we visited were occupied by Mongolian Gulls in large numbers, and they nested on the same islands occupied by the Bar-headed Geese. However, comparison of DNS rates between sites with high and low densities of Mongolian Gulls was not significant. We documented a total of 21 nests (15 on islands; six on cliffs) with eggs depredated by Mongolian Gulls, and nine nests (four on islands; five on cliffs) with eggs taken by Common Ravens. Also, tracks of a large canine (dog or wolf) and smaller dogs were documented at Khunt Lake where most of the colony was lost in 2010. Actual egg predation is likely much higher, because we were unable to visit these widely dispersed nests frequently enough to obtain a detailed record of egg fate. Goose colonies located near large Mongolian Gull colonies apparently suffered the most predation and may have lower nest survival during incubation and before hatch. On one occasion, a pair of Common Ravens depredated all six newly-hatched goslings from a cliff nest; however, we do not have detailed data to determine the prevalence of complete clutch loss caused by Common Ravens.

Many species of large gulls (*Larus* spp.) are known as important goose nest predators (Black *et al.* 2007; Merow *et al.* 2013), and Mongolian Gulls are known to steal eggs and chicks from other birds when given the opportunity. Nest predation by gulls, Black Kites (*Milvus migrans*), and Common Ravens on Bar-headed Geese also occurs in India, China and Russia (Gole 1982; Baranov 1991; Ma and Cai 1997). We suggest Mongolian Gulls were most responsible for nest failures on inaccessible islands (islands surrounded by deeper water that are often ideal places for gull nesting), whereas dogs and other mammals were likely related to nest failures on accessible islands.

Nests on islands were more vulnerable and contained fewer eggs compared to nests on cliffs. We observed significant variability in lake water levels during our study. In 2010, the water level at the major colony, Khunt Lake, was very low, and mammalian nest predators and cattle were able to reach the nesting islands in the late spring and destroyed or trampled most of the nests. Similarly, increased predation due to water level change was observed at Angirt Lake in 2011. In both cases, the water level was reduced as the season progressed in the late spring and the early summer.

The spring air temperature has increased by 1.4 °C from 1990-2006 throughout Mongolia, and water evaporation has increased by 10-15% in the Khangai region resulting in disappearance of many small and shallow lakes and streams (Dagvadorj *et al.* 2009). These landscape level changes may negatively affect the nesting of Bar-headed Geese, as well as other nesting waterbirds in the region, because their nesting is highly dependent on islands within lakes. If water levels continue to drop in this region during the spring, accessibility of island nest sites to mammalian predators and vulnerability of livestock trampling due to drying of lakes will likely increase. Also, we have seen larger numbers of non-breeding Bar-headed Geese in the same region when they molt in July. We estimate that the non-breeding population of Bar-headed Geese in the Khangai region is at least 15,000 individuals, but the full extent of their breeding grounds is not well documented.

Recent studies indicate that the warming climate is expected to be most obvious at northern latitudes (Mitchell *et al.* 1990), and during the spring, climatic variation has been documented to explain nearly 50% of variation in reproductive phenology of some Arctic nesting geese (Dickey *et al.* 2008). Similarly, it will be critical to understand the future effects of climate change on water levels of lakes and wetlands on Mongolian grassland steppe to predict future nesting success and conservation of Bar-headed Goose populations.

Mongolia has experienced the most rapid rise in temperatures in the past decade outside of the Arctic regions. In the semiarid grassland steppe, wetlands already have been affected by water use demands of local communities (Batima and Dagvadorj 1998). If the warming climate results in drying of lakes and reduction of protected areas available for nesting waterbirds, rapid reductions in their populations may occur in the near future (Xu *et al.* 2009). In future studies of waterbirds nesting on the semiarid steppe, researchers should attempt to use standardized nest-visit intervals for improved statistical power and collect additional island habitat features, climate variables, and nest site and forage availability. For Bar-headed Geese, increasing sample sizes of nests on cliff sites, identifying conditions resulting in increased Mongolian Gull and mammalian nest predation and livestock trampling, and comparing characteristics of islands with and without nests will provide support to better understand which islands are best suited for reproductive success, the role that cliff and tree nests play in alternative nesting strategies, and what actions are warranted for greatest future conservation efforts in this region.

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LITERATURE CITED

Aebischer, N. J. 1999. Multi-way comparisons and generalized linear models of nest success: extensions of the Mayfield method. Bird Study 46: 22-31.

Baranov, L. A. 1991. Rare and little-studied birds of Tuva. M.S. Thesis, Krasnoyarsk State University, Krasnoyarsk, Russia.

Batbayar, N., J. Y. Takekawa, S. H. Newman, D. J. Prosser, T. Natsagdorj and X. Xiao. 2011. Migration strategies of Swan Geese *Anser cygnoides* from northeast Mongolia. Wildfowl 61: 90-109.

Batima, P. and D. Dagvadorj. 1998. Climate change and its impact in Mongolia. JEMR Publishing, Ulaanbaatar, Mongolia.

BirdLife International. 2009. Species factsheet: *Anser indicus*. BirdLife International, Cambridge, U.K. http://www.birdlife.org/datazone/speciesfactsheet.php?id=379, accessed 2 May 2010.

Bishop, M. A., S. Yanling, C. Zhouma and G. Binyuan. 1997. Bar-headed Geese *Anser indicus* wintering in south-central Tibet. Wildfowl 48: 118-126.

Black, J. M., J. Prop and K. Larsson. 2007. Wild goose dilemmas: population consequences of individual decisions in Barnacle Geese. Branta Press, Groningen, The Netherlands.

Burnham, K. P. and D. R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York, New York.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd ed. Springer-Verlag, New York, New York.

Cargill, S. M. and R. L. Jefferies. 1984. The effects of grazing by Lesser Snow Geese on the vegetation of a sub-arctic salt-marsh. Journal of Applied Ecology 21: 669-686.

Chen, H., G. J. D. Smith, S. Y. Zhang, K. Qin, J. Wang, K. S. Li, R. G. Webster, J. S. M. Peiris and Y. Guan. 2005. H5N1 virus outbreak in migratory waterfowl. Nature 436: 191-192.

Contina, A., E. S. Bridge, N. E. Seavy, J. M. Duckles and J. F. Kelly. 2013. Using geologgers to investigate bimodal isotope patterns in Painted Buntings (*Passerina ciris*). Auk 130: 265-272.

Cui, P., Y. S. Hou, M. J. Tang, H. T. Zhang, Y. C. Zhou, Z. H. Yin, T. X. Li, S. Guo, Z. Xing, Y. B. He, D. J. Prosser, S. H. Newman, J. Y. Takekawa, B. P. Yan and F. M. Lei. 2011. Movement patterns of Bar-headed Geese *Anser indicus* during breeding and post-breeding periods at Qinghai Lake, China. Journal of Ornithology 152: 83-92.

Dagvadorj, D., L. Natsagdorj, J. Dorjpurev and B. Namkhainyam. 2009. Mongolia assessment report on climate change 2009. Ministry of Environment, Nature and Tourism, Ulaanbaatar, Mongolia.

Del Hoyo, J., A. Elliott and D. Christie. 2001. Handbook of the birds of the world, vol. 1. Ostrich to ducks, 2nd ed. Lynx Edicions, Barcelona, Spain.

Dickey, M. H., G. Gauthier and M. C. Cadieux. 2008. Climatic effects on the breeding phenology and reproductive success of an arctic-nesting goose species. Global Change Biology 14: 1973-1985.

Dinsmore, S. J. and J. J. Dinsmore. 2007. Modeling avian nest survival in program MARK. Studies in Avian Biology 34: 73-83.

Dinsmore, S. J., G. C. White and F. L. Knopf. 2002. Advanced techniques for modeling avian nest survival. Ecology 83: 3476-3488.

Fomin, V. E. and A. Bold. 1991. Catalogue of birds of the Mongolian People's Republic. Nauka, Moscow, Russia.

Gaidet, N., J. Cappelle, J. Y. Takekawa, S. A. Iverson, W. M. Perry, D. C. Douglas, D. J. Prosser, T. Mundkur and S. H. Newman. 2011. Potential spread of highly pathogenic avian influenza H5N1 by wildfowl: dispersal ranges and rates determined from large-scale satellite telemetry. Ecohealth 7: S35-S35.

Gole, P. 1982. Status of *Anser indicus* in Asia with special reference to India. Aquila 89: 141-149.

Gombobaatar, S. and E. M. Monks. 2011. Regional red list series, vol 7. Birds. Zoological Society of London, National University of Mongolia and Mongolian Ornithological Society, Ulaanbaatar, Mongolia.

Hawkes, L. A., S. Balachandran, N. Batbayar, P. J. Butler, P. B. Frappell, W. K. Milsom, N. Tseveenmyadag, S. H. Newman, G. R. Scott, P. Sathiyaselvam, J. Y. Takekawa, M. Wikelski and C. M. Bishop. 2011. The trans-Himalayan flights of bar-headed geese (*Anser indicus*). Proceedings of the National Academy of Sciences of the United States of America 108: 9516-9519.

Haywood, S. and C. M. Perrins. 1992. Is clutch size in birds affected by environmental-conditions during growth? Proceedings of the Royal Society B-Biological Sciences 249: 195-197.

Iverson, S. A., A. Gavrilov, T. E. Katzner, J. Y. Takekawa, T. A. Miller, W. Hagemeijer, T. Mundkur, B. Sivananinthaperumal, C. C. DeMattos, L. S. Ahmed and S. H. Newman. 2011. Migratory movements of waterfowl in Central Asia and avian influenza emergence: sporadic transmission of H5N1 from east to west. Ibis 153: 279-292.

Iwamura, T., H. P. Possingham, I. Chades, C. Minton, N. J. Murray, D. I. Rogers, E. A. Treml and R. A. Fuller. 2013. Migratory connectivity magnifies the consequences of habitat loss from sea-level rise for shorebird populations. Proceedings of the Royal Society B-Biological Sciences 280: 20130325.

Jambaajamts, B. 1989. Climate of Mongolia. The Institute of Geography, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia.

Jensen, R. A., J. Madsen, M. O'Connell, M. S. Wisz, H. Tommervik and F. Mehlum. 2008. Prediction of the distribution of Arctic-nesting pink-footed geese under a warmer climate scenario. Global Change Biology 14: 1-10.

Klett, A. T., H. F. Duebbert, C. A. Faanes and K. F. Higgins. 1986. Techniques for studying nest success of ducks in upland habitats in the prairie pothole region. U.S. Department of the Interior, Fish and Wildlife Service, Resource Publication 115.

Köppen, U., A. Yakovlev, R. Barth, M. Kaatz and P. Berthold. 2010. Seasonal migrations of four individual bar-headed geese *Anser indicus* from Kyrgyzstan followed by satellite telemetry. Journal of Ornithology 151: 703-712.

Lamprecht, J. 1986. Social-dominance and reproductive success in a goose flock (*Anser indicus*). Behaviour 97: 50-65.

Lindholm, A., G. Gauthier and A. Desrochers. 1994. Effects of hatch date and food-supply on gosling growth in Arctic-nesting Greater Snow Geese. Condor 96: 898-908.

Liu, J., H. Xiao, F. Lei, Q. Zhu, K. Qin, X. W. Zhang, X. L. Zhang, D. Zhao, G. Wang, Y. Feng, J. Ma, W. Liu, J. Wang and G. F. Gao. 2005. Highly pathogenic H5N1 influenza virus infection in migratory birds. Science 309: 1206-1206.

Ma, M. and D. Cai. 1997. Aggregated distribution of *Anser indicus* nest in Bayinbuluke of Tianshan Mountains and its breeding ecology. Chinese Journal of Applied Ecology 8: 287-290.

MacInnes, C. D. and E. H. Dunn. 1988. Components of clutch size variation in Arctic nesting Canada Geese. Condor 90: 83-89.

Madsen, J., T. Bregnballe and F. Mehlum. 1989. Study of the breeding ecology and behaviour of the Svalbard population of Light-bellied Brent Goose *Branta bernicla hrota*. Polar Research 7: 1-21.

Mayfield, H. F. 1975. Suggestions for calculating nest success. Wilson Bulletin 87: 456-466.

Merow, C., M. J. Smith and J. A. Silander. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. Ecography 36: 41-96.

Ming, M. and C. Dai. 1999. Breeding ecology of Bar-headed Goose in Tianshan, Xinjiang. Casarca 5: 177-181.

Mitchell, J., S. Manabe, V. Meleshko and T. Tokioko. 1990. Equilibrium climate change - and its implications for the future. Pages 283-310 *in* Climate Change, the IPCC Scientific Assessment (J. Houghton, G. Jenkins and J. Ephraums, Eds.). Cambridge University Press, Cambridge, U.K.

Murray, N. J. and R. A. Fuller. 2012. Coordinated effort to maintain East Asian-Australasian Flyway. Oryx 46: 479-480.

Newton, I. 1998. Population limitation in birds. Academic Press, San Diego, California.

Prins, H. H. and S. E. V. Wieren. 2004. Number, population structure, and habitat use of bar-headed geese *Anser indicus* in Ladakh (India) during the brood-rearing period. Acta Zoologica Sinica 50: 738-744.

Prosser, D. J., P. Cui, J. Y. Takekawa, M. Tang, Y. Hou, B. M. Collins, B. Yan, N. J. Hill, T. Li, Y. Li, F. Lei, S. Guo, Z. Xing, Y. He, Y. Zhou, D. C. Douglas, W. M. Perry and S. H. Newman. 2011. Wild bird migration across the Qinghai-Tibetan plateau: a transmission route for highly pathogenic H5N1. PLoS ONE 6: e17622.

R Development Core Team. 2013. R: a language and environment for statistical computing v. 3.0.2. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org, accessed 14 January 2012.

Reiter, M. E. and D. E. Andersen. 2008. Comparison of the egg flotation and egg candling techniques for estimating incubation day of Canada Goose nests. Journal of Field Ornithology 79: 429-437.

Rotella, J. J., S. J. Dinsmore and T. L. Shaffer. 2004. Modeling nest-survival data: a comparison of recently developed methods that can be implemented in MARK and SAS. Animal Biodiversity and Conservation 27: 187-205.

Roweling, D. G. 1978. The timing of egg laying by northern geese. Auk 95: 294-303.

Sedinger, J. S. and D. G. Raveling. 1986. Timing of nesting by Canada Geese in relation to the phenology and availability of their food plants. Journal of Animal Ecology 55: 1083-1102.

Takekawa, J. Y., S. R. Heath, D. C. Douglas, W. M. Perry, S. Javed, S. H. Newman, R. N. Suwal, A. R. Rahmani, B. C. Choudhury, D. J. Prosser, B. Yan, Y. Hou, N. Batbayar, T. Natsagdorj, C. M. Bishop, P. J. Butler, P. B. Frappell, W. K. Milsom, G. R. Scott, L. A. Hawkes and M. Wikelski. 2009. Geographic variation in Bar-headed Geese *Anser indicus*: connectivity of wintering areas and breeding grounds across a broad front. Wildfowl 59: 102-125.

Tsegmid, S. 1968. Physical geography of Mongolia. The Institute of Geography, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia.

Tserensodnom, J. 2000. Catalog of lakes of Mongolia. The Institute of Geography, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia.

Weller, M. 1956. A simple field candler for waterfowl eggs. Journal of Wildlife Management 20: 111-113.

Wetlands International. 2006. Waterbird population estimates, 4th ed. Wetlands International, Wageningen, The Netherlands.

White, G. C. and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46: S120-S139.

Xu, J. C., R. E. Grumbine, A. Shrestha, M. Eriksson, X. F. Yang, Y. Wang and A. Wilkes. 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. Conservation Biology 23: 520-530.

Zar, J. H. 1999. Biostatistical analysis, 4th ed. Prentice Hall, Upper Saddle River, New Jersey.