J Ornithol (2011) 152:83–92
DOI 10.1007/s10336-010-0552-6

ORIGINAL ARTICLE

Movement patterns of Bar-headed Geese *Anser indicus* during breeding and post-breeding periods at Qinghai Lake, China

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Received: 16 November 2009 / Revised: 17 March 2010 / Accepted: 15 June 2010 / Published online: 8 July 2010

Abstract The highly pathogenic avian influenza (HPAI) H5N1 outbreak at Qinghai Lake, China, in 2005 caused the death of over 6,000 migratory birds, half of which were Bar-headed Geese *Anser indicus*. Understanding the movements of this species may inform monitoring of outbreak risks for HPAI viruses; thus, we investigated the movement patterns of 29 Bar-headed Geese at Qinghai Lake, China during 2007 and 2008 by using high resolution GPS satellite telemetry. We described the movements and distribution of marked Bar-headed Geese during the pre-nesting, nesting, and moulting periods. Of 21 Bar-headed Geese with complete transmission records, 3 moved to other areas during the nesting period: 2 to Jianghe wetland (50 km northwest of Qinghai Lake) and 1 to Cuolongka Lake (220 km northwest of Qinghai Lake) during the nesting period. We identified nesting attempts of 7 of the marked geese at Qinghai Lake. Four completed successful nesting attempts according to our rules of judgment for the breeding status, and 2 geese lost broods soon after hatching (hereafter referred to as unsuccessful breeders). Of 18 geese present at Qinghai Lake during the nesting period, 9 (6 non-breeders, 2 successful breeders and 1 unsuccessful breeder) remained at Qinghai Lake during the moulting period; and 9 (5 non-breeders, 4 unsuccessful breeders) left Qinghai Lake for moulting. Kuhai Lake, Donggeicuona Lake, Alake Lake, Zhaling-Eling Lake area and Huangheyuan wetland area were used as moulting sites. Geese that moulted at Qinghai Lake, Cuolongka Lake, Kuhai Lake, Donggeicuona Lake and Alake Lake also moved to

Communicated by F. Bairlein.

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Electronic supplementary material The online version of this article (doi:10.1007/s10336-010-0552-6) contains supplementary material, which is available to authorized users.

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Zhaling-Eling Lake area or Huangheyuan wetland area and stayed there for several days prior to autumn migration. Mean home range and core area estimates did not differ significantly by sex, year and between breeders and non-breeders.

Keywords GPS satellite tracking · Bar-headed Goose · Breeding · Post-breeding · Moult migration

Introduction

In May 2005, more than 6,000 wild birds, including 3,282 Bar-headed Geese *Anser indicus* (BHG), died of H5N1 infection at Qinghai Lake, China (Chen et al. 2005; Liu et al. 2005). The outbreak began at Egg Island, the main nesting colony of BHG at Qinghai Lake, and subsequently dispersed to adjacent wetland areas used by waterbirds (Zhang et al. 2007; Hou et al. 2009). Thus, BHG may serve as an important vector of H5N1 virus at a local scale. A few long-distance migrations of BHG have been documented through bird ringing and satellite tracking (Zhang and Yang 1997; Javed et al. 2000; Prosser et al. 2009). Liu et al. (2008) reported on breeding season movements of BHG within Qinghai Lake using radio-telemetry. However, movements within the breeding and moulting grounds remain poorly known. Such basic baseline knowledge is valuable to understand the ecology of this poorly known bird species.

In many goose species, if feeding or cover conditions are not adequate on the breeding grounds, then individuals may depart the nesting area to moult elsewhere (Hohman et al. 1992; Hupp et al. 2007; Luukkonen et al. 2008). Moulting areas are often in remote regions where human disturbance is minimal, predation risk is low, and high quality forage provides nutrients for growth of new feathers (Owen and Ogilvie 1979; Derksen et al. 1982; Fox and Kahlert 2000). Geese exhibit strong annual fidelity to their breeding and moulting locations (Bollinger and Derksen 1996). On the breeding and moulting grounds, waterbirds may congregate within shallow water bodies, resulting in increased exposure to persistent diseases such as H5N1 avian influenza (Webster et al. 1992; Webster and Govorkova 2006). It is important to identify breeding and moulting areas of BHG at outbreak locations such as Qinghai Lake to create more effective surveillance strategies.

The focus of this study was to provide information on the distribution and movement patterns of BHG at Qinghai Lake during breeding and post-breeding periods. Our objectives were to: (1) identify areas used during pre-nesting, nesting, moulting and pre-autumn migration periods, (2) determine timing of autumn migration, (3) identify moulting migration paths and staging areas, and (4) identify home range size at different periods from pre-nesting to pre-autumn migration. We also discuss effects of sex and reproduction status on the movement patterns of BHG.

Methods

Capture, marking and satellite tracking

BHG were captured and marked at three sites at Qinghai Lake: Jiangxigou (36°44′N, 100°17′E), Hadatan (37°07′N, 99°43′E) and Heimahe (36°44′N, 99°47′E). Qinghai Lake is located at the northeastern end of the Qinghai-Tibetan Plateau and about 280 km west of the city of Xining in Qinghai Province (Fig. 1). It is situated at an elevation of 3,193 m and is the largest saltwater lake in China, with an area of ca. 4,200 km^2. BHG were captured on 25–31 March 2007 and 28 March–3 April 2008 using monofilament leg nooses (made by Indian trappers). We recorded mass, flat wing chord, short tarsus (diagonal length of the tarsometatarsus, measured along its outer edge; Dzubin and Cooch 1992), sex, and age for each bird. Adult birds and equal numbers of male and female were targeted for marking. Virology sampling was conducted for 22 BHG (Prosser et al. 2009). Each bird was equipped with a 45-g solar-powered portable transmitter terminal (PTT: Microwave Telemetry PTT-100, Columbia, Maryland USA). PTTs measured 57 × 30 × 20 mm and were attached dorsally between the wings with a harness system.

This study was conducted from late March when the BHG were captured and marked to the date when autumn migration began. We divided the study period into five phases: (1) the pre-nesting period; (2) the nesting period; (3) short period of moult migration; (4) moulting period; and (5) pre-autumn migration period. Here, we defined the pre-nesting period as the day an individual was captured to the day when it joined to the breeding colony. We defined the nesting period as the first day a marked individual arrived at the breeding colony to the day when this individual departed the breeding areas for other discrete wetlands. For the non-breeders, previous studies on nesting behaviour that were performed from 2003 to 2008 at Egg Island showed that the first egg was laid on average on 13 April (6–19 April). On 18 June, fewer than 10% BHG remained at breeding colony at Egg Island. Therefore, we arbitrarily defined the nesting period for the non-breeders as 13 April–18 June, and the pre-nesting period was defined as the short period when they stayed near their capture sites until the nesting period began. We inferred that geese were nesting based on the amount of time a bird was on the nesting colony (Egg Island and Sankuaishi

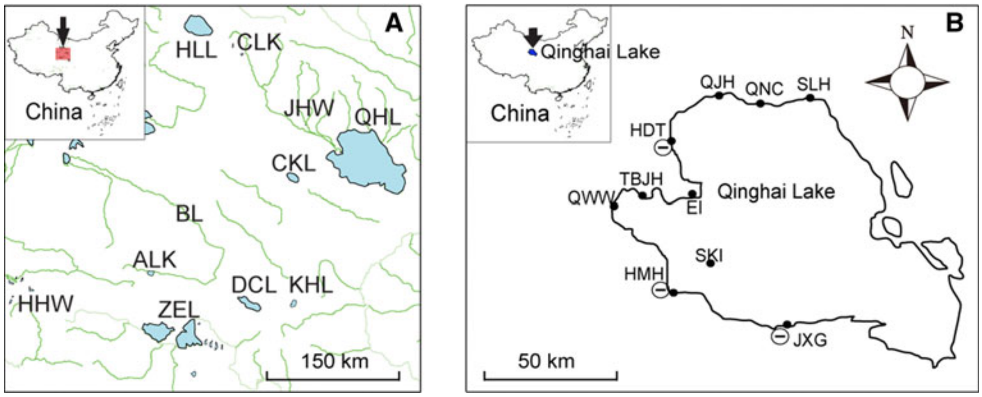

Fig. 1 Region used by Bar-headed Geese *Anser indicus* tracked with satellite transmitters from Qinghai Lake during the pre-nesting period to the pre-autumn migration period (**a**) and location map of Qinghai Lake (**b**). Codes for wetlands are: *HLL* Hala Lake, *CLK* Cuolongka wetland, *JHW* Jianghe wetland, *CKL* Chaka salt Lake, *QHL* Qinghai Lake, *BL* Balong, *ALK* Alake Lake; *DCL* Donggeicuona Lake, *KHL* Kuhai Lake, *HHW* Huangheyuan wetland, *ZEL* Zhaling-Eling Lake area, *SLH* Shaliuhe Estuary, *QJH* Quanjihe Estuary, *HDT* Hadatan wetland, *EI* Egg Island, *TBJH* Tiebujiahe Estuary, *QWW* Quanwan wetland, *HMH* Heimahe wetland, *SKI* Sankuaishi island, *JXG* Jiangxigou wetland. Capture sites are shown with *circles* and *minus signs*. Locations of sites used by Bar-headed Geese in the lake are shown by *black spots* (not all the sites are shown in the map)

Island were the only two breeding colonies of BHG in Qinghai Lake; Hou et al. 2009). Nesting was considered successful if a bird stayed more than 29 days at the nest colony (Cheng 1979).We defined moult migration as a sequential series of locations (on different days) moving in the same general direction from the last date a bird was on a potential breeding area until it arrived on a moulting area. A bird was considered staging if it remained in an area for more than 1 day during the moult migration and considered resting if it stayed in an area for less than 1 day during the moult migration. BHG were identified as moulting if they remained within a restricted area and moved less than 0.5 km between two consecutive locations for up to 4 weeks (Cheng 1979). We conducted ground surveys in mid-August 2008 at Qinghai Lake, Kuhai Lake, Donggeicuona Lake and Zhaling-Eling Lake area to verify moulting sites identified via satellite tracking locations. Moulting was confirmed by presence of birds or evidence of molted feathers.

Data analysis

Transmitter signals were received by the Argos data system (CLS America, Maryland, USA). Only GPS location information was used in analyses. Geese were located bi-hourly with location accuracy of ±15 m. The numbers of transmission received from the PTT per day ranged from 0 to 12. We used Google Earth (Google, California, USA) to plot the selected locations. We calculated the straight-line moult migration distance (the distance between the last location at breeding area and the first location at the moulting area) in ArcView GIS (v3.2; Environmental Systems Research, Redlands, California; Hooge and Eichenlaub 1997). We calculated home range and core area for each bird at the pre-nesting, nesting and moulting period using ArcView GIS Animal Movement Analysis Extensions (Hooge and Eichenlaub 1997). We used the fixed kernel home range utilisation distribution as a grid coverage using the default least squares cross-validation (LSCV) to calculate 95% home range area and 50% core area. We calculated home range and core area from individuals that had more than 30 locations at each period (Seaman and Powell 1996).

We evaluated the relationship between body mass and reproductive success. We evaluated differences between sexes for the dates when autumn migration began. We evaluated differences of the beginning dates of autumn migration between the individuals that remained on breeding grounds during moult and individuals that moved to other areas for moulting. We tested the differences of moulting migration distance between male and female and between breeders and non-breeders. All differences were tested using Mann–Whitney *U* test (SPSS 2006).

Results

All 22 BHG tested negative for avian influenza virus (Electronic supplementary material, Table S1). We were unable to track 8 geese through to the end of breeding season. Among them, 7 remained in Qinghai Lake; 1 bird (#67693) migrated 1,200 km to a chain of small lakes 200 km south of Erhel Lake, Arhangay Province, Mongolia. Therefore, we analysed data from 21 BHG (11 in 2007 and 10 in 2008) that were tracked successfully throughout the breeding and post-breeding period (including 2 geese those signals stopped just before autumn migration; transmissions for #82079 stopped on 13 October and transmissions for #82090 stopped on 29 October). The sex ratio (males: females) of geese was 11:10. The mean number of locations recorded per individual were 788.6 ± 169.2 ($n = 19$) and the mean number of locations per day per individual was 3.9 ± 0.8 ($n = 19$) (Table 1).

Distribution and movements

The pre-nesting period

All but 3 geese stayed at Qinghai Lake during the pre-nesting period. Bird #82086 departed Qinghai Lake soon after being marked on 2 April, and moved to Jianghe wetland (about 50 km northwest of Qinghai Lake). Two geese departed Qinghai Lake at the end of the pre-nesting period; bird #82082 departed for Jianghe wetland on 18 April, bird #82084 departed for Cuolongka Lake (about 220 km northwest of Qinghai Lake) on 22 April. The mean number of sites visited per individual was 1.43 ± 0.75 ($n = 21$) during the pre-nesting period. Most geese stayed near their capture sites at Heimahe and Hadatan. Three geese which were captured at Hadatan moved to estuaries or wetlands adjacent to the capture sites, such as Tiebujia estuary, Luci Island, Egg Island and Shaliuhe estuary (Fig. 2a).

The nesting period

During the nesting period, 3 geese that left Qinghai Lake were considered not to have nested. Bird #82082 and #82086 stayed at Jianghe wetland throughout the nesting period. Bird #82084 spent the nesting period at Cuolongka Lake.

We determined 7 (4 females and 3 males) of the 18 geese that remained at Qinghai Lake to have bred. Two geese joined the colony at Egg Island (#74898 and #74900) and 5 geese joined the colony at Sankuaishi Island (#67582, #67586, #67699, #82080 and #82090). One female and 3 males stayed on the colony at least 29 days and were considered to have nested successfully. Of 4 geese considered to have nested successfully at Sankuaishi

Table 1 ID number, sex, schedule, number of satellite tracking locations, and the total distance accomplished during the breeding season of the Bar-headed Geese *Anser indicus* satellite-tracked at Qinghai Lake, 2007 and 2008

ID no.	Sex M (male) F (female)	Beginning date of tracking	Date of birds left Qinghai Lake	Initiation of moult	Beginning date of autumn migration	No. of locations	Duration of study period (days)	Involved in reproduction?	Successfully hatched young?	Moulting migration distance (km)
2007										
67582	F	3-25	7-2	7-29	10-10	916	200	Y	N	298.14
67586	M	3-27	6-7	7-4	10-10	538	198	Y	N	259.5
67690	F	3-25	6-12	6-18	10-10	1,064	200	N		404.41
67695	M	3-29	6-22	7-15	10-12	838	199	N		376.46
67698	F	3-31	9-3	6-18	10-22	640	206	N		20.92
67699	F	3-26	9-13	7-10	10-28	928	217	Y	Y	0
74898	F	3-31	6-23	6-28	10-28	550	212	Y	N	195.47
74899	M	3-30	6-8	7-14	10-19	638	204	N		397.32
74900	F	3-31	9-16	7-4	10-22	671	204	Y	N	17.89
74901	M	3-31	6-21	7-7	10-2	680	185	N		201.44
74902	F	3-30	9-15	7-13	10-24	844	209	N		44.65
2008										
82076	F	4-1	6-19	6-30	10-23	814	206	N		303.61
82079	M	4-2	8-31	7-9	10-21	781	203	N		20.72
82080	M	4-1	6-29	7-5	10-22	1,117	205	Y	N	272.53
82081	M	3-30	8-24	5-23	10-14	841	202	N		26.34
82082	F	3-30	9-29	7-7	10-12	1,043	200	N		68.4
82084	M	3-30	4-22	7-1	10-22	740	210	N		16.25
82085	M	3-30	8-25	7-9	10-14	699	202	N		0
82086	F	3-31	8-20	7-4	10-15	641	202	N		81.02
82087	M	4-3	9-3	6-4	?	496	298	N		0
82090	M	4-3	10-13	7-12	?	863	210	Y	Y	0

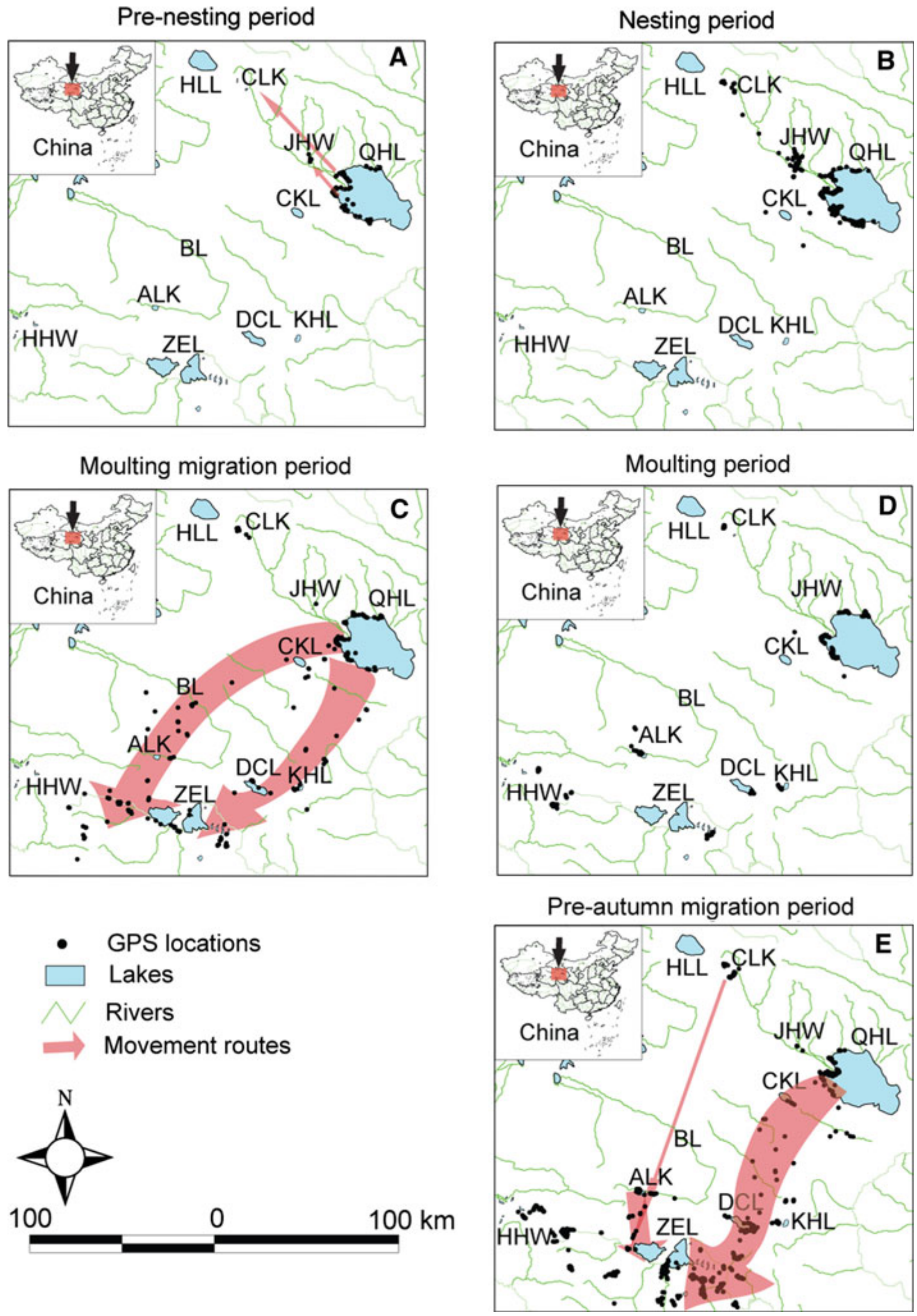

Fig. 2 GPS satellite telemetry locations of Bar-headed Geese marked at Qinghai Lake in 2007 and 2008 during the pre-nesting (**a**), nesting (**b**), moulting migration (**c**), moult (**d**) and pre-autumn migration (**e**) periods. **c** The moulting migration paths for Bar-headed Geese that moved from the breeding season area at Qinghai Lake to moulting sites at Kuhai Lake, Donggeicuona Lake, Alake Lake, Zhaling-Eling Lake area and Huangheyuan wetland. **e** The pre-autumn migration movement paths for Bar-headed Geese that moved from moulting areas at Qinghai Lake, Cuolongka Lake, Alake Lake, Kuhai Lake and Donggeicuona Lake to pre-autumn migration area at Zhaling-Eling Lake area. Codes for wetlands are listed in Fig. 1

Island, 2 moved long distances soon after nesting, suggesting their broods were not successful. We found no relationship between body mass and reproduction attempts ($U_{7,14} = 46.0$, $P = 0.823$) or hatching success rate ($U_{2,5} = 5.0$, $P = 1.00$). Of the 11 non-breeders that remained at Qinghai Lake through the nesting period, 4 geese stayed around their capture sites at Heimahe ($n = 3$) and Hadatan ($n = 1$), and the other 7 geese expanded their range to nearly all the wetlands and estuaries within the northwest part of Qinghai Lake, including Hadatan, Tiebujia estuary, Egg Island, Quanwan wetland, Heimahe, Sankuaishi and Qinghaihunongchang wetland (Fig. 2b). No geese moved out of Qinghai Lake during the nesting period. Four successful breeders stayed at Heimahe and Sankuaishi for the entire nesting period. Satellite-marked geese used an average of 2.52 ± 1.4 sites during the nesting period.

Moult migration and moulting period

The initiation of moult occurred over a 68-day period, with the average occurring on 2 July ($n = 21$; 23 May–29 July). There was no significant difference of distance moved to moulting grounds between males and females

($U_{10,11} = 49.5$, $P = 0.698$) or unsuccessful breeders and non-breeders ($U_{5,14} = 27$, $P = 0.459$). The moulting migration distance for geese that remained at breeding grounds for moulting was 14.7 ± 14.8 km, and it was 259.8 ± 115.4 km for geese left the breeding grounds to moult elsewhere.

Two geese that spent the nesting period at Jianghe wetland moved back to Qinghai Lake to moult: #82082 at Qinghaihunongchang wetland and #82086 at Heimahe. Bird #82084 spent nesting period at Cuolongka and moulted at a small lake within 17 km of its breeding ground. Of the 18 geese that remained at Qinghai Lake during nesting period, 9 (5 non-breeders, 4 unsuccessful breeders) geese left Qinghai Lake for moulting and 9 (6 non-breeders, 2 successful breeders and 1 unsuccessful breeder) remained at Qinghai Lake for moulting (Fig. 2c). We identified five moulting sites in Qinghai Lake: Heimahe, Tibujiahe estuary, Shaliuhe estuary2, Quanwan and Qinghaihunongchang. We also identified five moulting sites out of Qinghai Lake: Kuhai Lake, Donggeicuona Lake, Xingxinghai Lake, Alake Lake and Huangheyuan wetland. Our ground surveys at Kuhai Lake and Donggeicuona Lake confirmed that these two sites were used as moulting sites by BHG.

We examined moult migration routes for the 9 geese that moulted outside of Qinghai Lake. Departure dates averaged 20 June (ranged from 7 June to 3 July). After departing Qinghai Lake, intermediate staging sites of the moulting migration were used. On average, three (range 1–4) staging sites were used, and duration at the staging sites averaged 5 days (range 0.5–26), most geese (15 of 22) were detected at staging sites for less than 3 days, although 2 individuals remained at their staging sites for 25 and 26 days, respectively. Kuhai Lake, Donggeicuona Lake, Zhaling-Eling Lake, and some small lakes and wetlands were used as staging sites during the moult migration (Fig. 2d).

The pre-autumn migration period

The initiation of autumn migration occurred over a 27-day period, averaged on 17 October ($n = 18$; 2–28 October). There were no differences in start date of autumn migration between males and females ($U_{8,10} = 26.5$, $P = 0.227$), nor between the individuals that moulted at breeding areas versus those that moulted in other locations ($U_{8,10} = 20.0$, $P = 0.073$).

For the geese moulting at Huangheyuan wetland and Zhaling-Eling Lake area, after completing moult, BHG began autumn migration by staging near their moulting areas for several weeks (average 51.0 ± 12.2 days, range 40–69 days). Geese that molted at Qinghai Lake, Cuolongka Lake, Kuhai Lake, Donggeicuona Lake and Alake Lake, first stayed near their moulting areas for several weeks (average 31.5 ± 11.4 days, range 13–53 days) then moved rapidly to Zhaling-Eling Lake area or Huangheyuan wetland area and stayed there for several days before initiating of autumn migration (average 39.4 ± 12.4 days, range 19–56 days). Bird #67582 started autumn migration from its moulting site at Alake Lake, after remaining at the moulting site for 28 days. Bird #67582 also staged at Zhaling-Eling Lake during the autumn migration (Fig. 2e).

Home range and core area

There was substantial variation in mean home range and core area size during the pre-nesting period, nesting period and moulting period among the geese tracked (Table 2). Home range and core area were relatively small during the pre-nesting period: 56% geese had home ranges of less than 15 km^2 and core areas of less than 4 km^2. Only 1 bird (#82084) had an extreme large home range (1,234.7 km^2) and core area (210.5 km^2). Mean home range and core area size were smallest during the moulting period when the movements of geese were confined during the flightless period. Mean home range and core area estimates did not differ significantly by sex, year and between the breeders and non-breeders (Table 3).

Discussion

Here, we provide a comprehensive description of breeding season movements, moult migration, moulting locations and pre-autumn migration movements of BHG at Qinghai Lake using satellite telemetry. We discussed the breeding status of marked geese and their related moulting movements. The location data was sufficient in our analyses (averaged four locations per individual per day).

Table 2 Mean (± SD) core area (50% kernel) and home range (95% kernel) of Bar-headed Geese during the pre-nesting, nesting and moulting periods in 2007 and 2008

Period	n	Home range (km^2) (minimum–maximum)	Core area (km^2) (minimum–maximum)
Pre-nesting period	18	109.5 ± 288.5 (0.52–1,234.7)	21.3 ± 49.9 (0.07–210.5)
Nesting period	20	242.5 ± 316.6 (23.1–1,410.0)	49.6 ± 69.6 (4.7–317.5)
Moulting period	20	8.5 ± 9.0 (0.2–26.6)	1.8 ± 2.3 (0.02–8.0)

Table 3 Influences of sex, year and reproduction status on the home range and core area size during the pre-nesting, nesting and moulting periods in 2007 and 2008

Period	Sex		Year		Breeders and non-breeders	
	Mann–Whitney $U_{10,8}$	Asymp. Sig. (2-tailed)	Mann–Whitney $U_{10,10}$	Asymp. Sig. (2-tailed)	Mann–Whitney $U_{11,9}$	Asymp. Sig. (2-tailed)
Pre-nesting (50%)	31.5	0.427	31.0	0.424	35.0	0.786
Pre-nesting (95%)	36.5	0.724	30.5	0.398	33.0	0.618
Nesting (50%)	37.0	0.342	35.0	0.257	27.0	0.216
Nesting (95%)	34.0	0.239	43.0	0.597	22.0	0.099
Moulting period (50%)	46.0	0.762	40.0	0.470	36.0	0.621
Moulting Period (95%)	40.0	0.450	35.0	0.271	41.0	0.934

Considering the high degree of accuracy of the GPS locations, we believe that our results are highly trustworthy.

Movements and distribution

Prosser et al. (2009) have reported a migratory connection between Qinghai Lake and Mongolia. We found that one marked goose flew to Cuolongka Lake after 20 days at Qinghai Lake. Thus Qinghai Lake may serve as both the breeding ground and stopover site for BHG. Most geese that remained at Qinghai Lake during the pre-nesting period remained on or near their capture sites. Similar movement patterns during pre-nesting period have been recorded for Emperor Goose *Anser canagica* breeding in western Alaska where within 15 days after arrival, all females were located within 20 km from their capture sites (Hupp et al. 2006).

Based on our criteria for nesting, we identified 7 geese (33% of total) that likely nested at Sankuaishi Island and Egg Island colony sites. The results are similar to ground surveys in 2008 at Qinghai Lake that indicated 37% of BHG bred. We induced that GPS PTTs might have minimal effects on the reproduction status of BHG (Fleskes 2003; Robert et al. 2006). No new nesting sites were found in Qinghai Lake, Jianghe wetland and Cuolongka (Xian 1964; Hou et al. 2009). Breeding BHG generally remained at a single site throughout their nesting period. We observed nesting behaviour of BHG at the Egg Island colony. Females took on incubation, with male vigilant around the nests. Thus, movement of breeders would be constricted to nesting and feeding sites. Both breeders that failed to hatch young and non-breeders commonly moved between wetlands surrounding Qinghai Lake and were not restricted to colony locations. The wetlands surrounding Qinghai Lake are not contiguous, causing BHG to fly moderate distances between these wetlands (Liu et al. 2008; Hou et al. 2009). Although home range sizes were large, with mean home range of 242.5 ± 316.6 km^2, geese that stayed at Qinghai Lake showed strong fidelity to the lake; no geese moved out of the lake during the nesting period.

Previous research on moulting migration showed that the breeding performance of geese species had a strong influence on moulting migration patterns: the majority of successful breeders moulted on or near the breeding grounds, whereas most non-breeders and failed breeders left the breeding grounds to moult elsewhere (Bollinger and Derksen 1996; Reed et al. 2003; Luukkonen et al. 2008). In our study, it appeared that successful breeders moulted on the breeding grounds. However, the moulting locations for non-breeders and unsuccessful breeders were not as clear. There were no differences between males and females in selection of moulting locations in this study, similar to prior studies (Petersen 1981; Flint et al. 2000; Petersen et al. 2006). Moulting migration distances were not very large for BHG at Qinghai Lake when compared with the long distance moulting migration of other goose species such as the Lesser White-fronted Goose *Anser erythropus* and Emperor Goose (Aarvak and Oien 2003; Hupp et al. 2007).

Most ducks and geese would take a similar moulting migration route to that of autumn migration (Aarvak and Oien 2003; Petersen et al. 2006). However, Canada Geese *Branta canadensis maxima* satellite-marked in southern Michigan would return to their former nesting areas following moult of regimes (Luukkonen et al. 2008). In this study, geese that moved away the lake to moult elsewhere took a similar route to that of autumn migration (author's unpublished data), and no birds return to their former areas used during the nesting period.

Hupp et al. (2008) reported that Emperor Geese at the Yukon-Kuskokwim Delta mainly acquired their premigratory reserves near brood-rearing areas. BHG that moulted at Zhaling-Eling Lake area or Huangheyuan wetland remained near their moulting sites before autumn migration. All BHG that moulted at other sites first stayed at their moulting sites for about a month, then moved to Zhaling-Eling Lake area or Huangheyuan wetland, and stayed there for more than a month before beginning autumn migration. This suggests that pre-migratory reserves were acquired both at the moulting sites and the subsequent Zhaling-Eling Lake area and Huangheyuan wetland. The main habitat of Zhaling-Eling Lake area and Huangheyuan wetland are small lakes and wetlands devoid of human activity, thus providing important sites for BHG to build fat stores before beginning autumn migration.

Movements of BHG in relation to spread of HPAI H5N1 virus

Detection of H5N1 in healthy wild birds is rare (Chen et al. 2006; Goujgoulova and Oreshkova 2007; Wallensten et al. 2007), however, successful migration of an HPAI H5N2-infected White-faced Whistling Duck *Dendrocygna viduata* in Nigeria demonstrated that the possibility for wild birds to transmit the HPAI virus exists (Gaidet et al. 2008). Qinghai Lake was considered an important site for virus transmission between breeding and wintering birds, while these birds may carry the viruses spreading them from one area to the other.

In H5N1 innoculation studies, BHG had a delayed onset of detectable clinical signs (6.5 days) and death (8.0 days) (Brown et al. 2008), suggesting BHG might serve as a potential vector of HPAI H5N1 virus (Liu et al. 2005; Zheng and He 2006). Our study was carried out within a relative limited spatial (only including the breeding grounds and the moulting grounds) and temporal (from pre-nesting period to pre-autumn migration period) scale. None of the tracked birds was positive for H5N1 tests and no outbreaks were recorded at the moulting sites during the moulting periods (OIE 2009). Therefore, we cannot draw conclusions regarding whether BHG spread H5N1; however, considering the lack of poultry within the study area, one hypothesis of virus spread is via wild bird movement. Movements of BHG between Qinghai Lake and other lakes or wetlands may occur most frequently during the pre-nesting and moult migration period. During the pre-nesting period, some BHG would continue moving north to Hala Lake area in Qinghai Province China or lakes of Mongolia. During the moulting migration period, some non-breeders and failed-breeders would leave Qinghai Lake to moult at Kuhai Lake, Donggeicuona Lake or other locations. Then, BHG may carry the virus to these sites with their movements. Mixing of breeding populations on moulting sites has been described for other species of geese (Bollinger and Derksen 1996; Reed et al. 2003). Mixing of birds from different breeding populations increases the likelihood of virus exchange among populations.

In summary, the current study documents detailed movements of BHG during the pre-nesting, nesting, moult migration, moult and pre-autumn migration periods, provides new insights into the behaviour and ecology of this species. This knowledge could be helpful for tracking the spread of HPAI H5N1 in this region.

Zusammenfassung

Bewegungsmuster von Streifengänsen *Anser indicus* während und nach der Brut am Qinghai-See, China

Der Ausbruch der hoch pathogenen H5N1-Vogelgrippe am Qinghai-See in China im Jahr 2005 führte zum Tod von über 6000 Zugvögeln, von denen die Hälfte Streifengänse *Anser indicus* waren. Die Bewegungen dieser Art zu verstehen könnte helfen, Ausbruchsrisiken für HPA1-Viren zu überwachen; daher haben wir die Bewegungsmuster von 29 Streifengänsen am Qinghai-See, China, in den Jahren 2007 und 2008 mit Hilfe hochauflösender GPS-Satellitentelemetrie untersucht. Wir haben die Bewegungen und die Verbreitung markierter Streifengänse vor der Brut, während der Brut und während der Mauser beschrieben. Drei von 21 Streifengänsen mit kompletten Aufzeichnungen wanderten während der Brutperiode in andere Gebiete ab: zwei ins Jianghe-Feuchtgebiet (50 km nordwestlich vom Qinghai-See) und eine zum Cuolongke-See (220 km nordwestlich vom Qinghai-See). Wir fanden Brutversuche von sieben markierten Gänsen am Qinghai-See. Die Brutversuche von vier Gänsen wurden als erfolgreich gewertet, und zwei Gänse verloren ihre Brut kurz nach dem Schlupf (nachfolgend als erfolglose Brüter bezeichnet). Von 18 Gänsen, die während der Brutperiode am Qinghai-See anwesend waren, blieben neun (sechs Nichtbrüter, zwei erfolgreiche Brüter und ein erfolgloser Brüter) auch während der Mauser dort, während die übrigen neun (fünf Nichtbrüter, vier erfolglose Brüter) den Qinghai-See zum Mausern verließen. Mauserorte waren der Kuhai-See, der Donggeicuona-See, der Alake-See, das Zhaling-Eling-See-Gebiet und das Huangheyuan-Feuchtgebiet. Die Gänse, die am Qinghai-See, Cuolongka-See, Kuhai-See, Donggeicuona-See oder Alake-See mauserten, zogen vor dem Herbstzug ebenfalls ins Zhaling-Eling-See-Gebiet oder ins Huangheyuan-Feuchtgebiet und blieben dort für mehrere Tage. Die mittleren Aktions- und Kerngebietsschätzungen unterschieden sich nicht signifikant zwischen den Geschlechtern, Jahren sowie Brütern und Nichtbrütern.

Acknowledgments We thank the staff of Qinghai Lake National Nature Reserve for field and logistical support. We thank Yanhua Qu (Institute of Zoology, CAS) for helpful comments on earlier version of this manuscript. We thank Steve Schwarzbach (Western Ecological Research Center, WERC) and Judd Howell (Patuxent Wildlife

Research Center), United States Geological Survey (USGS) for supporting this project. We thank David Douglas for decoding and managing data from the satellite system and William Perry for webpage maintenance. The research was supported by CAS Innovation Program (KSCX2-YW-N-063), NSFC (30925008), China MOST Program (2006BAD06A01), and E-Science Program (INFO-115-D02). The research was also supported by IDRC, NIH and USDA to Lei F.M., and NSFC Program J0930004 to Cui P.). Funding was also provided by the Government of Sweden, USGS, United States National Science Foundation (No. 0713027) and the United Nations Food and Agriculture Organization-EMPRES Wildlife Program in the Animal Health Service.

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