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RESEARCH

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Assessing site-safeguard effectiveness and habitat preferences of Bar-headed Geese (*Anser indicus*) at their stopover sites within the Qinghai-Tibet Plateau using GPS/GSM telemetry

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Abstract

Background: The Bar-headed Goose (*Anser indicus*) breeds across the high plains and plateau of Central Asia and winters in the Qinghai-Tibet Plateau (QTP), the Yunnan-Guizhou Plateau and the Indian sub-continent. Of the two recognized discrete flyways of the Bar-headed Goose, the Eastern Tibetan Flyway (ETF) is the larger, comprising at least six migration routes. However, we remain ignorant about their migratory connectivity, habitat use and effectiveness of site-safeguard mechanisms set in place for the species.

Methods: We tracked 30 ETF Bar-headed Geese from Chinese and Mongolian breeding areas to their wintering grounds using GPS/GSM transmitters, to determine their migration routes and stopover staging patterns within the QTP, overlaying these upon GIS layers of protected area status and habitat type, to model their habitat selection.

Results: In total, 14 tagged Bar-headed Geese provided information on their entire autumn migration and 4 geese on their entire spring migration. Qinghai Lake marked birds overwintered in the QTP ($n=2$), geese tagged in Mongolia wintered either in the QTP ($n=3$) or in India/Bangladesh ($n=9$), representing three of the migration routes within the ETF. In total, tagged birds staged at 79 different stopover sites within QTP in autumn and 23 in spring, of which 65% (autumn) and 59% (spring) of all fixes fell within the boundaries of either National Nature Reserves (NNRs) or Important Birds Areas (IBAs) in the QTP. Bar-headed Geese predominantly occurred on four land-cover types: grassland (mostly by day), water bodies (at night), wetlands and bare substrates (salt flats, dry lake/river substrates and plough) with little change in proportion. Generalized linear mixed models comparing presence with pseudo-absence data suggested geese strongly selected for wetlands as staging habitat, avoiding bare substrates in spring.

Conclusions: Based on our limited observations of these tagged geese, this study is the first to show that the current designated National Nature Reserves in place in the staging areas within the QTP appear adequate to protect this increasing population. In addition, Hala Lake in Qinghai Province and adjacent areas used as initial QTP staging during

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Background

e Bar-headed Goose (*Anser indicus*) has increased greatly in abundance since the 1990s, reaching an esti-

Here, we attempt to define Bar-headed Goose habitat selection (as distinct from simple habitat use; Jones 2001) to understand how the birds might be showing behavioral responses to changes in habitat conditions, which potentially affect the survival and adaptability of individuals (Block and Brennan 1993). Only by revealing habitat selection patterns, can we fully understand the spatial and temporal distribution of the Bar-headed Geese we follow. Based on results from a previous study, which used geographical information to model habitat selection in ETF breeding areas (Zheng et al. 2018), we identified six key parameters in modelling habitat selection, including land cover (each class is treated as a separate variable), elevation, slope, aspect, distance to river/lake and road.

In this investigation, we applied further telemetry devices to samples of birds on their key breeding areas in China and Mongolia, to extend earlier studies of this species, with the specific aim of identifying key staging areas throughout the migratory life cycle of these birds. Most importantly, we specifically compare the areas used by tagged Bar-headed Geese to assess the effectiveness of currently designated areas in the QTP to protect key staging areas during migration for the species and to determine their habitat use and selection at these areas.

Methods

Capture of individuals and transmitter attachment

In June 2016, three Bar-headed Geese (of unknown age and sex) rescued and rehabilitated by the Qinghai Lake National Nature Reserve Rescue Center were fitted with neck collar-mounted GPS/GSM loggers (weight 40 g, Hunan Global Messenger Technology Co., China) and released at Qinghai Lake (37.07 °N, 99.82 °E, China). The signal was lost from one of the birds during autumn migration, but the two other geese completed their autumn migrations in 2016.

In July 2018, 27 individuals (adult, unknown sex) were rounded up during the flightless moult period and captured at Terkhiin Tsagaan Lake (48.15 °N, 99.59 °E, Mongolia) and Bayan Lake (49.94 °N, 93.90 °E, Mongolia), and fitted with backpack-mounted GPS/GSM loggers (weight natural and artificial waterbodies, such as lake, river and reservoir/pond (for detailed definitions of land cover categories, see Gong et al. 2013). We assigned each GPS location within the stopover sites in the QTP to a specific land-use type defined by the land cover data using R 3.6.0 (R Core Team 2019). GPS fixes were assigned to day or night based on local sunrise and sunset times calculated by "solartime" package (v0.0.1; Wutzler 2018).

We used elevation data measured from SRTM3-DEM dataset (resolution 30 m $\times$ 30 m) created by NASA and NIMA, and calculated slope and aspect (defined as a parameter value running from 0 to 360, starting from the West and increasing clockwise) for each GPS fix using ArcMap 10.6. Finally, we calculated the shortest distance of each GPS fixes in stopovers to roads (downloaded from https://www.worldclim.org/) and rivers (downloaded from https://download.csdn.net/downl

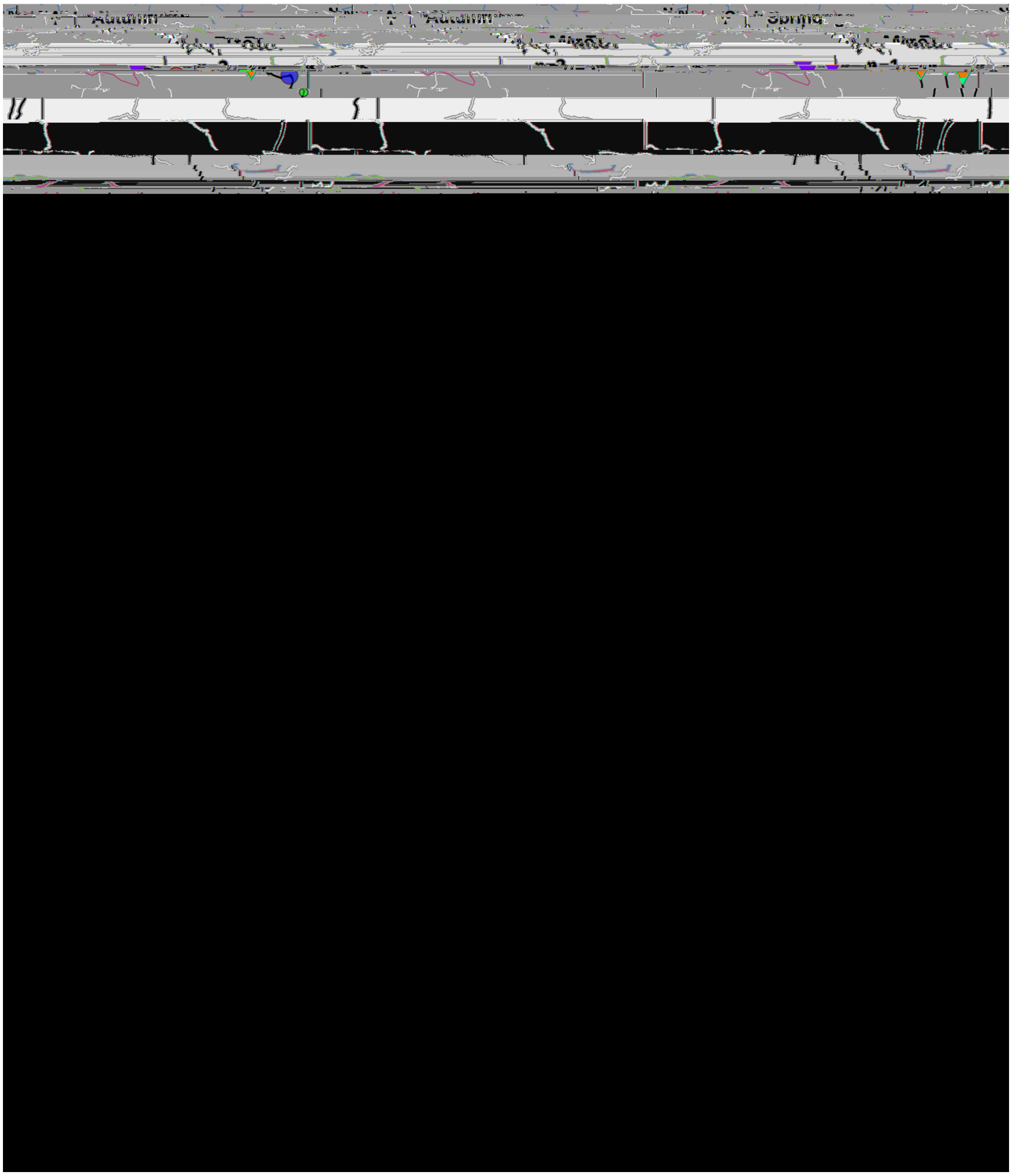

Fig. 1 Autumn and spring individual migration routes (black lines) and stopover sites (green circles) of Bar-headed Geese (*Anser indicus*) derived from GPS/GSM telemetry devices deployed on birds tracked in 2016 and 2018/2019. The shaded red region shows the Qinghai-Tibet Plateau. TtoT: Qinghai Lake – Shigatse Prefecture routes; MtoT, Mongolia – Shigatse Prefecture routes; MtoA, Mongolia-India/Bangladesh routes. Sample sizes are indicated by *n* (number of individuals finishing migration)

these, there were three areas containing at least three stopovers, which fell outside existing NNRs/IBAs designation (Fig. 2). ese were: (1) Shule River, Qinghai Province, $N_s = 6$ (N_s in each case represents the number of stopovers; No. 2 in Table 1; close to Hala Lake); (2) Dangqu River, TAR, $N_s = 3$ (No. 11; outside of the Se Lin Cuo NNR and near downtown Dangxiong county); (3) Duoqingcuo Lake, TAR, $N_s = 11$ (No. 12; a national wetland park and close to the highway).

Habitat use and selection in stopover sites

Habitat types used by the Bar-headed Geese were predominantly natural ecosystems: 31% grassland, 29% bare substrate (including dry salt flats, bare herbaceous croplands and dry lake/river bottoms; Gong et al. 2013), 26% water bodies and 11% wetlands. Habitat types used by

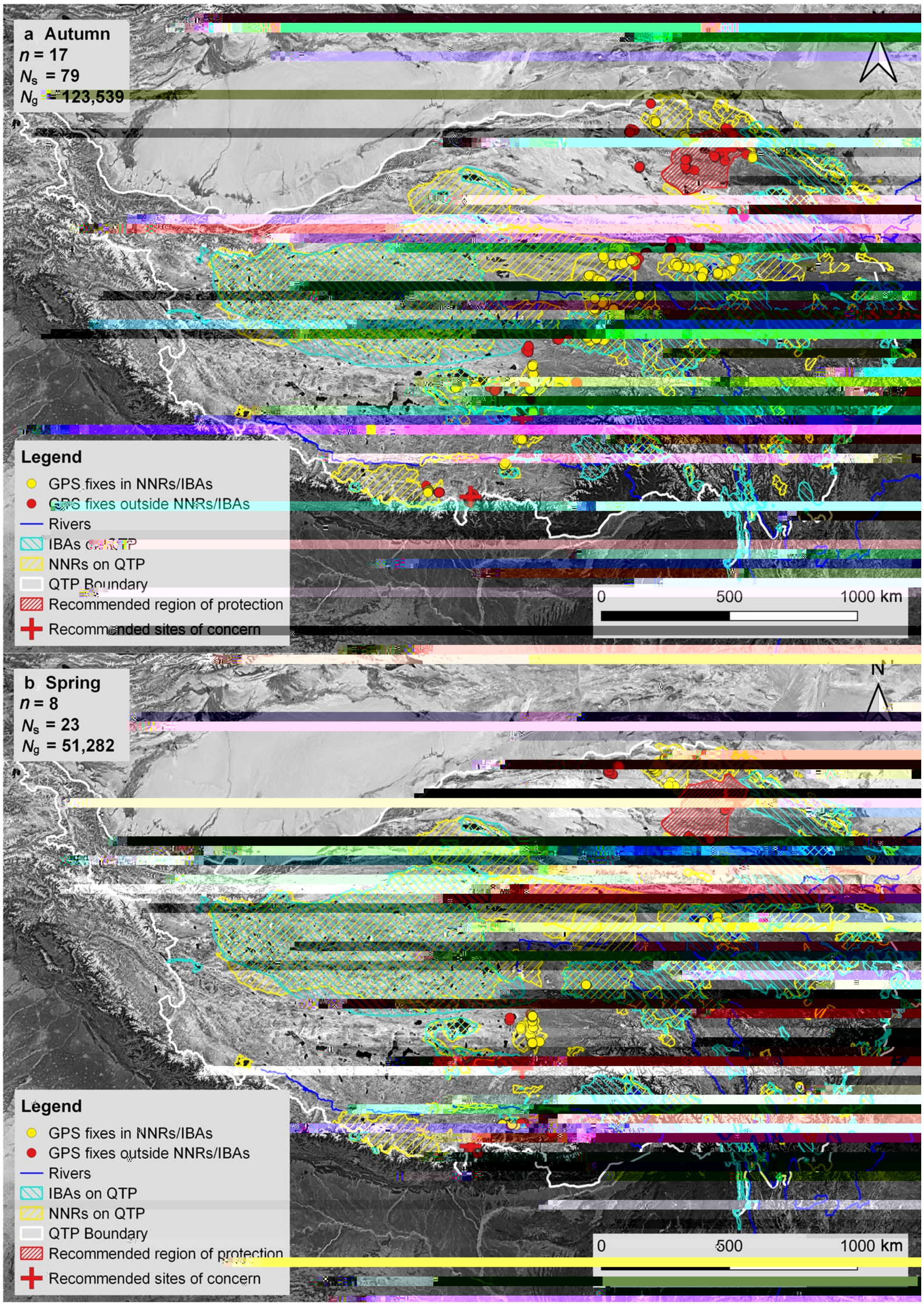

Fig. 2 GPS fixes of stopover sites within the QTP for tagged Bar-headed Geese during autumn and spring migration in 2016 and 2018/2019. **a** stopovers during autumn migration; **b** stopovers during spring migration. NNRs: National Nature Reserves of China; IBAs: Important Bird and Biodiversity Areas; QTP, the Qinghai-Tibet Plateau. Sample sizes are indicated by n (number of instrumented individuals generating the data), N_s (number of stopovers within QTP) and N_g (total number of GPS fixes per category). The explanations apply also to Figs. 3, 4

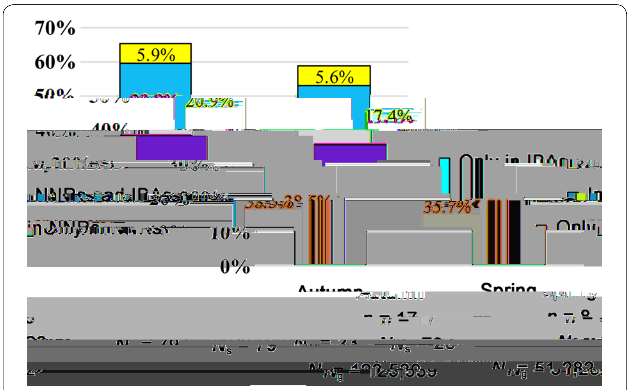

Fig. 3 Conservation status of Bar-headed Geese stopovers within the Qinghai-Tibet Plateau during autumn (totally 63.3%) and spring (58.7%) migration in 2016 and 2018/2019

geese differed between day (the majority on grassland, 47% in autumn and 33% in spring) and night (when the majority were using waterbodies, 33% in autumn and 41% in spring), but were similar during autumn and spring migration (Fig. 4).

Comparing GLMMs results, the best fit models for predicting spring and autumn Bar-headed Goose stopover sites within the QTP were based on the same nine parameters. These included the four habitat types, as well as slope, aspect, elevation, distance to roads and rivers (autumn: weight = 1.000, AUC = 0.80; spring: weight = 1.000, AUC = 0.83; Table 2). All these parameters are significant ($p < 0.001$; Fig. 5). Among habitat types, Bar-headed Geese tended to strongly select wetlands ($\beta_{autumn} = 1.94$, $\beta_{spring} = 2.03$), slightly select water bodies ($\beta_{autumn} = 0.62$, $\beta_{spring} = 0.80$), slightly avoided to select grassland ($\beta_{autumn} = -0.95$, $\beta_{spring} = -1.05$), and were least likely to select bare substrates in spring ($\beta_{spring} = -2.01$). Among terrain variables, geese tended to select stopovers facing south ($\beta_{autumn} = 0.30$,

Table 1 Important staging areas used by tagged Bar-headed Geese (*Anser indicus*) migrating in the Eastern Tibetan Flyway in 2016 and 2018/2019

Only areas with at least two stopovers sites where the estimated duration of stay was at least two days are shown

$\beta_{spring}=0.32$), with low elevation ($\beta_{autumn}=-0.12$, $\beta_{spring}=-0.31$) and slope ($\beta_{autumn}=-2.00$, $\beta_{spring}=-1.17$) both during autumn and spring migration. Among other variables, geese tended to select stopover sites, which were away from roads ($\beta_{autumn}=0.16$, $\beta_{spring}=0.29$) and close to rivers ($\beta_{autumn}=-0.22$, $\beta_{spring}=-0.43$) both during autumn and spring migration (see Additional file 2: Tables S5, S6 for full model details).

Discussion

e results of this tracking study clearly show that three NRRs: Yan Chi Wan (Gansu Province), San Jiang Yuan (Qinghai Province), and Se Li Cuo (TAR) are of critical importance to Bar-headed Geese in the ETF during both autumn and spring migration. In particular, the importance of rivers in Yan Chi Wan (No. 1 in Table 1) and San Jiang Yuan NNRs (No. 5, 6) were not previously known. Overall, 65% of autumn GPS fixes were from within NNRs/IBAs and 59% in spring. Our studies confirmed the importance of Hala Lake (close to Shule River, No. 2), San Jiang Yuan NNR (No. 3, 4) and Se Lin Cuo NNR (No. 7–10) indentified by tagged Bar-headed Geese in previous studies (Hao et al. 2010; Zhang et al. 2011b; Prosser et al. 2011). Nevertheless, our tracking data found additional areas frequently used by tracked geese, which are not currently designated as NNRs/IBAs. Of these, the most important appear to be the Shule River, Qinghai Province, the Dangqu River, TAR and Duoqingcuo Lake, TAR, all of which are recommended for ground survey during the migration season based on their prolonged use (3–26 days) by tagged birds from this study.

We would also recommend surveying the suitability of adding Hala Lake and adjacent areas (97.60 °N, 38.30 °E; Fig. 2) to the protected area network for this species, as part of the ecological redline for the region. is is part of the NE edge of the QTP which represents the first staging area encountered and used by geese during autumn migration, yet very few of our tracked birds used areas inside the current protected area boundaries, despite the importance of the position of this area in the overall migration network (Xu et al. 2020).

e ETF represents the larger of the two flyways of the Bar-headed Goose, supporting more than 80,000 individuals. Within this flyway, it is thought that there at least six migration routes (Additional file 1). ese are: (1) Mongolia–Yarlung Zangbo River, China; (2ht tYang Ymigiiver, Qin(al)-4.9

forest and 18% bare substrate in Qinghai Lake ($n = 8$). We found very low forest cover when overlaying the home ranges from Zheng et al. (2018) on the ESA Global Cover 2009 maps and goose use of forest habitats seems extremely unlikely.

During migration, geese mainly used grassland, water bodies, wetlands and bare substrates at their stopover sites in our study. Prosser et al. (2011) reported 75% of positions of tagged Bar-headed Geese came from grassland and > 12% from wetlands during autumn and spring migration. Both studies therefore confirmed tagged geese mainly used natural ecosystems during migration. Small di erences between our and Prosser et al.'s (2011) results may be the consequence of land-cover changes that have a ected goose habitat availability in the last two decades and improvements in accuracy of the land cover dataset. Prosser et al. (2011) used the 2003 dataset based on 1 km resolution, whereas our study used the 2019 dataset with 10 m accuracy.

During winter, geese mainly used winter wheat fields, or fallow croplands, rivers, lakes and marshes along the Yarlung Zangbo River. Ground counts of feeding geese ($n = 44{,}657$ in January 2009) found 72.1% on fallow cropland (Liu et al. 2010). Prosser et al. (2011) also reported tagged geese used 39% cropland near Lhasa city. In addition, Bar-headed Geese also used grassland and cropland as their main diurnal feeding areas at Caohai, China (Yang et al. 2013), Lashihai Lakes, China (Yan et al. 2014) and Keoladeo National Park, India (Middleton and Van der Valk 1987). Hence, like many northern hemisphere goose species, the Bar-headed Goose has shown a plasticity that has enabled it to take advantage of the new farmland feeding opportunities on the wintering areas (Fox and Abraham 2017). We speculate that restricted use of croplands in summer and on migration simply reflects the general remoteness of the areas that they use at these stages of the life cycle, in regions where the area of cropland available for foraging is extremely restricted.

In our original GLMM modelling to compare the habitat types used by geese with pseudo-absence measures in the immediate vicinity, we also entered water recurrence (Pekel et al. 2016) as a potential explanatory parameter, but it was highly correlated with "water body". Deletion of water recurrence from the model resulted in an AUC of more than 0.7, indicating reasonable predictions from this simplified model. In our final model, geese tended to select wetland and water bodies as habitat, because the seasonal growth of aquatic plants provides accessible digestible biomass which can be exploited to accumulate fat stores by day (Cong et al. 2012; Wang et al. 2013), and open water o ers a night time roosting refuge to avoid predators. Geese also appeared to prefer south facing stopover sites, probably because these areas gain maximum solar insolation to stimulate the growth of food plants to support fat accumulation during the spring migration and shelter from the north wind during the autumn migration. Geese avoided bare substrates strongly in spring, probably because of the low surface temperatures and frost during spring migration in these areas. Summering Bar-headed Geese at Qinghai Lake preferred wetland, open land with sparse vegetation, sites close to rivers/lakes and away from roads, croplands and higher elevations (Zheng et al. 2018) and we contest that they also avoided forest. Wintering Bar-headed Geese at Caohai Lake showed a preference for sites with high vegetation cover, low vegetation height, far from human disturbance, close to the water, open habitats and lower elevation as their foraging sites (Yang et al. 2013). Our results closely followed theirs, confirming that all stages of the life cycle, Bar-headed Geese tend to select wetland areas, close to rivers/lakes, away from roads and at lower elevations than would be expected by chance.

e habitat selection patterns of Bar-headed Geese also reflect patterns shown by Greylag Geese in their breeding and wintering areas in East China (Li 2019). Both species tend to select water bodies and wetland as habitat, although Greylag Geese occur in sites nearer to roads and tend to show greater selection for cropland, suggesting they are more tolerant of human disturbance than Bar-headed Geese. Cropland was not used as a parameter in our model, because it contributed only 1% to habitat use among tagged Bar-headed Geese. In conclusion,

diate vic-9.4fbitand feed2(s)-5c-t(t p)-6(a)9(Tw ((e amm99618(ar990 0 is increasing (Li et al. 2020), suggesting that site protection can contribute to supporting increasing numbers of geese over time. It would therefore appear that Bar-headed Geese have benefitted from improved conservation action (especially protected areas designation) at migration stopovers en route to and from their breeding areas, as well as from the increasing use of energy rich agriculture areas as winter quarters. Nevertheless, as we identify above, with climate change imposing spatially explicit patterns of change in di erent parts of the annual range of the Bar-headed Goose, it remains essential we improve our understanding of their migration routes and flyways through extended telemetry studies and monitor their population dynamics and abundance to ensure the future of this unique Asian goose species.

Conclusions

is study is the first to identify the paramount importance of stopover sites within the QTP to Bar-headed Geese in their annual cycle, but also to confirm the satisfactory level of current site protection given the patterns revealed by our telemetry data, which is consistent with the upward trend in abundance of the ETF Bar-headed Goose. We recommend Hala Lake and adjacent areas for protection because of their disproportionate importance to the geese d(iven 42 Tw T* [(prvnden(e pr(e)-8er)-12(474(over si5)6(e)-17 Kn(ers)]TJ3.064 Tw T* [(mig)-11(ra)9(618(,

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