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# Use of geolocators reveals previously unknown Chinese and Korean scaly-sided merganser wintering sites

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ABSTRACT: We determined, for the first time, individual linkages between breeding areas of nesting female scaly-sided mergansers *Mergus squamatus* in the Russian Far East and their previously unknown wintering grounds in coastal Korea and inland China. Geolocators were deployed on nesting females caught and recaptured on nests along a 40-km stretch of the Kievka River. Mean positions for brood-rearing females during the summer were on average within 61.9 km of the nest site, suggesting reasonable device accuracy for subsequent location of winter quarters. Geolocation data showed that most birds wintered on freshwater habitats throughout mainland China, straddling an area 830 km E–W and 1100 km N–S. Most wintered in discrete mountainous areas with extensive timber cover, large rivers and low human population density. Three birds tracked in more than one season returned to within 25–150 km of previous wintering areas in successive years, suggesting winter fidelity to catchments if not specific sites. A single female from the adjacent Avvakumovka catchment wintered on saltwater in Korea, at least 1300 km east of Chinese wintering birds. Most sea duck species (Tribe Mergini) form pairs away from breeding areas, suggesting that this high level of winter dispersal amongst close-nesting females is a potential mechanism to maintain gene flow in this threatened species that has specialist habitat requirements. Hence, female scaly-sided mergansers disperse widely from breeding areas, but show fidelity to nesting areas and winter quarters.

KEY WORDS: Scaly-sided merganser · *Mergus squamatus* · Geolocation · Winter dispersal



## INTRODUCTION

The scaly-sided merganser *Mergus squamatus* is amongst the most threatened sea ducks (Mergini), listed as Endangered by the IUCN (www.iucnredlist.org); it is in the first rank category of the List of the Protected Wildlife of National Importance in China and is on the Red Lists of the Russian Federation, the Republic of Korea, and Japan. Scaly-sided mergansers are only known to breed in a small part of the southeastern Russian Far East, northeast China and northern North Korea (Fig. 1). In Russia, ca. 1700 pairs nest in Sikhote-Alin, with most of the remainder in the Zeya-Bureya area,

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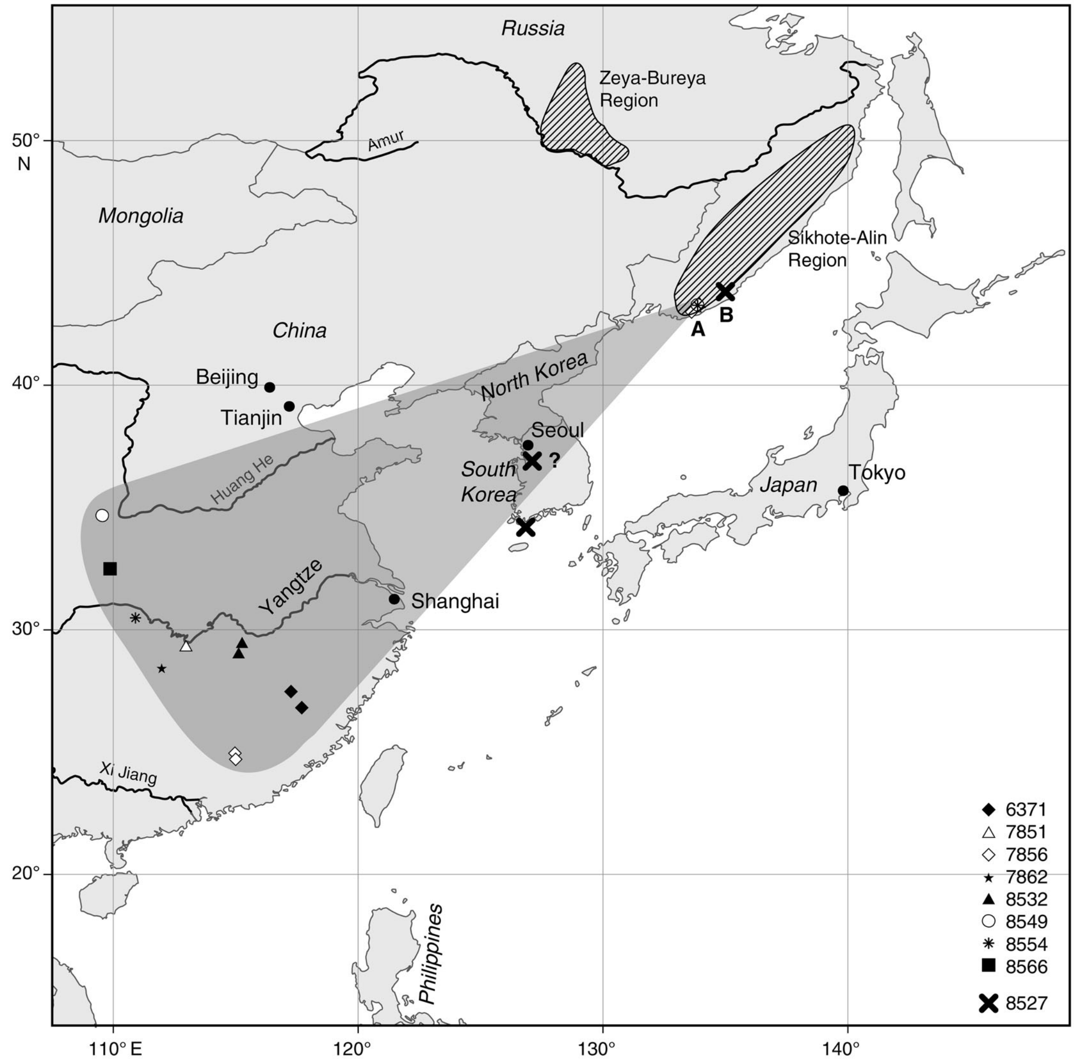


Fig. 1. Winter locations in China of scaly-sided merganser *Mergus squamatus* nesting females captured in the Kievka River catchment, Primorye, Russian Far East (A). A single female caught on the Avvakumovka River (B) wintered in Korea in 2008–2009 (bold crosses). Different symbols represent individual females as described in the text and identified in the tables. Note that standard error bars on the latitude and longitude of these positions do not extend beyond the symbols as plotted and are therefore not shown. The core breeding areas of the scaly-sided merganser in Russia are identified by the named hatched areas to the north, although no breeding birds were found during surveys in the Zeya-Bureya Region in summer 2011. The map is Equirectangular Projection, showing degrees of latitude and longitude as equal distances. As a guide, 10° longitude at 50° N equates to 720 km, but 970 km at 30° N in the area shown

although the size and distribution of the population there is unclear (none were found during surveys in summer 2011) and the northwest edge of the range out to 128.5° E is poorly known (Dymin & Kostin 1977, BirdLife International 2001). In China, 180–200 pairs breed exclusively in the Changbaishan Mountains (Liu et al. 2010). Breeding scaly-sided mergansers used to be widely distributed in the Lesser Xingan Mountains, but numbers declined sharply to fewer than 6 pairs in 1994–1995 in this area, where it is probably now extinct (Liu Bowen pers. comm.). None were found in formerly occupied areas of Heilongjiang Province during surveys in 1984–1985 and 1987–1988 (Zhao et al. 1994). In North Korea, probably less than 200 pairs breed, mainly on Mayang Chosuji reservoir (Chong & Morishita 1996). The total world population therefore consists of less than 3000 pairs, 85 to 90 % of which nest in Russia, although total population size has been variously estimated at 2500 to 10 000 individuals (Hughes & Hunter 1994, Shokhrin & Solovieva 2003, Solovieva et al. 2006).

The winter distribution of scaly-sided mergansers is almost totally unknown, although small numbers occur on rivers and bodies of freshwater in southern and central China (BirdLife International 2001, He et al. 2002, 2006). Very small numbers winter in Japan, South Korea and Taiwan, with scattered records from Myanmar, Thailand and northern Vietnam (BirdLife International 2001). Small wintering flock size, inaccessibility of the habitat and poor count coverage make it impossible to assess the current winter population size and distribution of the species (He et al. 2006).

Recent provision of artificial nest cavities for scaly-sided mergansers in Primorye, Russian Far East, has provided new insights into the breeding biology and ecology of the species, allowing unprecedented access to breeding hens during egg laying and incubation (Solovieva et al. 2005). Sequential recapture of reproductively active females at nest sites has enabled the deployment of geolocator logging devices, which allows us to track individual females throughout their annual cycle, enabling the identification of hitherto unknown wintering grounds in China and Korea.

## MATERIALS AND METHODS

Twenty-one breeding scaly-sided merganser females at least 2 yr old were each fitted with Mk9 light level geolocators (2.5 g, British Antarctic Survey) in 2006 to 2008 and with Mk11 geolocators (2.5 and 1.5 g, British Antarctic Survey) in 2009 (Table 1). Devices were attached to engraved plastic tarsus rings by 2 cable ties and secured through drilled holes. Birds were trapped in their nests at artificial nest sites and known natural cavities along a 40-km stretch of the Kievka catchment (43.3° N, 133.8° E, 18 females), as well as in the Avvakumovka (43.8° N, 135.0° E, 2 females) and Margaritovka (43.5° N, 134.7° E, 1 female) catchments in South Primorye, Russia (Fig. 1, Table 1). Some devices were redeployed following a year of use on other females, after data had been downloaded and deleted from the device memory.

The geolocator devices measured visible light intensity every 1 min, logging to memory the maximum reading within each 10 min (Mk9) or 2 min interval (Mk11). Raw data files containing the precise time and light data collected through the intervening period from deployment to recapture were corrected for clock drift (1 to 3 min lost during deployment) and then analyzed using TransEdit software (Fox 2010) to determine the sun elevation that corresponded with a particular light threshold level. Sharp transitions can be generated by events other than sunrise and sunset, so every diurnal cycle was filtered with this software and visually verified to remove obvious anomalous shading events during daylight and lighting events at night. Light threshold levels were set to 32 for both sunrise and sunset, the median between the minimum (0) and maximum (64) light levels. During spring and autumn equinox periods, day length is similar at all positions, so we were unable to determine latitude for at least 30 d around these periods. Because there was much migration activity around the equinox periods, we retained estimates of longitude because this provided considerable information on the E–W movements during spring and autumn migration despite our inability to

Table 1. *Mergus squamatus*. Scaly-sided merganser female capture-recapture histories in 2006 to 2010 in Primorye, Russia. A total of 29 geolocators were deployed on 21 females, providing data on 10 females for 1 or more years, resulting in records from 17 years from these 10 individuals. Note that because some females deserted clutches or lost broods and some geolocators provided periods of poor light transitions, not all 10 individuals contributed to spatial analyses of brood-rearing and winter areas; hence there are differences in sample sizes in all 4 tables

| Female ID | Year(s) deployed with geolocator | Year(s) re-trapped | No. of years recorded | Catchment |
|---|---|---|---|---|
| 7852 | 2006 | – | 0 | Kievka |
| 7854 | 2006 | – | 0 | Kievka |
| 7851 | 2006, 2007, 2009 | 2007, 2008 | 2 | Kievka |
| 7853 | 2006 | – | 0 | Kievka |
| 7512 | 2006 | – | 0 | Margaritovka |
| 6371 | 2006, 2008 | 2008, 2009 | 3 | Kievka |
| 7855 | 2006 | – | 0 | Kievka |
| 7856 | 2006, 2007, 2009 | 2007, 2009, 2010 | 4 | Kievka |
| 7516 | 2007 | 2008 | 1 | Kievka |
| 8549 | 2007, 2008 | 2008 | 1 | Kievka |
| 7558 | 2007 | – | 0 | Kievka |
| 7862 | 2007, 2009 | 2008 | 1 | Kievka |
| 7867 | 2007 | – | 0 | Kievka |
| 8532 | 2008, 2009 | 2009, 2010 | 2 | Kievka |
| 8566 | 2008 | 2009 | 1 | Kievka |
| 8529 | 2008 | – | 0 | Avvakumovka |
| 7860 | 2008 | – | 0 | Kievka |
| 8527 | 2009 | 2010 | 1 | Avvakumovka |
| 8554 | 2009 | 2010 | 1 | Kievka |
| 8524 | 2009 | – | 0 | Kievka |
| 8522 | 2009 | – | 0 | Kievka |

obtain precise positions on a N–S axis (see Table 3). The exposed metal terminals on the geolocators (to enable data download) also provided a record of when birds were on brackish water or saltwater at each logging interval.

We estimated latitude and longitude coordinates for each date using BirdTracker software (Fox 2010) to determine midnight and noon locations. All positions generated by sunrises (sunsets) delayed (advanced) by 15 min or more compared with the previous and following days (which would imply a bird moving an improbably large distance within 1 d) were examined visually and deleted from location analyses to remove false 'nights' caused by birds experiencing temporary dark conditions.

We calibrated the initial positions of the loggers based on 8 to 12 d of the brood-rearing period when brood age exceeded 15 d (i.e. after the end of intensive brooding) with each set of nest site coordinates. Sun elevation values derived from loggers calibrated on females in this way at the nest site coordinates were averaged for 8 to 12 d for each data logger and the average sun elevation coefficient was used for processing of geolocation files using Locator software (Fox 2010).

Scaly-sided merganser broods are known to stay in close proximity to nest sites after departure from the nest (V. Shokhrin pers. obs.). Given the fact that females with duckling broods moved relatively little before departure from the breeding grounds, we assessed the distribution of fixes derived from the loggers of such females on the breeding areas compared with the position of their nest sites. Thirteen data sets were collated from 7 individuals across 4 breeding seasons to relate the mean summer position logged by the devices to the location of the nest site used in that season, using only devices with at least 60 easting and northing positions post-fledging. We derived a mean daily position from data obtained from the geolocation device for days when both noon and midnight positions were available. We calculated the distance of each of these mean daily positions from that of the nest site to obtain a mean distance for each individual as the length of the corresponding orthodrome (the shortest distance between points on a spherical surface), using the formula of Imboden & Imboden (1972). We also obtained an overall mean E and N coordinate for each female during the summer by taking the mean of all the individually derived positions determined from the geolocator data and calculated the distance from this point to the nest site for each individual. It was very evident for all individuals when birds departed breeding rivers and had reached their winter quarters, based on sudden daily changes (or lack of these) in longitude, enabling definition of duration of stay in both areas and calculation of average summer and winter coordinates.

## RESULTS

### Geolocator retrieval and data analysis

Of 21 females fitted with geolocators, 10 were retrapped and loggers were retrieved. A total of 29 loggers were deployed, as some individuals were refitted in some cases. These deployments resulted in 17 individual year records, but because some females deserted their clutches or lost broods, only 7 individuals contributed to the 13 individual years used in the assessment of geolocation accuracy on the brood-rearing grounds. Equally, extended periods of poor light transitions constrained the use of whole winter data for certain individuals, with the result that only 8 individuals contributed 11 individual years used in the assessment of average winter quarter positions from these results.

### Brood-rearing locations and geolocating accuracy

All females successfully raising their broods stayed at the breeding river until autumn departure for winter grounds in late October or November (Tables 2 & 3), confirmed by brood-rearing locations and absence of 'marine' records in salinity files for all successful breeding birds. In these 13 cases, geolocating devices provided mean E and N positions for the female during brood-rearing of ducklings older than 15 d close to the original nest sites (mean 61.9 km difference between nest site and brood location, range 3.3 to 246.8 km), sufficient to confirm the river catchment in which the broods were situated (Table 2). In the 11 cases with reasonable sample sizes, the mean distance between each daily position generated from the logging data (averaged noon and midnight positions) and the nest site was 145.7 km (i.e. the mean of means for each individual) ranging from 80.4 to 209.2 km, still sufficient to judge the catchment in which the females were present (Table 2). The device on female #8527 in 2009 showed aberrant differences in device coordinates compared with breeding site latitude. This female successfully hatched her brood and the salinity trace indicated that she remained in freshwater until departure on 1 November 2009. The average position of the device between 3 and

Table 2. *Mergus squamatus*. Comparison of the brood-rearing locations of successfully breeding female scaly-sided mergansers, based on data from geolocating loggers fitted in 2006 to 2010, with the known coordinates of their nest sites in each particular year. Values are given for the distance between the nest site and the mean latitude and longitude positions for each bird during the logged period indicated, and the mean of all distances between all available daily positions for each bird (taken as the mean of noon and midnight positions for each day with both positions) prior to the equinox. Means are presented ±SE (n)

| Female ID | Year | Period of location (dd.mm) | Decimal degrees Latitude N | Decimal degrees Longitude E | Mean nest site coordinates °N | Mean nest site coordinates °E | Logger type | Distance between nest site and mean N/E position (km) | Mean distance between nest site and daily mean position (km) |
|---|---|---|---|---|---|---|---|---|---|
| 7851 | 2006 | 09.06–08.11 | 43.11 ± 0.23 (156) | 133.82 ± 0.05 (216) | 43.20 | 133.79 | Mk9 | 10.3 | 147.4 ± 19.9 (57) |
| 7851 | 2007 | 05.06–30.10 | 42.63 ± 0.22 (131) | 133.65 ± 0.08 (237) | 43.20 | 133.79 | Mk9 | 64.4 | 163.0 ± 15.9 (56) |
| 7856 | 2006 | 25.06–02.11 | 42.83 ± 0.16 (120) | 133.59 ± 0.07 (217) | 43.00 | 133.62 | Mk9 | 19.1 | 100.8 ± 10.8 (48) |
| 7856 | 2007 | 09.06–06.11 | 43.38 ± 0.21 (147) | 133.73 ± 0.05 (251) | 43.00 | 133.62 | Mk9 | 43.2 | 155.0 ± 20.0 (59) |
| 7856 | 2009 | 15.07–04.11 | 43.00 ± 0.62 (60) | 133.58 ± 0.08 (163) | 43.00 | 133.62 | Mk11 | 3.3 | 80.4 ± 32.2 (18) |
| 6371 | 2006 | 10.07–06.11 | 43.32 ± 0.31 (87) | 134.15 ± 0.09 (158) | 43.28 | 133.86 | Mk9 | 23.9 | – |
| 6371 | 2007 | 17.06–03.11 | 42.87 ± 0.22 (98) | 134.26 ± 0.08 (182) | Unknown | | Mk9 | – | – |
| 6371 | 2008 | 28.06–26.10 | 42.23 ± 0.25 (95) | 133.86 ± 0.11 (188) | 43.24 | 133.83 | Mk9 | 112.3 | 151.1 ± 11.3 (39) |
| 8532 | 2008 | 02.06–08.11 | 42.81 ± 0.17 (142) | 134.03 ± 0.07 (224) | 43.38 | 133.95 | Mk9 | 63.7 | 133.0 ± 16.1 (43) |
| 8532 | 2009 | 20.05–02.11 | 43.40 ± 0.21 (153) | 133.71 ± 0.08 (252) | 43.38 | 133.95 | Mk11 | 19.5 | 114.9 ± 15.9 (56) |
| 8549 | 2007 | 16.06–30.10 | 42.53 ± 0.17 (121) | 133.62 ± 0.07 (152) | 43.29 | 133.86 | Mk9 | 86.7 | 165.3 ± 18.6 (52) |
| 8527 | 2009 | 01.06–01.11 | 41.24 ± 0.37 (100) | 134.20 ± 0.08 (203) | 43.83 | 135.00 | Mk11 | 246.8 | 183.0 ± 20.5 (19) |
| 8554 | 2009 | 21.06–13.09 | 43.67 ± 0.24 (84) | 133.60 ± 0.13 (110) | 43.27 | 133.87 | Mk11 | 49.5 | 209.2 ± 22.1 (30) |

19 June 2009 (44.1° N, 134.0° E) was 88.3 km from the nest site, but for some reason, the device failed to provide accurate positions after 20 June, causing an apparent (but highly unlikely) set of positions from a more southerly latitude at sea. We cannot account for the discrepancy between nest site and geolocation coordinates, which must have been due to a device error. Without this device, the mean difference between the mean brood logged E and N positions during the brood-rearing period and the nest sites of individual females was 45.0 km. Mk11 devices with 2 min logging intervals did not provide better locations than Mk9 devices with 10 min intervals (Table 2).

### Residency at breeding and wintering quarters

Female scaly-sided mergansers spent an average of 125.5 d on the winter quarters (±2.58 SE, n = 17, range 106 to 146 d) and 229.1 d on the breeding rivers (±3.22 SE, n = 7, range 219 to 240 d; Table 3).

### Winter locations

All birds fitted with geolocators from the Kievka catchment spent the winter in south and central China, several of these in the Yangtze catchment (Fig. 1, Table 4). In comparison with the highly restricted breeding areas in the Russian Far East, the wintering dispersal area straddled an area 830 km E–W and 1100 km N–S and most individuals were widely separated from each other. Three birds tracked in 2 subsequent winters returned to mean winter positions within 26, 48 and 150 km of each other in successive years, suggesting winter fidelity to catchments if not specific sites. Data from 2 of these individuals (in one case a third winter of data, in another 2 yr) were rejected because they included too many bad light transitions and hence too few data, but despite northward displacement compared with other years, both individuals showed almost identical longitude fixes, lending additional support for winter site fidelity in these other years.

Female #8527 fitted with a geolocator in the Avvakumovka catchment apparently spent the winter in the southernmost part of South Korea (Fig. 1), but allowing for the displacement associated with the shift in latitude in breeding location, this bird could have wintered in the northern part of South Korea. The distance between Kievka and Avvakumovka Rivers is 200 km compared with the 1300 km distance

Table 3. *Mergus squamatus*. Timing of breeding and winter residency of female scaly-sided mergansers based on data from geolocating loggers fitted in 2006 to 2010. Movements of 2 failed breeders (#7516 and #7862) that left early to moult in areas to the north of breeding rivers are not considered here. Dates are presented as dd.mm.yy

| Female ID | Departure breeding river | Arrival winter grounds | Departure winter grounds | Arrival breeding river | Duration of stay at breeding river (d) | Duration of stay at winter grounds |
|---|---|---|---|---|---|---|
| 7851 | 08.11.06 | 19.11.06 | 19.03.07 | 24.03.07 | – | 120 |
| 7851 | 30.10.07 | 16.11.07 | 08.03.08 | 17.03.08 | 220 | 113 |
| 7856 | 03.11.06 | 20.11.06 | 21.03.07 | 23.03.07 | – | 121 |
| 7856 | 06.11.07 | 08.11.07 | 19.03.08 | 21.03.08 | 228 | 132 |
| 7856 | 15.11.08 | 18.11.08 | 14.03.09 | 16.03.09 | 239 | 116 |
| 7856 | 04.11.09 | 07.11.09 | 10.03.10 | 14.03.10 | 233 | 123 |
| 6371 | 06.11.06 | 11.11.06 | 21.03.07 | 23.03.07 | – | 130 |
| 6371 | 03.11.07 | 05.11.07 | 19.03.08 | 21.03.08 | 225 | 135 |
| 6371 | 26.10.08 | 28.10.08 | 14.03.09 | 16.03.09 | 219 | 137 |
| 8532 | 08.11.08 | 11.11.08 | 14.03.09 | 15.03.09 | – | 123 |
| 8532 | 02.11.09 | 10.11.09 | 16.03.10 | 24.03.10 | 240 | 126 |
| 8566 | 16.11.08 | 19.11.08 | 13.03.09 | 17.03.09 | – | 114 |
| 8549 | 30.10.07 | 28.11.07 | 13.03.08 | 20.03.08 | – | 106 |
| 8527 | 01.11.09 | 03.11.09 | 29.03.10 | 30.03.10 | – | 146 |
| 8554 | 13.09.09 | 21.11.09 | 23.03.10 | 04.03.10 | – | 122 |
| 7516 | | 07.11.07 | 13.03.08 | 14.03.08 | – | 127 |
| 7862 | | 18.11.07 | 08.04.08 | 11.04.08 | – | 142 |
| Mean | 01.11 | 12.11 | 17.03 | 20.03 | 229.1 | 125.5 |
| Median | 03.11 | 11.11 | 16.03 | 20.03 | | |

between wintering areas used by birds from these catchments (based on the shortest distance to Chinese winter locations for Kievka birds). This was the only bird that wintered on saltwater; all others were confined to freshwater in winter (based on logger salinity records).

## DISCUSSION

These results provide the first definitive linkage between breeding areas in the Russian Far East and the Chinese and South Korean winter quarters used by individual scaly-sided mergansers. The species has been reported occasionally at East Dongting Lake, Hunan Province, since the beginning of the 1990s (perhaps because of the concentration of ornithologists there). However, there are few reports of birds from the mountains 120 km to the southwest, from which female #7862 provided locations. In Jiangxi Province, up to 100 birds were found wintering in 1999 on the Xinjiang River in Yiyang County (BirdLife International 2001), but the species is not apparently known from the mountains to the western side of Poyang Lake (#8532). In the extreme south of Jiangxi, south of Gazhou, female #7856 returned to the same upland vicinity based on mean positions from her geolocator in 2008–2009 and 2009–2010; longitude data from the 2 previous years that were not robust enough to provide reliable latitudinal data suggest she may have used the same wintering area 4 yr in succession. Individual female fidelity to the winter quarters has been suspected

Table 4. *Mergus squamatus*. Mean (±SE) wintering locations of female scaly-sided mergansers fitted with geolocating loggers. n: number of position records

| Winter | Logger ID | Latitude (°N) | n | Longitude (°E) | n | Inferred location |
|---|---|---|---|---|---|---|
| 2006–2007 | 7851 | 29.35 ± 0.21 | 181 | 112.97 ± 0.04 | 225 | Dongting Lake, Hunan Province |
| 2007–2008 | 7862 | 28.43 ± 0.27 | 114 | 111.98 ± 0.06 | 248 | Mountains south of Dongting Lake, Hunan Province |
| 2008–2009 | 7856 | 24.96 ± 0.23 | 152 | 114.97 ± 0.06 | 178 | Mountains in extreme southern part of Jiangxi Province, south of Gazhou |
| 2009–2010 | 7856 | 24.71 ± 0.31 | 172 | 115.00 ± 0.09 | 194 | Mountains in extreme southern part of Jiangxi Province, south of Gazhou |
| 2006–2007 | 6371 | 27.48 ± 0.30 | 168 | 117.26 ± 0.07 | 200 | Mountains in north of northern Fujian Province, northwest of Nanping |
| 2007–2008 | 6371 | 26.82 ± 0.41 | 163 | 117.70 ± 0.09 | 184 | Mountains in north of northern Fujian Province, northwest of Nanping |
| 2008–2009 | 8532 | 29.48 ± 0.20 | 171 | 115.26 ± 0.06 | 201 | Mountains in north of Jiangxi Province, north of Wuning |
| 2009–2010 | 8532 | 29.06 ± 0.30 | 172 | 115.12 ± 0.07 | 195 | Mountains in north of Jiangxi Province, south of Wuning |
| 2008–2009 | 8566 | 32.50 ± 0.36 | 122 | 109.87 ± 0.12 | 145 | Mountains in NW corner of Hebei Province, west of Shiyan |
| 2009–2010 | 8527 | 34.20 ± 0.17 | 219 | 126.85 ± 0.06 | 281 | Northern part of southern Korea[a] |
| 2009–2010 | 8554 | 30.49 ± 0.39 | 130 | 110.91 ± 0.15 | 169 | Mountains in west of Hebei province west of Yichang |

[a]Inferred from systematic differences in geolocations calibrated on the nesting site

but is rarely definitively proven in sawbills *Mergus* spp. (e.g. Miller 1973).

There are wintering scaly-sided merganser records from the mountainous country of northern Fujian Province from the first half of the 1900s (BirdLife International 2001), but there have been few recent reports from this part of China. However, the area is confirmed as still being used by the species by the presence of female #6371 in 2006–2007 and 2007–2008, with longitudinal support for her presence in the same area in 2008–2009, when data were insufficient to provide latitude from the entire winter. The presence of female #8566 apparently wintering in the mountains of NW Hubei Province and female #8554 in the west of Hebei represent 2 potentially new wintering areas for the species.

There are relatively few records of wintering scaly-sided mergansers from the extreme south end of the Korean peninsula, and although we should take care not to overinterpret material relating to one individual, the mean winter position in the very south of the peninsula represents a report from an area not previously known to be frequented by this species (rare wintering reports having been confined to Kangwon, Kyonggi/Seoul and South Chungchong Provinces; BirdLife International 2001, Duckworth & Chol 2004). This device on the Korean bird (#8527) atypically reported the mean summer brood rearing position 250 km SSW of the known nest location (after 20 June), which would place the mean wintering position in the middle of the previously reported wintering resorts mentioned above, so we contend that it is likely that this individual in fact was present in traditionally known wintering areas for this species.

Ten out of 21 females were retrapped in the immediate vicinity of the original nest site in subsequent years during this study and 5 of these returned up to 3 yr after initial capture. These results confirm the general patterns amongst sawbill species (of the genus *Mergus* and *Lophodytes*) of high female nest site fidelity (e.g. *Mergus merganser*, Eriksson & Niittylä 1985, and *M. serratus*, Titman 1997) and general nesting area fidelity in the case of *Lophodytes cucullatus* (Zicus 1990, Pearce et al. 2008, Dugger et al. 2009). Because this also extends to natal philopatry in these species, there is a real risk in such populations of restricted gene flow if males were to show similar tendencies. Our results, however, suggest a high degree of dispersal in winter amongst females, which breed together in very close association along a 40-km stretch of a single river system only 130 km long. Limited evidence suggests that these individuals are loyal to general wintering areas with all sequential geolocation data suggesting wintering of females in the same general area (although the location accuracy limits our conclusions). Although we have no information on male dispersal in scaly-sided mergansers, pairing amongst members of the Mergini tribe mostly occurs away from nesting areas. If this were the case for scaly-sided mergansers, this would seem to provide a mechanism to maintain genetic heterogeneity in this species by encouraging females to pair with males originating from a different breeding provenance to their own. Four haplotypes were found in scaly-sided merganser males trapped in the Kievka catchment, but only 2 of these were found in females from the same catchment (Solovyeva & Pearce 2011). There is evidence for female philopatry and male dispersal in the genetically related and ecologically similar *M. merganser* (e.g. Pearce & Petersen 2009), which may be responsible for population structure (especially via maternally transmitted mitochondrial DNA) in that species (Pearce et al. 2005, Hefti-Gautschi et al. 2009), although less so in *M. serrator* (Pearce et al. 2009). We therefore contend that pairing in winter, after dispersal of both sexes from the same breeding areas, contributes to the maintenance of genetic diversity in this small and limited population as a result of female dispersal over such large areas in winter. This is especially the case in *M. squamatus*, which apparently requires fast-flowing unpolluted rivers for winter habitat, which constitutes an extremely rare and geographically limited biotope in China and Korea (He et al. 2002, 2006, D. V. Solovyeva pers. obs.).

We have to accept the inaccuracy associated with using this method for tracking birds and the difficulties involved in interpreting the results of analyses of data from such geolocation devices. In particular, some devices contributed systematic uncertainties that clearly affected winter locations, perhaps the result of light reception (e.g. because of dirt or damage to the sensor, water turbidity, position on the leg, plumage, foliage, weather, shaded roost site). Our geolocation calibrations in summer were carried out in relatively clear waters, whereas many Chinese rivers supporting scaly-sided mergansers can be highly turbid. Such systematic error associated with light attenuation would be expected to displace locations to the north of their true positions, as was the case for females #7856 and #6371 (the geolocators from these 2 females logged a series of poor transitions, thus they were eliminated from the analyses). However, it is also possible that, in winter, geolocators could receive more light (perhaps because of more open landscapes) than during the summer, potentially contributing to a southern displacement. Clearly mounting the geolocation device on the legs of swimming birds is not optimal, especially because this may cause shading when the bird sits or rests with the leg tucked under the plumage (especially at dawn or dusk), which could affect light intensity and transition timing. However, alternative forms of external deployment are restricted on an endangered diving bird, where the dangers of fouling on vegetation and objects underwater preclude alternative forms of attachment. We continue to be averse to applying more accurate tracking techniques (such as implanted satellite tracking PTTs used in more common sea duck species, but known to affect diving performance and survival; Latty et al. 2010, Fast et al. 2011) because of the endangered conservation status of the scaly-sided merganser.

Despite these theoretical concerns, with the exception of female #8527 and some other devices that clearly failed to log good-quality light transitions for a run of successive dates (which were obvious and hence filtered out), most geolocators provided clear transitions and times for sunrise/sunset that did not differ radically on successive dates whilst birds were largely static, giving us confidence in the positional accuracy of these results (cf. Conklin et al. 2010). As such they have been highly effective in locating previously unknown areas in China with high relief, high forest cover and low human population densities, which have the potential to hold hitherto unknown concentrations of this species in winter and hopefully enable conservation measures to be taken. These areas, together with key coastal areas in Korea, represent major priority areas in which to search for scaly-sided mergansers to determine their status and distribution, and this information will contribute to conservation management efforts for this species.

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LITERATURE CITED

BirdLife International (2001) Scaly-sided merganser. In: Collar NJ, Andreev AV, Chan S, Crosby MJ, Subramanya S, Tobias JA (eds) Threatened birds of Asia: the BirdLife International Red Data Book. BirdLife International, Cambridge, p 523–541. Available at http://birdbase.hokkaido-ies.go.jp/rdb/rdb_en/mergsqua.pdf

Chong JR, Morishita T (1996) Report on conservation measures for important areas of cranes in East Asia. Wild Bird Society of Japan, Tokyo (in Korean and Japanese)

Conklin JR, Battley PF, Potter MA, Fox JW (2010) Breeding latitude drives individual schedules in a trans–hemispheric migrant bird. Nat Commun 7:67

Duckworth JV, Chol K (2004) Scaly-sided mergansers *Mergus squamatus* in the lower Chongchon River, central Korea, in autumn 2003. Wildfowl 55:133–141

Dugger BD, Dugger KM, Fredrickson LH (2009) Hooded merganser (*Lophodytes cucullatus*). In: Poole A (ed) The birds of North America online. Cornell Laboratory of Ornithology, Ithaca, NY

Dymin VA, Kostin BG (1977) *Mergus squamatus* Gould — a breeding species of the upper Amur region. In: Voinstvenskiy MA (ed) Proceedings of the VII All Union Ornithological Conference, Part 2, Cherkassy, 27–30 September 1977. Naukova Dumka, Kiev, p 211

Eriksson K, Niittylä J (1985) Breeding performance of the goosander *Mergus merganser* in the archipelago of the Gulf of Finland. Ornis Fenn 62:153–157

Fast PLF, Fast M, Mosbech A, Sonne C, Gilchrist HG, Deschamps S (2011) Effects of implanted satellite transmitters on behavior and survival of female common eiders. J Wildl Manag 75:1553–1557

Fox JW (2010) Geolocator manual v8 (March 2010). British Antarctic Survey, Cambridge

He FQ, Melville D, Gui XJ, Hong YH, Liu ZY (2002) Status of the scaly-sided merganser wintering in mainland China in the 1990s. Waterbirds 25:462–464

He FQ, Lin J, Yang B, Jiang H, Cheung H (2006) Current distribution and status of the wintering scaly-sided merganser *Mergus squamatus* in China. Chin J Zool 41:52–56

Hefti-Gautschi B, Pfunder M, Jenni L, Keller V, Ellegren H (2009) Identification of conservation units in the European *Mergus merganser* based on nuclear and mitochondrial DNA markers. Conserv Genet 10:87–99

Hughes B, Hunter J (eds) (1994) The scaly-sided merganser *Mergus squamatus* in Russia and China. Threatened Waterfowl Research Group Special Publication No. 1. Wildfowl and Wetlands Trust, Slimbridge

Imboden C, Imboden D (1972) Formel für Orthodrome und Loxodrome bei der Berechnung von Richtung und Distanz zwischen Beringungs- und Wiederfundort. Vogelwarte 26:336–346

Latty CJ, Hollmen TE, Petersen MR, Powell AN, Andrews RD (2010) Abdominally implanted transmitters with percutaneous antennas affect the dive performance of common eiders. Condor 112:314–322

Liu P, Li F, Song H, Wang Q, Song Y, Liu Y, Piao Zh (2010) A survey to the distribution of the scaly-sided merganser (*Mergus squamatus*) in Changbai Mountain range (China side). Chin Birds 1:148–155

Miller SW (1973) Predation by the common merganser in a warm water reservoir. Q Rep Okla Coop Wildl Res Unit 26:14–20

Pearce JM, Petersen MR (2009) Postfledging movements of juvenile common mergansers (*Mergus merganser*) in Alaska as inferred by satellite telemetry. Waterbirds 32: 133–137

Pearce JM, Reed JA, Flint PL (2005) Geographic variation in survival and migratory tendency among North American common mergansers. J Field Ornithol 76:109–118

Pearce JM, Blums P, Lindberg MS (2008) Site fidelity is an inconsistent determinant of population structure in the hooded merganser (*Lophodytes cucullatus*): evidence from genetic, mark-recapture, and comparative data. Auk 125:711–722

Pearce JM, McCracken KG, Christensen TK, Zhuravlev YN (2009) Migratory patterns and population structure among breeding and wintering red-breasted mergansers (*Mergus serrator*) and common merganser (*M. merganser*). Auk 126:784–798

Shokhrin V, Solovieva D (2003) Scaly-sided merganser breeding population increase in Far East Russia. Threat Waterbird Spec Group News 14:43–51

Solovieva DV, Shokhrin VP, Vartanyan SL, Dondua AG (2005) Scaly-sided merganser (*Mergus squamatus*) in Kievka-River basin: numbers, ecology and achievements of artificial nest program. In: Myslenkov AI (ed) Scientific investigations of nature in Lazovsky Reserve. Proceedings of the Lazovsky State Nature Reserve, Vladivostok. Russkij Ostrov, Vladivostok, p 188–202 (in Russian)

Solovieva DV, Shokhrin S, Vartanyan A, Dondua AG, Vartanyan N (2006) Scaly-sided merganser surveys in Primorye, Russia, 2003–05. Threat Waterbird Spec Group News 15:60–69

Solovyeva DV, Pearce JM (2011) Comparative mitochondrial genetics of North American and Eurasian mergansers with an emphasis on the endangered scaly-sided merganser (*Mergus squamatus*). Conserv Genet 12:839–844

Titman RD (1997) Population dynamics and social system of reproductive red-breasted mergansers in Kouchibouguac National Park, New Brunswick. In: Tremblay E (ed) Proceedings of a workshop on Research, Monitoring and Natural Resource Management in the Greater Kouchibouguac Ecosystem. Parks Canada Ecosystem Science Review Report No. 3. Richibucto, New Brunswick, p 119–128

Zhao ZJ, Han XD, Wu JC (1994) Current status and distribution of the scaly-sided merganser *Mergus squamatus* in China. In: Hughes B, Hunter J (eds) The scaly-sided merganser *Mergus squamatus* in Russia and China. Threatened Waterbird Research Group Special Publication No. 1. Wildfowl and Wetlands Trust, Slimbridge, p 21–24

Zicus MC (1990) Nesting biology of hooded mergansers using nest boxes. J Wildl Manag 54:637–643

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