JOURNAL OF
AVIAN BIOLOGY

Communication

Migratory routes of red-necked phalaropes *Phalaropus lobatus* breeding in southern Chukotka revealed by geolocators

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Journal of Avian Biology
2018: e01853
doi: 10.1111/jav.01853

Subject Editor: Thomas Alerstam
Editor-in-Chief: Jan-Åke Nilsson
Accepted 23 April 2018

The migration routes of red-necked phalaropes breeding around the Bering Sea are poorly known, despite the fact that the Bering Sea could mark the boundary between the East Palearctic populations that winter in the Pacific Ocean around the East Indies and the West Nearctic populations that winter in the Pacific Ocean off the coast of South America. Geolocator data retrieved from two male phalaropes tagged in southern Chukotka, Far Eastern Russia, confirm that birds breeding in this region belong to the East Palearctic population and winter in the East Indies, suggesting that the division line with the West Nearctic population is farther to the east. The routes taken by the two phalaropes were almost entirely pelagic, totaling around 18 000–20 000 km round-trip, with the birds continuously on the move during migration, rather than resident in any particular stopover site, contrary to most other migratory shorebirds.

Keywords: red-necked phalarope, *Phalaropus lobatus*, migration, geolocator, Chukotka, East Indies

Introduction

The red-necked phalarope *Phalaropus lobatus* is a small shorebird with a circumpolar breeding distribution primarily in the Arctic and sub-Arctic tundra (Rubega et al. 2000, Lappo et al. 2012). In contrast to the species' vast, continuous breeding distribution, only three discrete major wintering areas have been identified: the Pacific Ocean off South America, the Arabian Sea, and the East Indies (Cramp and Simmons 1983, Del Hoyo et al. 1996, Higgins and Davies 1996). Apart from a number of ring recoveries showing that Scandinavian birds migrate in a southeast direction to the Black and Caspian Seas (Kistchinski 1985, Bakken et al. 2003, Fransson et al. 2008, Saurola et al. 2013), the connectivity between breeding and wintering ranges in other areas is poorly understood, largely due to the phalarope's pelagic lifestyle during the nonbreeding season. Recently, researchers in Scotland and Sweden tagged individual red-necked phalaropes with geolocators to uncover their migration routes and wintering areas. The Scottish bird crossed the Atlantic Ocean and Caribbean Sea and wintered in the Pacific Ocean between the Galapagos Islands and mainland South America (Smith et al. 2014), while the Swedish birds crossed the vast land-mass of eastern Europe and the Middle East and wintered in the Arabian Sea (van Bemmelen et al. 2016).

However, virtually nothing is known about the migratory connectivity of the red-necked phalarope populations breeding around the Bering Sea, even though this region potentially marks the boundary between the East Palearctic and West Nearctic populations (Rubega et al. 2000, Lappo et al. 2012). Field sightings of red-necked phalaropes passing along the coasts of Kamchatka (Lappo et al. 2012), Japan (Brazil 1991), and China (Wang et al. 2006) suggested that the wintering destination of the east Siberian breeding population was the East Indies, where large concentrations of wintering phalaropes have been noted (Higgins and Davies 1996, Bishop 2006). However, no ring recoveries are available along the flyway to confirm this linkage.

In this study, we tracked the migration of red-necked phalaropes breeding in southern Chukotka, Russian Far East, to find their major pathways and wintering grounds, providing another reference point delineating the connectivity between the breeding ranges and wintering destinations for the species. We also analyzed the migration strategy of red-necked phalaropes breeding in Chukotka, and compared it with the strategies of phalaropes heading to the other two wintering areas.

Methods

Five male red-necked phalaropes were captured and tagged with geolocators during the nesting and brooding period using walk-in traps and clap-nets near the coastal village of Meinypilgyno in southern Chukotka, Russia (62.55N, 177.05E), between 28 June and 8 July, 2016. Model P65A geolocators from Migrate Technology (UK) were back-mounted using leg-loop harnesses (Rappole and Tipton 1991) made of 1 mm stretch magic cord (Pepperell Braiding Company, USA), averaging 0.89 g (including harness) and representing 2.9–3.0% of the body mass of tagged individuals (29.5–31.0 g). Each individual was also marked with a metal ring and a unique combination of plastic bands and flags for field identification. The geolocators were programmed to measure the ambient light level every minute, with the maximum light level recorded every 5 min, as well as the number of 'wet' counts in every hour (capped at 14 times), where 'wet' refers to a contact with saline water indicated by the conductivity measurements every 30 s.

Two individuals (BA055 and BA057) were recaptured on 1 and 4 July, 2017, respectively, using a horizontal mist-net at the same site. Analysis of light-level data was performed in R 3.4 (R Core Team) using packages GeoLight (Lisovski et al. 2012) and FLightR (Rakhimberdiev et al. 2017). Twilight events were identified using a threshold value of 2 for log-transformed light intensity, and obvious outliers were picked out by visual inspection. For analyses in both GeoLight and FLightR, the period between tag attachment and departure from breeding site (BA055: 8 to 23 July, 2016; BA057: 4 to 25 July, 2016) was used as the calibration period, and an additional calibration period was used for FLightR after the birds came back to the breeding site (BA055: 21 June to 1 July, 2017; BA057: 25 June to 4 July, 2017). Sun angles were calculated for the calibration period and used in location estimation in GeoLight. Subsequent analyses using FLightR were performed following the workflow of Rakhimberdiev et al. (2016). All analyses were run without a behavioral mask as phalaropes are known to be capable of both flying over large land areas and using inland waters, despite their primary pelagic character. Locations indicating erratic movements were filtered out using a maximum daily flight distance set to 1500 km. No further refinement was performed on the raw position outputs to minimize subjective interpretation of the migration behavior and pathways of red-necked phalaropes.

The migration schedule and movement of the red-necked phalaropes were derived combining the output of FLightR and the wet/dry data. Conductivity measurements have been shown to accurately reflect the arrival and departure of coastal shorebirds based on the signals indicating contact with seawater (Battley and Conklin 2017), so wet/dry data were used to validate the movement pattern calculated by FLightR. Cumulative distances were calculated as the sum of great-circle distances between locations at each twilight event, and the average migration speed was derived dividing the cumulative distance of movement by the total duration of migratory movement.

Data deposition

Light level and wet/dry data are available from Movebank Digital Repository: <doi:10.5441/001/1.p41784h5> (Mu et al. 2018).

Results

The first phalarope, BA055, was captured on its nest on 8 July, 2016. This male was last seen with a chick on 14 July, and left the breeding area on 23 July. It then cruised along the east side of Kamchatka Peninsula and crossed the Sea of Okhotsk with short intermittent flights, before reaching the east coast of Honshu, Japan, on 7 August. For the following 9 d, the phalarope moved slowly south along the coast of Honshu and did not remain at any one site for more than a day. The bird then crossed the Philippine Sea, and reached the waters off Palawan around 27 August.

After reaching tropical waters, BA055 continued moving (Fig. 1a). It spent approximately 2 months in the South China Sea off NW Borneo and in the Sulu Sea (but note the large credible intervals of the fixes due to the equinox, Fig. 2a), before reaching the Banda Sea and staying around Sulawesi from mid-November 2016 to mid-February 2017.

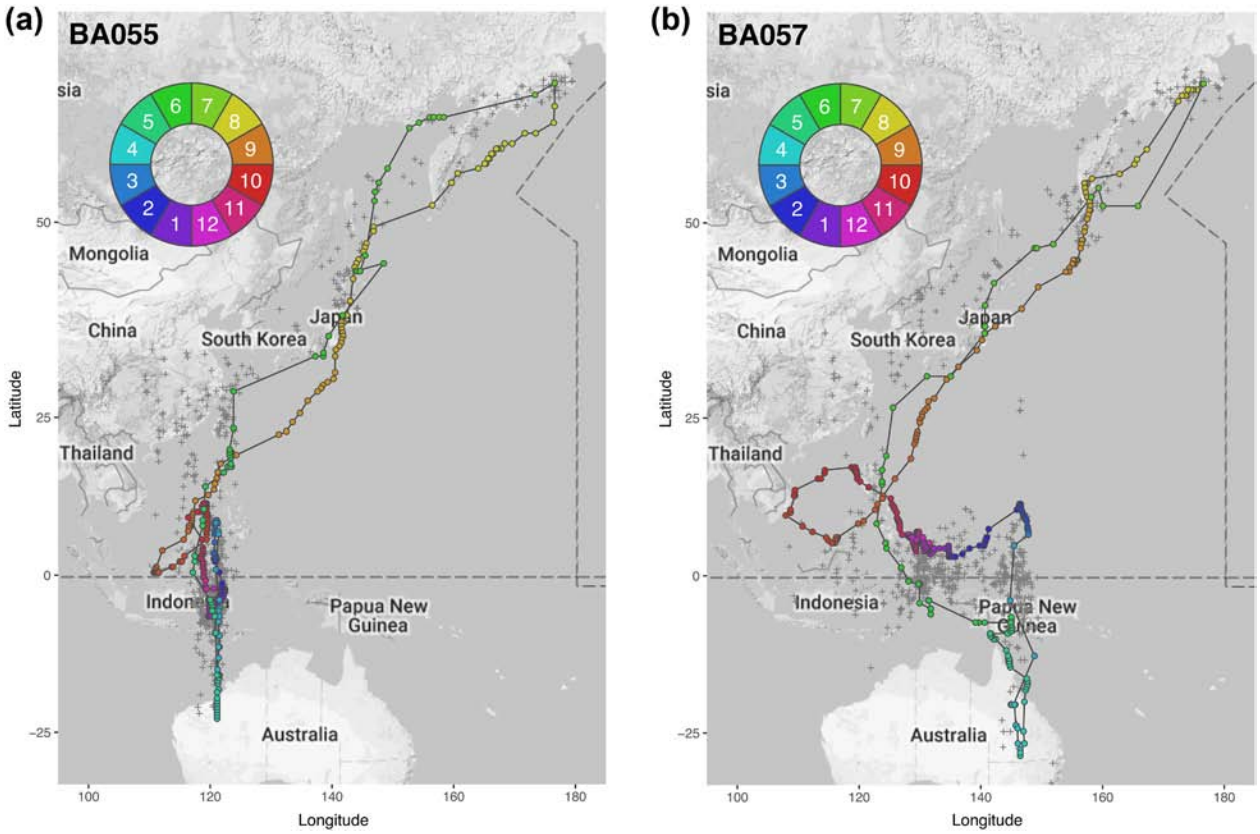

Figure 1. Migration tracks of two red-necked phalaropes from July 2016 to July 2017 estimated by GeoLight (grey crosses) and FLightR (colored circles). Median positions calculated by FLightR are colored by month of the year. Map data from Google ©2017.

The fixes between mid-February and mid-April appeared to be mirror images and are associated with large credible intervals, likely an effect of the equinox on location inference. The longitudinal positions of the bird during this period remained the same, suggesting that BA055 might have stayed in the Banda Sea until early May.

BA055 moved to the coastal waters off the northeastern Philippines on 10 May and left that area on 31 May. It than flew in a northeasterly direction, passing Japan and Sakhalin again and reaching the north shore of the Sea of Okhotsk around 10 June. The last contact with seawater occurred on 13 June, and the bird was spotted in the breeding area on 21 June, 2017. No nest belonging to BA055 was found before it was recaptured on 1 July.

The migration of the second phalarope, BA057, followed a similar route and schedule, but this bird ended up wintering in the waters around Palau and Guam (Fig. 1b). BA057 was captured while brooding chicks on 4 July, 2016, and was last observed with 3 chicks on 8 July. It left the breeding site on 25 July, and stayed along the coast of south Chukotka until 2 August. It then flew to the southern tip of the Kamchatka Peninsula (with flights partly overland), moving slowly southward until 27 August. It sped up while passing through the northwestern Pacific Ocean and the Philippine Sea, and entered the South China Sea on 9 September.

BA057 showed a more prominent westward movement than BA055 from mid-September to mid-October (Fig. 2b), likely a response on the part of both individuals to the series of typhoons that struck south China and southeast Asia during this period. BA057 reached the waters around Palau in late October and stayed in this area until the end of January. It then moved to the waters south of Guam and spent another month there until 5 March. The latitude of the fixes became difficult to interpret between early March and late April due to the effect of equinox.

BA057 started its journey north with an westward movement towards the Philippines around 15 May, and then spent two weeks heading westward before shifting to a NNE direction on 3 June after passing the Philippines. It then rapidly moved north without staying in any area longer than 2 d, and was back at the breeding area on 24 June, 2017. It was sighted on 25 June, and was subsequently recaptured on 4 July.

Given the red-necked phalarope's pelagic lifestyle and continuous movements during the nonbreeding season, as well as the confounding effect of the equinox on decoding the geolocator data, it is difficult to clearly distinguish the end of the southward migration and the start of the northward migration for either of the two tagged birds. We therefore used the arrival and departure times at the waters off the northeast Philippines as the cutoff points defining the south- and northward movements, respectively (Table 1). As

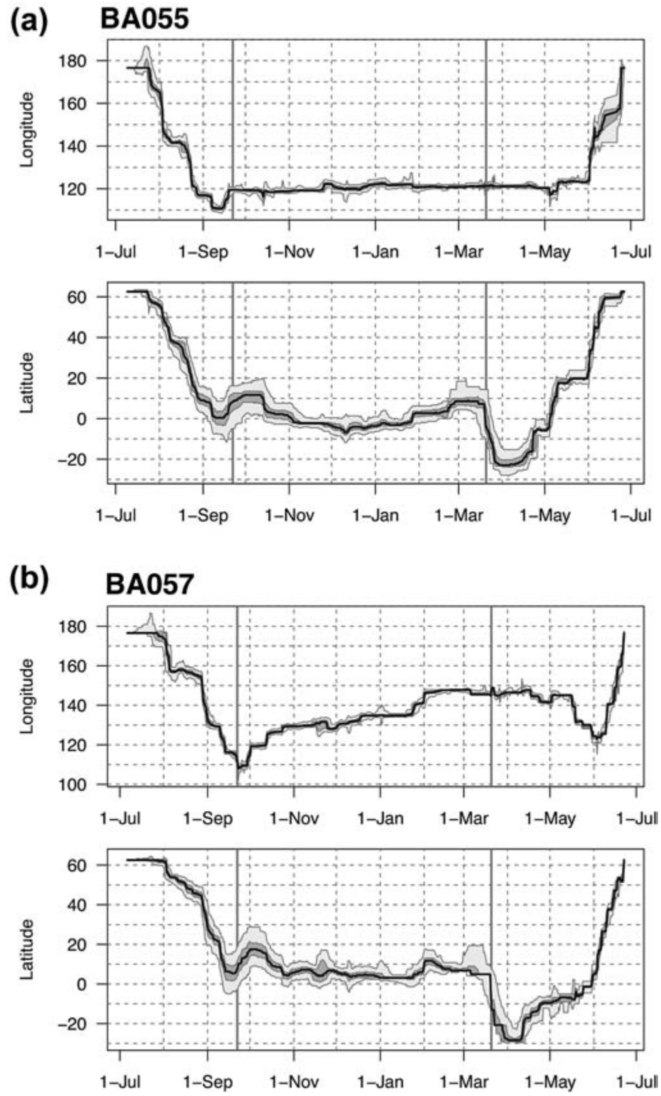

Figure 2. Distribution of estimated positions by FLightR. Solid lines represent median positions, with accompanying quartile ranges (dark grey) and 95% credible intervals (light grey). Note the large uncertainty in latitude estimations around the equinoxes (vertical lines).

can be seen from the data presented in Table 1, the migratory journey back to the breeding grounds was much faster than the southward migration, with the two phalaropes spending fewer days but achieving higher migration speeds while covering similar distances.

Discussion

The migration routes and wintering destinations of red-necked phalarope populations breeding in Europe revealed by geolocators suggest that the division of the breeding populations wintering in the Arabian Sea versus the Pacific Ocean off South America occurs between Scotland and Scandinavia (Smith et al. 2014, van Bemmelen et al. 2016). Lappo et al. (2012) proposed that the boundary between the West and East Palearctic populations, which winter in the Arabian Sea and the East Indies respectively, exists in east Siberia between Taimyr Peninsula and Lena Delta, based on observational data and the gradient of breeding densities in Siberia. However, little is known regarding the migratory connectivity of the phalarope populations breeding around the Bering Sea, where lies the potential boundary between East Palearctic and West Nearctic populations.

The migration routes of the two Chukotka red-necked phalaropes we tagged indicate that this breeding population is, in effect, part of the east Siberian population that heads to the East Indies, suggesting that the division line with the West Nearctic population is farther east. However, we can only speculate as to precisely where this line lies. Based on the density and distribution patterns of breeding populations in Chukotka, Lappo et al. (2012) suggested that the eastern Chukotski Peninsula may be the westernmost breeding area of birds belonging to the Nearctic population and migrating along the Pacific coast to winter off the coast of South America, whereas others proposed that birds of the Alaskan population may join the east Siberian population during migration and winter in the East Indies (Higgins and Davies 1996, Rubega et al. 2000).

Fixes calculated from light-level data using threshold (GeoLight) and template fitting (FLightR) methods

Table 1. Summary of duration, flight time and migration speed of two red-necked phalaropes in the nonbreeding season.

	Southward movement[1]		Northward movement[1]		Wintering period[2]	
Individuals	BA055	BA057	BA055	BA057	BA055	BA057
Start date	23 July 2016	25 July 2016	31 May 2017	3 June 2017	7 Nov 2016	23 Oct 2016
End date	27 Aug 2016	9 Sep 2016	13 June 2017	24 June 2017	12 Feb 2017	23 Jan 2017
Total duration (d)	35	46	13	21	97	92
Cumulative distance (km)	8433	7217	7264	7721	3188	3804
Migration speed (km d^{-1})	241	157	559	368	N/A	N/A

[1]The movement period is defined as the time moving between the Chukotka breeding ground and the W Philippine Sea off the coast of NE Philippines.
[2]The wintering period refers to the time in the Banda Sea (BA055) and around Palau (BA057) when the two birds stayed in the same area over three months.

generally agreed with each other (Fig. 1). We chose to use the results from FLightR to illustrate the migratory movement of red-necked phalaropes in this study because of the greater accuracy in location and time estimations achieved by this method (Rakhimberdiev et al. 2016). Also, the pelagic lifestyle of the phalaropes limited the utility of most conventional techniques used in the threshold method to improve the accuracy of geolocation of migrating shorebirds (Porter and Smith 2013). However, the credible intervals of fixes calculated by the FLightR package for locations near the equator around equinoxes are still relatively large (Fig. 2), blurring the migratory movement of the phalaropes during the two-month period.

Unlike shorebirds using discrete terrestrial stopover sites, our red-necked phalaropes did not linger at single sites during migration. Instead, they apparently rested and refueled during periods of slow movements during which they travelled less than 200 km between twilights (Fig. 1), presumably making use of readily available habitat and resources along the migration route while reducing the number of long, non-stop flights needed by moving constantly for small distances. These periods of slow-paced movement, which we believe serve the dual purposes of refueling and migration simultaneously, are difficult to detect using the threshold method, demonstrating the need for more advanced and less subjective analytical tools to process light-level geolocator data with improved accuracy and robustness (Rakhimberdiev et al. 2016). This pattern of interspaced rapid- and slow-paced periods was more prominent during the southward migration (Fig. 1). The northward migration, in contrast, was faster paced overall, thereby minimizing the time spent heading back to their breeding grounds (Fig. 1, Table 1). Differences in migration time and speed during north- and southward migrations have also been demonstrated in red-necked phalaropes from Scotland (Smith et al. 2014) and Sweden (van Bemmelen et al. 2016), suggesting a general pattern for this pelagic species.

Because of the continuous movements of red-necked phalaropes during the nonbreeding season and the effect of the equinox on decoding geolocator data (Fig. 2), we cannot unambiguously define the end of southward migration and the start of northward migration. van Bemmelen et al. (2016) also noted for the Arabian Sea wintering phalaropes that the distinction between migration and wintering periods was not clearly defined even for those birds that migrate overland with well-separated stopover sites. We estimate that the total migration distance between southern Chukotka and the East Indies is around 18 000–20 000 km, similar to the distance covered by the Scottish phalarope, and around 6000 km longer than that of the Swedish birds.

The Swedish phalaropes tracked the most productive waters while wintering in the Arabian Sea (Smith et al. 2014). In contrast, the two red-necked phalaropes we tracked from Chukotka do not appear to have sought out areas of especially high primary productivity in the East Indies. Spatial heterogeneity in primary production is more prominent than temporal changes in this region, with the latter occur mostly in response to the seasonal monsoon (Moore et al. 2003). BA055 spent the majority of its wintering period using the west Banda Sea, an area of higher primary productivity than that used by BA057 (the open ocean around Palau and Guam), but neither of them used the Arafura Sea as a major wintering area, even though the Arafura Sea has the highest primary productivity (measured by chlorophyll *a* concentration) in the East Indies (Jones 2002, Moore et al. 2003, Sigman and Hain 2012). The difference in productivity might have led to the different wintering patterns in the two phalaropes, where BA055 stayed mostly in the Banda Sea while BA057 used two different areas (Fig. 1). However, more individuals need to be tracked, combined with more advanced and accurate methods for location estimation, to fully unravel the habitat use and preferences of red-necked phalaropes during the wintering period.

In summary, by using geolocators, we discovered the migratory routes of the red-necked phalaropes breeding in southern Chukotka, confirming that they winter in the East Indies. Further study is needed to establish the linkages between other breeding and wintering areas, particularly around the proposed boundaries between the East Palearctic and both the West Nearctic and West Palearctic populations.

Acknowledgements – This study was undertaken within the framework of the International Arctic Expedition of BirdsRussia. We thank Nikolay Yakushev, Roland Digby, Andrey Maximov, and Majorie Bousfield for their field assistance; Bruce Beehler and Thane Pratt for information pertaining to wintering phalaropes around the East Indies; James Fox for valuable guidance in geolocator use; and the editors and reviewers who greatly improved the quality of the manuscript.
Funding – Major support for this work came from the High Meadows Foundation. Involvement of PST outside the field seasons was supported by RSF grant no. 14-50-00029.
Permits – Capturing and tagging of red-necked phalaropes was approved by the Institutional Animal Care and Use Committee of Princeton University.

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