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SHORT ARTICLE

Flight range estimation of migrant Yellow-browed Warblers *Phylloscopus inornatus* on the East Asian Flyway

Martha Maria Sander[a], Jana A. Eccard[b] and Wieland Heim[a,b]

[a]Animal Ecology, University of Potsdam, Potsdam, Germany; [b]Institute of Landscape Ecology, Münster University, Münster, Germany

ABSTRACT
Fat loads were quantified for 2125 Yellow-browed Warblers *Phylloscopus inornatus* trapped at a stop-over site in Far East Russia during autumn migration. Flight ranges of 660–820 km were estimated for the fattest individuals, suggesting that they would need to stop for refuelling at least six times to reach their wintering areas in South East Asia.

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The East Asian-Australasian flyway encompasses the highest number of threatened migratory bird species of any flyway (Yong *et al.* 2015). Little is known about the routes or stop-over sites of most East Asian passerine species using the flyway. Since many of these species are threatened by habitat loss, degradation and fragmentation (Yong *et al.* 2015, Edenius *et al.* 2016) knowledge on migration ecology is vital for effective conservation measures. The drivers for the observed population declines are not well understood, but large-scale illegal trapping might be a major factor for some species (Kamp *et al.* 2015). However, habitat loss caused by intensification of agriculture, deforestation and urbanization might also contribute (Achard *et al.* 2006, Alauddin & Quiggin 2008).

The Yellow-browed Warbler *Phylloscopus inornatus* is a widespread and abundant breeder in forests of northern Siberia from the Ural Mountains to the Pacific Ocean, and winters in South East Asia (Clement 2016). This species is a light-weight (6–8 g) nocturnal long-distance migrant, with a migration span of up to 6000 km (Thorup 1998). In the Western Palaearctic, the species was considered a vagrant but numbers have increased during recent decades and Yellow-browed Warblers now occur regularly in many parts of Europe (Fraser 2013). The debate is still open as to whether these birds have established new wintering grounds or if they simply have failed to migrate in the right direction (Thorup 1998, Gilroy & Lees 2003, Bozo *et al.* 2016). Explanations might remain speculative while almost nothing is known about the traditional route and migration strategies of Yellow-browed Warblers on the East Asian flyway. Ringing recoveries are lacking (McClure 1974) and satellite tracking of small passerines is still limited by their size. Making use of biometric data collected through mist netting we estimated fuel loads as an indicator for body condition. We estimated flight ranges (Mcneil & Cadieux 1972, Pennycuick 1975) of individual birds from the point of capture based on their fuel load and other parameters (Delingat *et al.* 2008, Salewski *et al.* 2010, Maggini & Bairlein 2011, Arizaga *et al.* 2013), with the aim of understanding more of the migration ecology of the Yellow-browed Warbler.

Data were collected within the volunteer-based Amur Bird Project at Muraviovka Park (Heim & Smirenski 2013) in Far East Russia (49°55′08.27″N 127° 40′19.93″E). The study site is an important stop-over for migrating songbirds along the East Asian flyway (Yong *et al.* 2015), including eight species of *Phylloscopus* warblers (Bozó & Heim 2016). We used records of 2125 Yellow-browed Warblers (including 199 recaptures) from five autumn seasons (August–October 2011–15), that included measurements of wing lengths (W_{max}) and of eighth primary feather (P8, numbered descendantly), both measured to the nearest mm, body mass (m) measured to the nearest mg, and fat and muscle scores following Eck *et al.* (2011).

Body condition can be quantified as the viewable subcutaneous fat (Kaiser 1993) and by the size of the pectoralis muscle (Bairlein 1995). We calculated individual lean body mass (m_0), which represents the body mass of a bird without any fuel deposits, to quantify the fat mass each bird was carrying. Since fat masses are size dependent (Salewski *et al.* 2009) we estimated lean body masses from a size measurement (wing length and P8), similar to Arizaga *et al.* (2013) and Delingat *et al.* (2008), by conducting a linear

CONTACT Martha Maria Sander mariasander.berlin@yahoo.de Animal Ecology, University of Potsdam, Maulbeerallee 1, Potsdam 14469, Germany

regression (dependent variable = body mass, explanatory = size) based on 153 'lean' individuals with fat score 0 (recaptures excluded) caught at the study site in the years 2011–15. Based on this regression, we calculated a size-based lean body mass for each captured individual ($n = 2068$). The difference between body mass, m, at capture and calculated lean body mass, m_0, was defined as fat mass ($m–m_0$). Relative fuel load was calculated as f (where $f = (m–m_0)/m_0$) (Delingat *et al.* 2008) representing the energy resources of the bird. Since birds may build up fuel during the day (Dunn 2000) and thus have the lowest body mass in the morning, we investigated the influence of time of day on body mass. Fat scores '5' ($n = 33$) and '6' ($n = 4$) were grouped due to small sample sizes.

For the estimation of the flight range (Y) we used the complete data set ($n = 2068$) applying two different formulas. After Delingat *et al.* (2008), flight range of passerines increases with the log-scaled relative fuel load (f) and flight speed (U; passerine air speed without considering wind profit) (Equation 1):

$$Y = 100 \times U \times \text{In}\,(1 + f). \qquad (1)$$

After Roberts *et al.* (2005), the flight range increases with the individual fat mass, the energy content of fat ($E_f = 9$ kcal/g), flight speed (U), and decreases with the metabolic rate during flight (FMR = 0.9 kcal/g) (Equation 2). However, with the latter variables (for general passerine flight, as reviewed in Roberts *et al.* 2005) fed in as constants, flight range increases directly with fat mass:

$$Y = \frac{\text{Fatmass} \times E_f}{\text{FMR}} \times U. \qquad (2)$$

We compared flight ranges calculated with both equations assuming a constant flight speed of $U = 55.6$ km/h (Roberts *et al.* 2005). All statistics were carried out in R version 3.3.2 (R Core Team 2016) and Microsoft Office Excel 2007. The mean estimated flight range for each fat score category calculated with the formula of Delingat *et al.* (2008) is shown on a map including breeding and non-breeding ranges of Yellow-browed Warblers (Figure 1).

Body mass differed significantly among fat score classes which increased strongly with body mass (Analysis of variance: $F = 146.7$, $P < 0.001$, and Tukey's HSD: $P < 0.001$, $n = 2094$). The subset of birds with fat score '0' did not differ significantly in body size estimators from birds with higher fat scores but were on average 5% lighter (t-tests: W_{max} $t = 0.04$, $P = 0.97$,

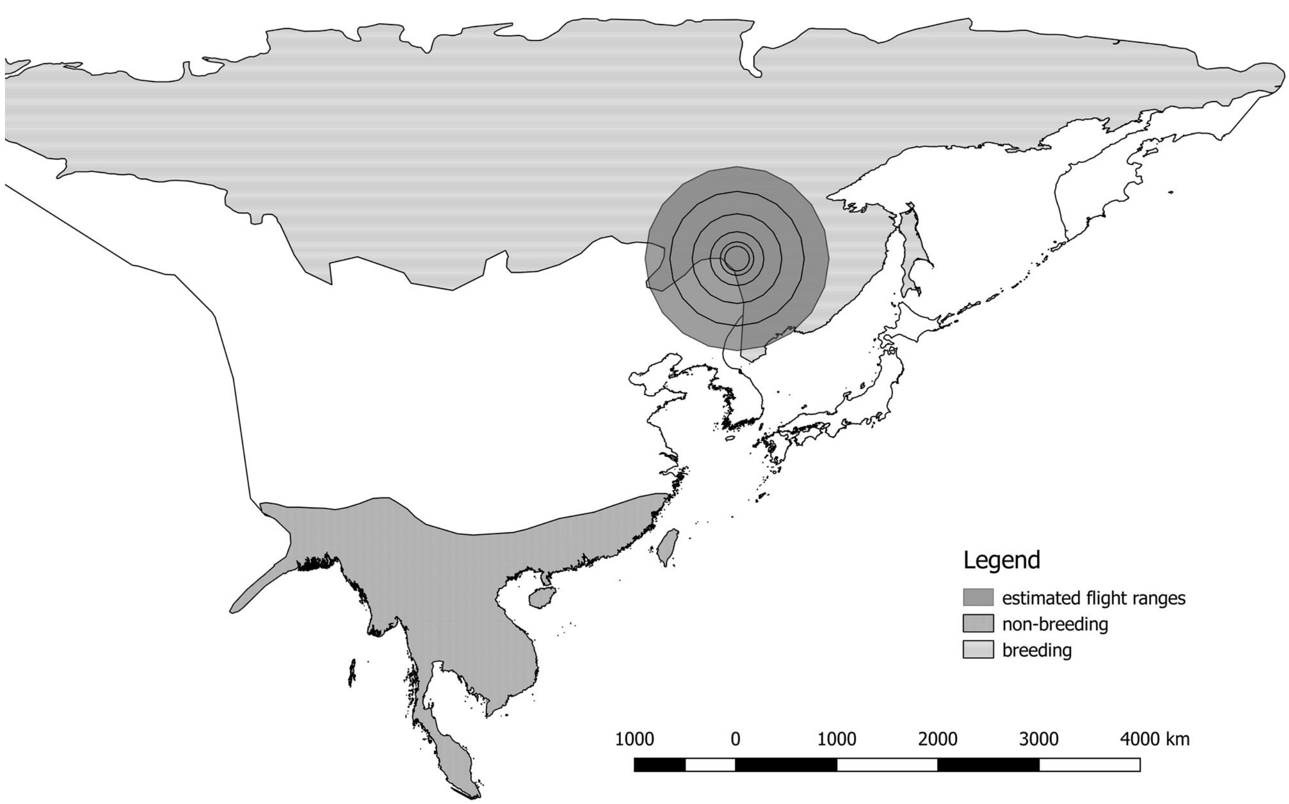

Figure 1. Mean estimated flight ranges (after Delingat *et al.* 2008) of Yellow-browed Warblers for each fat score group 0–5 (rings from inside to outside). Estimated values of distance from Muraviovka Park are given in Table 1. Map generated in QGIS Developement Team (2016) with WGS84, breeding and non-breeding distribution data from Birdlife International 2016.

Table 1. Comparison of estimates for flight ranges after 1: (Delingat *et al.* 2008) and 2: (Roberts *et al.* 2005) with air speed = 55.6 km/h and calculated mean difference of flight ranges for each fat score class ($n = 2069$). *n*: number of individuals. Percent of trapped individuals in each fat score class.

fat score	*n*/%	Mean fuel load ± sd	Min/max fuel load	Estimate 1: mean flight range ± sd (km)	Estimate 2: mean flight range ± sd (km)	Mean difference (km)
0	153/7.4	0.00 ± 0.05	−0.17/0.21	110 ± 180	70 ± 130	40
1	510/24.6	0.02 ± 0.05	−0.23/0.16	150 ± 180	100 ± 120	50
2	549/26.5	0.04 ± 0.05	−0.12/0.24	240 ± 210	160 ± 150	80
3	629/30.4	0.07 ± 0.06	−0.16/0.30	400 ± 260	280 ± 200	120
4	191/9.2	0.11 ± 0.06	−0.06/0.27	600 ± 290	450 ± 250	150
5 + 6	37/1.8	0.16 ± 0.07	0.00/0.29	820 ± 340	660 ± 320	160

$n = 176$ and P8 $t = 0.76$, $P = 0.45$, $n = 169$. Mean ± se W_{max} where fat score was 0 = 56.3 ± 2.3 mm, all other fat scores = 56.3 ± 2.4 mm. Mean ± se P8 where fat score was 0 = 42.9 ± 2.3 mm, all other fat scores = 42.7 ± 2.1 mm. Mann–Whitney-*U*-test: body mass $W = 234.420$, $P < 0.001$, $n = 2111$, mean ± se body mass where fat score was 0 = 6.0 ± 0.4 g, all other fat scores = 6.3 ± 0.5 g). We calculated individual lean body mass using wing length (linear regression: individual lean body mass = 0.095*wing length + 0.063, $R^2 = 0.293$, $P < 0.001$, $F = 62.6$, $n = 153$), which predicted body mass better than P8 ($R^2 = 0.156$, $P < 0.001$, $F = 29.1$, $n = 153$).

Body mass per fat score and mean fat score (ranging from 0 to 5) were found to increase continuously with time of day until the later evening hours (Pearson's correlation: fat score cor = 0.43, $t = 22$, df = 2104, $P < 0.001$; body mass cor = 0.39, $t = 20$, df = 2108, $P < 0.001$), whereas mean muscle score (ranging from 1 to 3) did not differ among morning, afternoon and evening periods ($\chi^2_6 = 4.55$, $P = 0.60$). Thus, birds captured in the evening hours were fatter and heavier. Across all samples, mean individual fuel load was 5% with a standard deviation of 7% of the bird's body mass, ranging from 0% to 41%. We calculated flight ranges based on fuel load for every fat score group (Table 1). Estimated flight ranges of birds with the highest fat scores were 820 ± 340 km or 660 ± 320 km, depending on calculation method (Table 1). The equation of Roberts *et al.* (2005) gave estimates approximately 70% of the range of the Delingat *et al.* (2008) equation, or approximately 160 km less range for the highest fat scores (5 + 6).

Migration distances are often estimated by measuring the distance between the centre of the breeding range and the centre of the wintering range (Huber *et al.* 2017). In this case, the distance between these centres (Yakutsk and Bankok, https://www.luftlinie.org) is about 5800 km. From the point of capture, which is at the southern border of the breeding range, individuals need to fly a further 4700 km to reach the centre of the wintering range. Comparing this with our flight range estimates, it is obvious that even the fattest individuals need to stop-over several times along the route. Based on the method of estimates and assuming a similar and optimal refuelling at each stop-over site, individuals would have to stop between six and seven times before reaching their South-east Asian wintering sites. The method is easily applicable for other species and a comparison of fuel loads and flight ranges between several species in the *Phylloscopus* genus caught at the study site might substantially increase our knowledge of passerine migration along the East Asian flyway.

The Yellow-browed Warbler is still a common species (Birdlife International 2016), but a recent study found that the number of wintering individuals is decreasing on Hainan (Xu *et al.* 2016). This indicates the necessity of studying the distribution of this species at breeding and non-breeding grounds as well as the habitat requirements on stop-over sites to enhance conservation strategies on a global scale. In further studies, geolocators might be used to test the assumptions of flight range estimates for one stage and to detect the realized route of the birds (Bächler *et al.* 2010).

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