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Autumn migration of passerine long-distance migrants in northern Morocco observed by moon-watching

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The aim of this study was to test two different models of migratory orientation in passerines passing through the Iberian Peninsula. One model predicts a change of direction in southern Europe and the other predicts that migration follows an arching route through Europe and along the West coast of Africa. Measurements of migration direction were obtained by moon-watching at three sites in Morocco: Témara and Âin-el-Âouda, situated in the coastal region of Rabat, and near Douyèt, 150 km further east. There was no statistically-significant difference between the directional distributions of migrants in the coastal region and the inland site. Overall, the mean migration direction of 211° is consistent with the model that passerines passing through the Iberian Peninsula take an arching route through southwestern Europe and along the African West coast. Thus, an endogenous change of direction, previously demonstrated experimentally for the Garden Warbler *Sylvia borin*, may occur gradually along the migration route.

For European bird populations wintering in Africa, south of their breeding areas, the shortest route would be to fly directly south. However, most migrants leave central Europe in southwesterly directions, thus avoiding crossing the Alps, the Mediterranean and central parts of the Sahara (Bruderer & Liechti 1990, Hilgerloh & Bingman 1992). Therefore, since there are significant geographical barriers perpendicular to the direction of the shortest route, a longer route may be optimal to reach wintering quarters safely (Alerstam 2001). However, further south, it is an open question whether the Atlas Mountains, like the Alps, act as a barrier for migrants that have passed the Iberian Peninsula.

An endogenous change of migration direction during the course of autumn migration was demonstrated experimentally for the Garden Warbler *Sylvia borin* (Gwinner & Wiltschko 1978). Two models exist with respect to where the change of direction takes place. The first predicts a change from southwesterly directions to southerly or south-southeasterly directions ('Zugknick') in the south of the Iberian Peninsula (Gwinner & Wiltschko 1978). The Atlas Mountains would not act as a barrier and be crossed in a southerly or south-southeasterly direction. The second model suggests that the long-distance migrants travel on an arching route from Central Europe through the Iberian Peninsula and continue along the African west coast (Hilgerloh 1989a, 2001). After passing the Sahara at its western edge they would turn to more easterly directions in the savannah to reach their wintering quarters. According to this model, south-southwesterly migration directions would prevail in Morocco. While migration directions have been observed in the south of the Iberian Peninsula (Hilgerloh 1988, 1989b, 1989c, Bruderer & Liechti 1998), data from Morocco are lacking. We observed migration directions by moon-watching in northern Morocco and analysed the results in the light of these models.

METHODS

Study sites and data collection

Nocturnal migration was observed by the moon-watching method (Lowery 1951) in 2002 from 18 to 24 September at three sites in northern Morocco: 1) Témara, situated 10 km SW of Rabat at the Atlantic coast (33° 56'N, 6° 54'W, 40 m asl), 2) Al Kruaieb, near Âin-el-Âouda and 35 km SE of Rabat and Témara (33° 43'N, 6° 42'W, 330 m asl) and 3) Duar Arab Sabba, close to Douyèt and at 35 km NW of Fès (34° 02'N, 5° 15'W, 412 m asl). Site 3 is situated 152 km east of site

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1 and 140 km ENE from site 2. The main ridge of the Atlas Mountains runs SW to NE along an angle of 250° at a distance of about 200 km south of Douyèt. The observations were performed during the migration period of long-distance migrants (Hilgerloh 1985, Hilgerloh unpublished data from Morocco).

Moon-watching was carried out according to the guidelines of Liechti (1996). The observer watched the full moon by telescope (30x magnification) and recorded the relative size, entrance and exit of all passing birds according to the face of a clock in 15° sectors. Under the assumption that the birds were flying horizontally, flight directions were calculated according to the position of the moon. Migration traffic rate (MTR), expressed as birds per h per km (birds h^{-1} km^{-1}), was calculated on the basis of individual distance estimation, flight direction and the position of the moon (Liechti *et al* 1996). Estimations of the distance were based on the relative size classes calibrated by a pencil beam radar (Liechti *et al* 1995); real size differences between birds were ignored. Observations were performed if the elevation of the moon exceeded 15° and for a total of 21 hours and 55 minutes during 10 nights between 18 and 24 September. Between 20 and 22 September observations were performed simultaneously at Douyèt and at Témara. Observations were performed four nights at Témara, one night at Âin-el-Âouda and five nights at Douyèt. Only Passeriformes, identified according to their intermittent flight pattern, were included in the analysis.

Data analysis

The frequency distribution of flight directions was calculated on the basis of the MTRs of the individual bird movements. The angle of the mean vector (μ), referred to throughout as the mean migration direction, and the mean vector length (r) for each site were calculated by vector addition on the basis of all nights at each site as independent events. To test whether the directions of the birds differed significantly from randomness, the Rayleigh test was used (Batschelet 1981). Comparisons between mean migration directions at different sites were performed by the Watson–Williams test, which allows comparisons if samples contain at least five values; height distributions were compared by the t-test (Kovach 2003). In total, 636 birds were observed by moon-watching.

RESULTS

Mean nocturnal migration directions pointed to the south and southwest, varying between 174° and 235° (Table 1). At Témara, the mean migration direction amounted to 214° (vector length: r = 0.99, nights: n = 4, Rayleigh test: $P < 0.01$), at Âin-el-Âouda to 231° (n = 1) and at the inland site, Douyèt, to 204° (r = 0.94, n = 5, $P < 0.01$). There was no statistically-significant difference between the directional distributions of migrants in the coastal region (Témara and Âin-el-Âouda together: mean direction (μ) = 217°, r = 0.98, n = 5, $P < 0.01$) and the inland site (Watson–Williams test: $P > 0.05$). Summarising all nights, the mean direction was 211° (r = 0.96, n = 10, $P < 0.01$).

On an average, the MTR amounted to 1806 ± 905 (± SD; nights: n = 9) birds h^{-1} km^{-1} if the night of 23 September 2002 with a ninefold-higher MTR was excluded (Table 1). There was no statistically-significant difference between the MTR of Témara and Douyèt (t-test; t = 0.44, $P = 0.68$), if 23 September 2002 was excluded and also if only the three nights with the simultaneous observations were compared (Table 1; t-test: t = 1.16, $P = 0.9131$).

An exceptionally high density of migration occurred on 23 September 2002 (Table 1). More than 16,000 birds migrated per hour per km that night, and the MTR was as high as the total of the other nine nights. While migration on 23 September 2002 was directed towards 225° (Table 1), on the other nights migration was directed on average towards 209° (r = 0.96, $P < 0.001$; Fig 1).

Differences in the height distribution of birds on migration might be caused by different wind conditions, migrants flying lower in head winds and higher in tail winds (*eg* Hilgerloh 1981). At the coastal sites, migrants were flying up to higher altitudes above the ground than at the inland site during simultaneous observations (Fig

Table 1. Migration direction and traffic rate at three sites in northern Morocco . Number of observed birds (n) in each night at the sites Témara, Âin-el-Âouda (Âouda) and Douyèt, migration traffic rate (MTR), minutes (m) of observation, mean nocturnal migration direction (μ), vector length (r) and Rayleigh test (*P*).

Site	Date	n	MTR	m	μ	r	*P*
Témara	20-09	27	1488	127	210°	0.79	<0.001
Témara	21-09	11	855	100	203°	0.83	<0.001
Témara	22-09	108	2936	181	218°	0.87	<0.001
Témara	23-09	208	16274	60	225°	0.89	<0.001
Âouda	24-09	70	2568	175	231°	0.77	<0.001
Douyèt	18-09	41	1622	130	200°	0.85	<0.001
Douyèt	19-09	44	1860	120	199°	0.71	<0.001
Douyèt	20-09	101	3160	120	210°	0.90	<0.001
Douyèt	21-09	4	642	60	174°	0.97	<0.05
Douyèt	22-09	8	1127	60	235°	0.73	<0.01

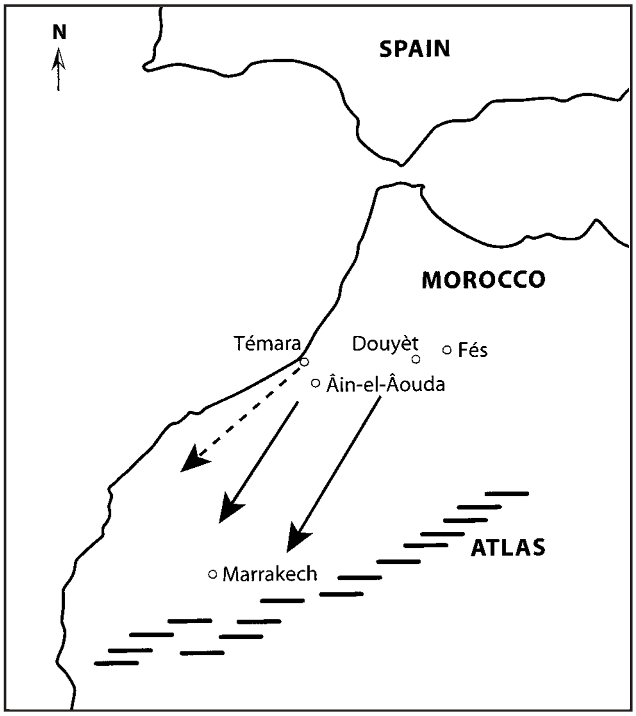

Figure 1. Map with the three observation sites Témara, Âin-el-Âouda and Douyèt and the mean migration direction (solid arrows) during all ten observation nights (μ = 211°) and the mean migration direction (two dot line) of the night with most intensive migration (μ = 225°, Témara).

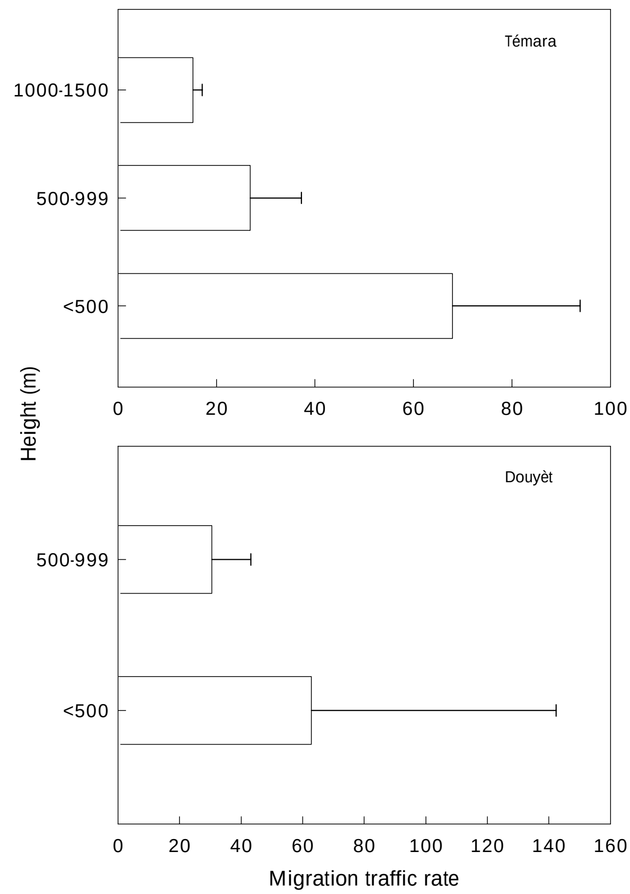

Figure 2. Average migration traffic rate (birds h^{-1} km^{-1}) and standard deviation per flight altitude range during simultaneously-performed observations at Témara (coastal site, upper graph) and Douyèt (inland site, lower graph) from 20 to 22 September 2002.

2). However, as Douyèt was situated about 400 m higher than Témara, birds were flying at similar heights above sea level at the two sites.

DISCUSSION

The mean migration direction in the study area was identical to that observed in Gibraltar (Hilgerloh 1989b). This direction would not be expected if birds performed an abrupt change of direction in the south of the Iberian Peninsula (Gwinner & Wiltschko 1978). Southwesterly migration directions would be predicted by the second model (Hilgerloh 1989a, 2000), according to which migrants continue migration in a fringe along the West African coast. This suggests that migrants perform an endogenous change of direction gradually along their migration route. This migration route implies that migrants cross the most westerly parts of the Atlas Mountains, the Atlantic Atlas. Birds migrating in the eastern part of our study area would have to cross higher Atlas mountains further east if they maintained the same mean direction. However, they might shift to more westerly directions before they reach the Atlas and continue migration closer to the coast since we would expect that most birds would bypass the higher parts of the Atlas Mountains.

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