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# Short-toed snake eagles *Circaetus gallicus* (Gmelin, 1788) (Aves: Accipitridae) approaching a water barrier show reverse direction of migration

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**Abstract**
We investigated the directions of migration (reversed vs. expected) of raptors approaching a geographical strait in relation to local wind conditions, time of day, flock size and location of the observation post (coastal zone vs. inland zone). Fieldwork was conducted during autumn migration in 2011, 2012 and 2013 at a migratory bottleneck located in the southernmost part of the Italian Peninsula (Calabrian Apennines), using four watch points. In this area, migrating birds face the narrowest water surface between continental Italy and Sicily, the Strait of Messina. The only species showing substantial reverse migration was the short-toed snake eagle (*Circaetus gallicus*). In particular, eagles, mostly first calendar year (cy) birds, showed this behavior when passing closer to the coast (5 km inland of the Strait of Messina). Our results could reflect the reluctance of these birds to head south when approaching this relatively short stretch of sea, even before reaching the coastline. This behavior could be evidence of the strong selective pressure, which would have led to the evolution of the extremely detoured flight path of birds breeding in Italy.

**Keywords:** *Reverse migration, short-toed snake eagle, sea-crossing, detour, Mediterranean*

## Introduction

Reverse migration is a behavior shown by birds moving in the opposite to expected direction of migration (Åkesson et al. 1996). Three factors appear to cause this behavior in birds. During spring movements, some birds overshoot breeding sites because of their “crude” navigation system (Mueller & Berger 1969; Rabøl 1993). These birds may use reverse migration to reach their goals, sometimes showing a high degree of directional scatter (Karlsson et al. 2010). Birds perform reverse migration because of adverse weather conditions, with birds turning back when conditions ahead are bad (Nilsson & Sjöberg 2015). Alternatively, birds may travel along the coast in order to find suitable stop-over sites to feed inland and increase their fat reserves before setting out over water (Alerstam 1978, 1990; Åkesson et al. 1996; Bruderer & Liechti 1998; Åkesson 1999; Komenda-Zehnder et al. 2002; Smolinsky et al. 2013; Deppe et al. 2015). The proportion of birds showing a reversed direction of migration increases at night (Bruderer & Liechti 1998). In the case of a sea barrier, soaring raptors show reverse migration on coastal areas, flying inland and sometimes flying back from the sea (Agostini et al. 1994, 2000; Agostini & Panuccio 2004; Panuccio et al. 2004, 2011; Mellone et al. 2013). In this case, among factors affecting reverse migration, wind condition, flock size and time of day are of paramount importance in explaining the flight direction of raptors (Agostini & Duchi 1994; Panuccio & Agostini 2010). The reluctance of raptor species to fly across the sea proportionally increases with the body size of the bird species. Their morphology and weight affect the energy consumption rates and therefore their chance to safely cross the sea barrier (Panuccio et al. 2013; Agostini et al. 2015a). For this reason, some heavy species with broad and rounded wings evolved an extremely detoured (circuitous) route involving reverse migration at the end (spring) or at

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the beginning (autumn) of migration to avoid the crossing of large bodies of water (Alerstam 2001; Agostini et al. 2002; Mellone et al. 2011, 2016; Panuccio et al. 2012). This research investigates the factors affecting an eventual reverse migration in some Afro-Palearctic raptors approaching a sea strait. The aim of this research is to verify whether inter-specific differences occur and which variables can induce raptors to move in the opposite direction of migration when still flying some kilometers far from the coastline. The hypothesis is that larger and heavy species should be more likely to perform reverse migration than smaller species. Moreover, it is expected that migrants change direction of migration more often with adverse wind conditions (strong or head winds) or during the afternoon.

## Study area and methods

To test these hypotheses we analyze here directions of raptors migrating along the southernmost portion of the Calabrian Apennines, in the “toe” of the Italian peninsula, oriented along their direction of migration (NE–SW; Agostini et al. 2015b). In this study area, there is a flat highland west of a mountain ridge, while west of the highland lies the Strait of Messina which is the narrowest water surface (minimum distance about 3.5 km) between southern continental Italy and eastern Sicily (Figure 1; see also Agostini et al. 2015b). Data were collected from four observation posts from 23 August to 10 October 2011, from 12 August to 10 October 2012 and from 11 August to 10 October 2013. Three watch points were located on the mountain ridge or close to it (minimum distance from the coast about 10, 15 and 18 km; altitude 1052, 1807 and 1762 m, respectively), and one about 5 km from the Tyrrhenian coast, on the edge of the flat highland (altitude 987 m; Figure 2). During the fieldwork, the directions of disappearance were recorded. In the

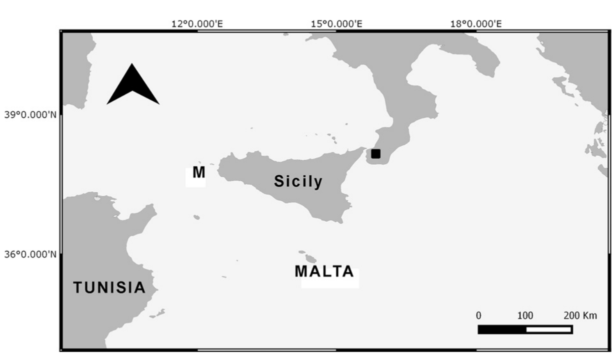


Figure 1. Location of the study area (the black square) in southern continental Italy. M = Marettimo.

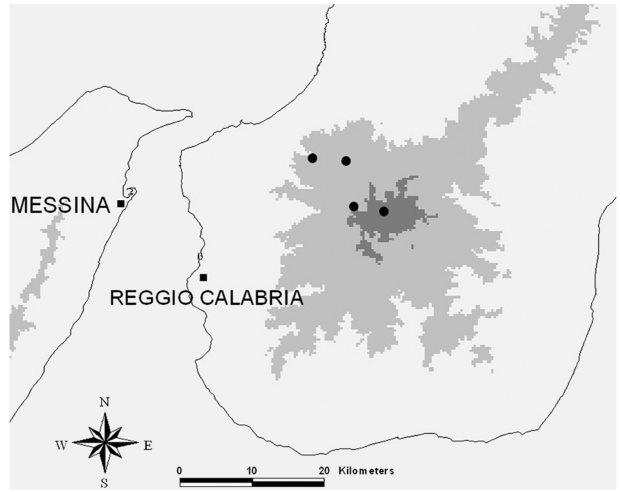


Figure 2. Location of the four watch points in the southernmost portion of the Calabrian Apennines (white = 0–800 m; grey = 801–1600 m; dark grey: 1601–1956 m).

analysis, flocks (two or more individuals flying together) and solitary birds were considered sampling units to avoid a bias of data (Hurlbert 1984). All the observed directions of migration were categorized as expected or reversed. As a result, this research focused on the short-toed snake eagle, which was the only species showing a substantial reverse migration (see Results section). Therefore, we verify which factors affected this behavior by running a binary logistic regression analysis (hereafter BLRA) with binomial error distribution comparing recorded directions of birds flying toward a northerly (reverse migration) or a southerly (expected) direction, and using as predictors the following variables: time of day (morning: 09:00–11:59; midday: 12:00–14:59; afternoon: 15:00–sunset), flock size, location of the observation post (coastal vs. inland zone), wind direction (head component: S, SW; tail component: N, NE; lateral component: W, NW, E, SE), wind speed (km/h) and the interaction between the last two variables. At first we tested for autocorrelation of flock size and wind speed variables using Spearman’s correlation test. We selected variables using a stepwise procedure based on the Akaike Information Criterion (AIC) values of the different models (Akaike 1973). We furthermore tested the significance of each variable in the selected model using analysis of covariance (ANCOVA). We tested the ability of the BLRA model to distinguish between the two different behaviors by means of the area under the curve (AUC) of the receiver operating characteristic (ROC) using the pROC package in R software (Pearce & Ferrier 2000; Boyce et al. 2002; Fawcett 2006; Robin et al.

2011). Wind data at 1500 m. above sea level were obtained from the National Centers of Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis project (NOAA/OAR/ESRL PSD, Boulder, CO, USA, http://www.esrl.noaa.gov/psd/; National Oceanic and Atmospheric Administration/Oceanic and Atmospheric Research/Earth System Research Laboratory, Physical Sciences Division) and downloaded using RNCEP package in R software (Kemp et al. 2012). Variables in the model were chosen following a backward stepwise approach using an information theoretic approach (Burnham & Anderson 2002), selecting the variables by the AIC (Akaike 1973).

## Results

A total of 12,147 directions of migration were recorded, involving 67,235 raptors belonging to 23 species; of these only 158 (1.3%) resulted in reverse migration (Tables I, II). The short-toed snake eagle *Circaetus gallicus* (Gmelin, 1788) was the only species showing a significant proportion of reverse migration (19 vs. 64, 23%; Table II). As a result, we focused the analysis on this species. Since this eagle does not breed in the study area (Panuccio et al. 2015), our observations involved migrating birds. The median date of the passage of this species was on 26 September, and among aged eagles (N = 40) 33 (82.5%) were first calendar year (cy) birds. Finally, we reported 69 solitary individuals and 14 flocks containing on average 2.7 ± 0.7 (standard error, SE) birds. Among birds and flocks showing reverse migration (N = 83), we directly observed the change in the direction (from expected to reversed) in six cases (two flocks and four solitary birds), and always in the coastal zone; all birds of the two flocks behaved in the same way, showing a strong social attraction. As regards statistical analysis, variables were not auto correlated ($P > 0.05$). The ANCOVA run on the most parsimonious BLRA model (Table S1) shows that only the observation zone significantly affected the behavior of short-toed snake eagles (Table III). In particular along the mountain chain eagles were more likely to migrate in the expected direction of migration (heading south) than along the coastal zone. The AUC of this model was 0.96 ($P < 0.001$), so the accuracy of the model was good.

Table I. Numbers of observed directions of migration (flock and solitary bird sampling units) reported during autumn migration 2011, 2012 and 2013 in southern continental Italy.

| Species | Inland zone | Coastal zone |
|---|---|---|
| *Accipiter nisus* | 42 | 26 |
| *Aquila clanga* | 1 | 0 |
| *Aquila pomarina* | 1 | 0 |
| *Buteo buteo* | 139 | 47 |
| *Buteo rufinus* | 2 | 0 |
| *Circus pygargus/macrourus* | 39 | 9 |
| *Circus aeruginosus* | 3329 | 1085 |
| *Circus cyaneus* | 2 | 1 |
| *Circaetus gallicus* | 47 | 36 |
| *Circus macrourus* | 19 | 2 |
| *Circus pygargus* | 62 | 17 |
| *Falco subbuteo/eleonorae* | 24 | 5 |
| *Falco tinnunculus/naumanni* | 1075 | 138 |
| *Falco eleonorae* | 13 | 5 |
| *Falco naumanni* | 106 | 4 |
| *Falco peregrinus* | 14 | 9 |
| *Falco subbuteo* | 116 | 31 |
| *Falco tinnunculus* | 25 | 5 |
| *Falco vespertinus* | 14 | 2 |
| *Hieraaetus pennatus* | 138 | 73 |
| *Milvus migrans* | 427 | 137 |
| *Milvus milvus* | 10 | 1 |
| *Neophron percnopterus* | 4 | 0 |
| *Pandion haliaetus* | 99 | 29 |
| *Pernis apivorus* | 4081 | 656 |

Table II. Reverse migration (flock and solitary bird sampling units) reported in the study area.

| Species | Inland zone | Coastal zone |
|---|---|---|
| *Accipiter nisus* | 2 | 1 |
| *Buteo buteo* | 1 | 0 |
| *Circus aeruginosus* | 15 | 13 |
| *Circus pygargus* | 1 | 0 |
| *Circaetus gallicus* | 4 | 15 |
| *Falco tinnunculus* | 1 | 0 |
| *Falco tinnunculus/naumanni* | 3 | 0 |
| *Hieraaetus pennatus* | 2 | 2 |
| *Milvus migrans* | 11 | 0 |
| *Pandion haliaetus* | 1 | 0 |
| *Pernis apivorus* | 85 | 1 |

Table III. Results of binary logistic regression analysis; asterisk flags significance.

| Explanatory terms | Wald | *df* | *P* |
|---|---|---|---|
| Watch site | 10.5 | 1 | 0.001* |
| Wind speed | 0.03 | 2 | 0.9 |
| Wind direction | 1.9 | 3 | 0.8 |
| Wind direction*Wind speed | 0.01 | 3 | 1 |

## Discussion

The low proportion of raptors showing reverse migration was probably caused by the location of watch points, far from the shoreline, but also because the Strait of Messina is not an insurmountable water barrier for raptor species, being between 3 and 12 km wide (Agostini et al. 2015a).

Our starting hypotheses are partially confirmed. In particular the short-toed snake eagle, which is the largest species regularly migrating in autumn at the site, is the only raptor showing substantial reverse migration. This behavior could reflect the strong selective pressure of water barriers on short-toed snake eagles which would be reluctant to continue migrating as soon as they approach even relatively short stretches of sea (e.g. between southern continental Italy and Eastern Sicily), and even before reaching the coastline. This would have led to the evolution of the extremely detoured path in birds breeding both in Italy and Greece, favored by the partial overlap in the migration periods of individuals belonging to different age classes (Agostini et al. 2002; Panuccio et al. 2012). Notably, nearly all short-toed snake eagles breeding in Italy cross the Mediterranean Sea at the Strait of Gibraltar during both spring and autumn, probably retracing the colonization process (Agostini & Mellone 2008; Panuccio et al. 2015). Most juveniles learn this flyway by following adults (see also Mellone et al. 2016), while some, migrating later in the season than older (experienced) birds, head southward passing along southern continental Italy and concentrating over the island of Marettimo (western Sicily; Figure 1) located 130 km NE of the Cap Bon promontory (Tunisia), and rarely also over Malta (Agostini et al. 2002; Sammut & Bonavia 2004; Mellone et al. 2016). Observations made over Marettimo during autumn migration reported tens of juveniles and few immature and adult birds hesitating in front of the open sea, sometimes flying back toward the mainland (Agostini et al. 2004, 2009; Panuccio et al. 2011). Such reversed migration has been also recorded in a recent study made by satellite telemetry (Mellone et al. 2016). In particular, two eagles tracked from their natal sites in southern Italy travelled two and three times between the Sicilian mainland and Marettimo and, finally, spent the winter in Sicily. The proportion of juveniles recorded in southern continental Italy during this research is nearly the same as that reported over Marettimo (between 79 and 95.8%; Agostini et al. 2009; Panuccio et al. 2011). Considering the behavior here reported (as well as at the island of Marettimo), and that at least some birds winter in Sicily (Mascara 1985; Mellone et al. 2016), we suggest that many individuals heading south during autumn movements do not reach Africa, but interrupt their migration or die during the crossing, such as juvenile Egyptian vultures (*Neophron percnopterus*) attempting the crossing of the Mediterranean Sea between southern Greece and North Africa (Oppel et al. 2015). In reference to birds passing over Malta, their reluctance to continue migrating over the water surface makes them more vulnerable to poaching, since they probably remain on the island longer than other migrating birds do (Del-Hoyo et al. 1994). In a recent paper, Panuccio et al. (2015) suggested that the Italian population of the short-toed snake eagle should be considered part of a metapopulation comprising those in Western Europe (France, Spain). Small and peripheral populations of southern Italy could be considered small patches of this metapopulation system cut off from the bulk of the population of Western Europe (Panuccio et al. 2015). If this were the case, a high mortality of juveniles moving through southern Italy and belonging to these small and periphery patches could maintain a low density in the future, despite the availability of suitable areas for this species (Panuccio et al. 2015).

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## Supplemental data

The supplemental data for this article can be accessed here: http://dx.doi.org/10.1080/11250003.2016.1240833.

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