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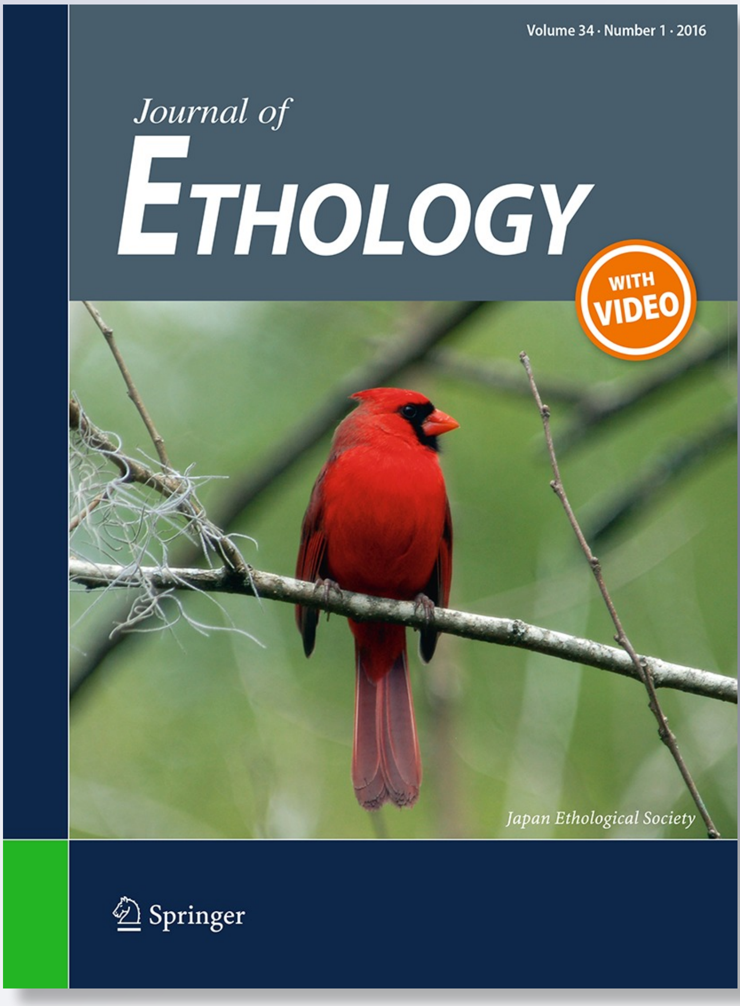

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ARTICLE

Radar tracking reveals influence of crosswinds and topography on migratory behavior of European honey buzzards

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Abstract Variables affecting the choice of migrating European honey buzzards to fly over a flat highland or to outflank it by flying over steep slopes and deep valleys were tested. Radar located at a Mediterranean bottleneck enabled collection of raptor tracks. Variables included the effects of weather, flock size, time of day, and ground speed of buzzards. It was found that raptors passed over the highland when wind speed (mostly lateral) increased as a result of partial drift, whereas buzzards tended to outflank the highland during midday and afternoon, probably when stronger thermals generated on the valley slopes were available. These results suggest that, in this case study, European honey buzzards modulate the compensation of wind drift at different times of the day, showing a highly plastic behavior during migration.

Keywords Radar tracking · European honey buzzard · Wind drift · Migration · *Pernis apivorus*

Introduction

The path of a migrating bird is influenced by various factors, such as the location of the starting place and final destination, the topography and distribution of ecological barriers, and the leading lines of the territory (Alerstam 1990; Newton 2008). Individuality also plays a role in determining spatial flexibility (Vardanis et al. 2011). Weather conditions are of paramount importance in explaining the migratory path; in particular, wind speed and direction can dramatically affect the flight behavior of birds (Alerstam 1979; Richardson 1991). By adjusting their body orientation (heading) or changing their flight style, birds can influence their direction in relation to the ground and compensate for wind drift. Moreover, during migration, raptors are also influenced by ground morphology, because they actively search for stronger updrafts since they move mostly using soaring–gliding flight over land (Kerlinger 1989). Thermal currents allow higher migration efficiency than other currents such as ridge-lifts (Duerr et al. 2012). Therefore, migrating raptors are expected to select flight paths over hilly terrain that warms more quickly than horizontal surfaces (Bildstein 2006). The European honey buzzard (*Pernis apivorus*) is a good model species, being a soaring raptor exploiting thermal currents during migration movements and changing its behavior under different weather conditions (Throurp et al. 2003; Panuccio et al. 2010; Vansteelant et al. 2014a, b).

To investigate features influencing the flight behavior of migrating European honey buzzards, radar tracks collected at a Mediterranean bottleneck were analyzed, in particular variables affecting the choice of raptors to fly over a flat highland or to move around it by flying over steep slopes and deep valleys. We hypothesized that raptors moving across the study area would select areas with strong thermal currents and compensate for drift of lateral winds, since such behavior has been widely reported (Throurp et al. 2003; Panuccio et al. 2010; Agostini et al. 2015).

Methods

The study was conducted over the period from April to May 2014 using a 10-kW, X-band (9.1 GHz) marine surveillance radar with a 7.1-foot antenna set horizontally and rotating at

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38 RPM, alongside visual observations. The radar beam covered an area of about 2 km radius with about 180° range of vision. Data were collected from 08:00 to 18:00 (solar time). The field station was positioned on the edge of a highland (38°23'N, 15°79'E) at about 1000 m a.s.l., located some kilometers inland of the Strait of Messina (southern Italy), an important site for migratory raptors (Panuccio 2011). Radar echoes were corresponded to bird species and flock size identified by observers, as suggested by previous studies (Kerlinger and Gauthreaux 1985a, b). Videos gathered from the radar monitor were processed using the radR package in R software (Francis et al. 2014), which allows assignment of coordinates and time to echoes. Furthermore, echo data were imported into QGIS software (QGIS 2015) and used to reconstruct bird flight trajectories. From a dataset of 2436 tracks of European honey buzzards, 26 flying over the highland and 26 flying around it were randomly selected (Fig. 1) and projected over a digital elevation model (DEM). A binary logistic regression analysis (BLRA) was run to compare the two different behaviors, using the following variables as predictors: time of day (morning, midday, afternoon), ground speed of raptors (m/s), flock size, air temperature (°C), air pressure (mbar), humidity (%), and wind speed (km/h). Wind direction was almost always lateral (from West–North–West and North–West) during the study period. Weather data were collected using a meteostation with an anemometer positioned about 10 m above the ground close to the radar station; data were downloaded every 10 min. To avoid autocorrelation of variables, a Spearman test was run with wind speed retained a priori since it is one of the most important variables in explaining variations of migratory flight (Alerstam 1979; Richardson 1991; Green and Alerstam 2002). Therefore, covariates that were strongly correlated ($P < 0.01$) with wind speed (air pressure and air temperature) were excluded. Variables were chosen for inclusion in the model following a backward stepwise approach using an information-theoretic approach (Burnham and Anderson 2002), selected based on the Akaike information criterion (AIC; Akaike 1973) and retaining the model with the lowest AIC value. The ability of the model to distinguish between the two different behaviors by means of the area under the curve (AUC) of the receiver-operating characteristic (ROC) was tested using the pROC package in R software (Pearce and Ferrier 2000; Boyce et al.

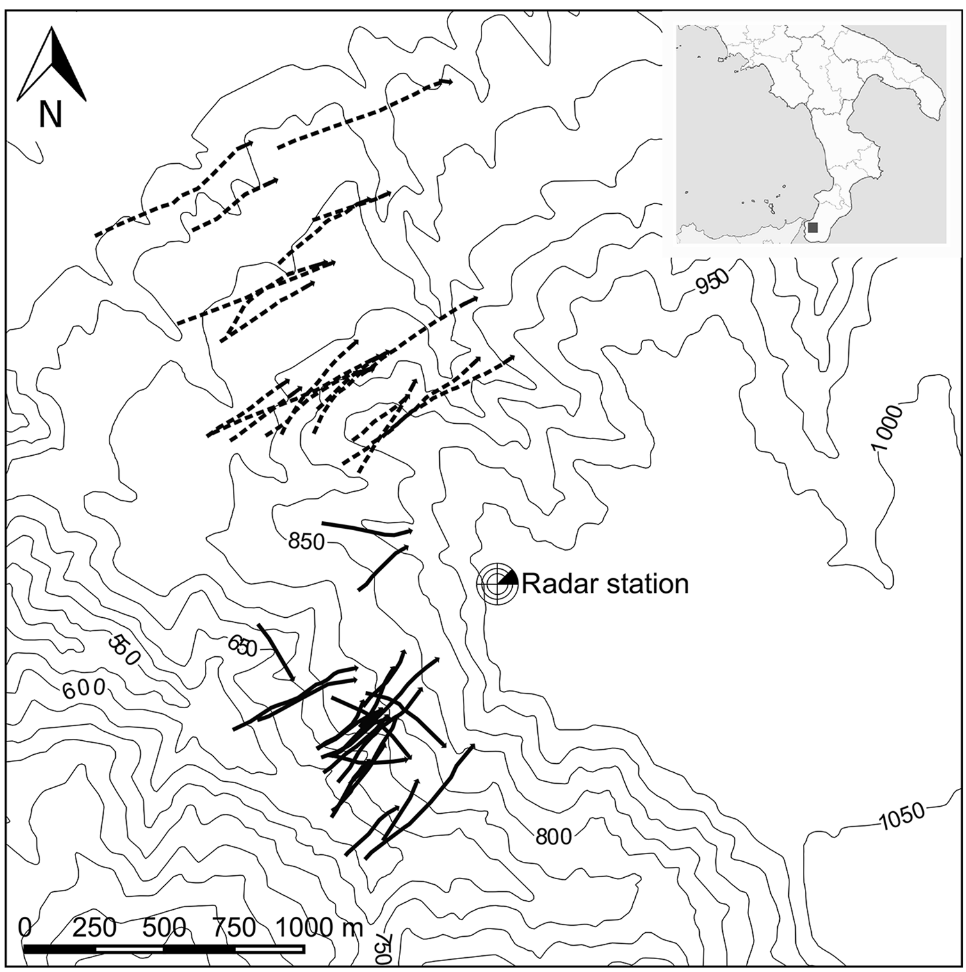

Fig. 1 Tracks of European honey buzzards recorded at the site. *Dotted lines* represent tracks of raptors outflanking the highland; *solid lines* represent buzzards approaching the flat highland. In the small map on the upper right the *black square* indicates the study area in Southern Italy

2002; Fawcett 2006; Robin et al. 2011). This area provides a measure of the discrimination ability, varying from 0.5 for a model with discrimination ability no better than random to 1.0 for a model with perfect discriminatory ability. A rough guide for classifying the accuracy of this diagnostic test is the traditional academic point system (Swets 1988): 0.90–1.00 = excellent; 0.80–0.90 = good; 0.70–0.80 = fair; 0.60–0.70 = poor; 0.50–0.60 = fail.

Results

The model with the lowest AIC value showed that wind speed and time of day were significant terms explaining the behavior of European honey buzzards to fly over or around the highland (Table 1). The AUC of this model was 0.87, thus the accuracy of the model is good. Looking at the models with highest AIC values (ΔAIC = 3.42), it was highlighted that all models reported almost the same results with exactly the same significant covariates as the model with the lowest AIC value. Taking into account the last model, it was shown that, with stronger winds (estimate: 0.5), raptors tended to fly over the highland more often than with weaker winds (Fig. 2). During midday (estimate: −2.7) and the afternoon (estimate: −4.1), raptors were more likely to circumvent the highland than during the morning.

Table 1 Results of binary logistic regression analysis; asterisks flag significance

Explanatory term	Wald	*df*	*P*
Wind speed	12.4	1	<0.001**
Ground speed	2.4	1	>0.05
Time of day	9.8	2	<0.01*

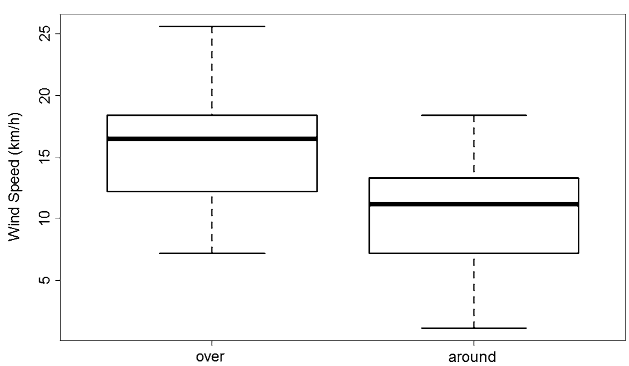

Fig. 2 *Boxplot* showing wind speed variation recorded when raptors passed over the highland (on the *left*) and around it (on the *right*). *Horizontal bold line* shows median wind speed for each category. The *bottom* and *top* of *boxes* show 25 and 75 percentiles, respectively. *Horizontal lines* joined to the *box* by a *dashed line* show the maximum and minimum range of the data

Discussion

The results show that, with increasing wind speed (mostly lateral from North and North-West), raptors were more likely to pass over the highland. This is probably the effect of a light wind drift that pushed European honey buzzards more inland, funneling them to fly across the highland without compensating for the wind drift, mostly in the morning. This last result can be explained as, in the study area, slopes have more westerly rather than easterly aspects (Fig. 1). Therefore, raptors prefer to fly over valleys during midday and afternoon, probably because insolation is at its peak at that time of the day or simply because the sun's rays are in the west at the hottest time of the day in the afternoon (Shamoun-Baranes et al. 2003). In both cases, thermal currents are stronger and more available. This interpretation is corroborated by the daily variation of the gliding speed of raptors in the study area, which increases during midday and afternoon (Panuccio et al. 2014). Since both variables, i.e., wind speed and time of day, are significant terms, we can suggest that these birds can modulate the response to wind drift depending on time of day and convenience in relation to exploitation of updrafts. A recent study on golden eagles (*Aquila chrysaetos*) showed that migrating raptors are able to apply a time-selection strategy in order to gain the best support from thermals (Duerr et al. 2014). Successful arrival requires adjustment of headings to compensate for any cumulative lateral drift (McLaren et al. 2014). However, this study indicates that European honey buzzards allow partial wind drift during spring migration at a local scale. The behavior of raptors during migration and their response to wind drift may change depending on season (Duerr et al. 2014) and geography (Klaassen et al. 2011). The results from this study differ from previous research showing that, in closer study areas, European honey buzzards compensate for wind drift by limiting use of soaring flight during autumn migration (Panuccio et al. 2010; Agostini et al. 2015). Earlier studies in the Middle East showed that geomorphological structure influences migratory flyways to a different extent along the day length and among different seasons as a result of the combination of radiation and wind direction (Leshem and Yom-Tov 1998). The time-minimizing orientation strategy to reach a goal has been proposed to involve minimizing the remaining distance to the goal in a sequence of steps, resulting in an increased degree of compensation on approach to the final destination (McLaren et al. 2014). In the studied species, it is known that spring migration is more time-minimized than autumn migration at a regional and transcontinental scale (Agostini and Panuccio 2005; Agostini and Panuccio 2015; Vansteelant et al. 2014a, b). In this picture it is not yet clear why European honey buzzards compensate drift of lateral winds more during autumn than spring migration. However, we can state that, since the reaction to wind drift performed by raptors in our study case was not the same along the day, European honey buzzards modulate their response to lateral winds at different places and times during their movements, selecting when it is more convenient to compensate the drift for better exploitation of thermal currents in relation to the slope aspect of the territory.

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