STSM Report - COST Action: ES1305

The effects of fog on the flight behaviour of migrating Honey Buzzards as recorded by radar

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1. INTRODUCTION

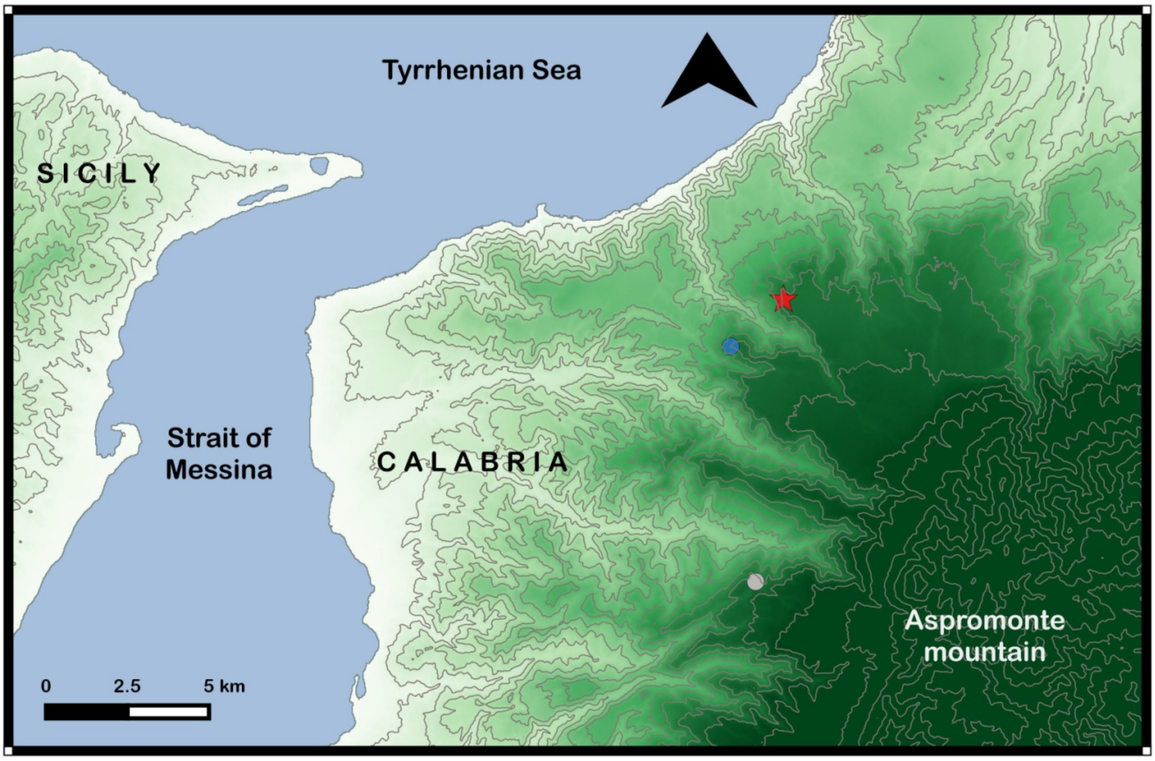
Weather conditions may influence the movement of birds and several studies have suggested that migrating birds show a high selectivity of weather conditions during their journeys (Elkins 2004; Newton 2008). As a general pattern, migration is facilitated by clear skies and tailwind assistance and hampered by precipitation and opposing winds (Erni et al. 2002). Fog and low clouds reduce the visibility during flight and thus can negatively affect the orientation of birds (Alerstam 1990; Richardson 1990; Chiaradia et al. 2007) as well as disrupting various other migratory behaviours (e.g., Alerstam and Ulfstrand 1974). Consequently, fog may cause mass-mortality events of migrating birds (Newton 2007). However although it is generally known that fog may negatively affect migrating birds, there is lack of studies quantifying the effect of fog on active bird migration and with this STSM we try to address this gap. Radars can detect echoes of birds in low visibility conditions such as darkness and fog (but not rain), allowing rigorous examination of the effects of fog on bird migration. We consequently analysed radar data of diurnal migrating birds at an important Mediterranean migratory bottle-neck along the Central Mediterranean Flyway where the commonest migrant is the European Honey Buzzard (*Pernis apivorus*). Tens of thousands Honey Buzzards migrate across this flyway both in spring and autumn and several studies highlighted that its migratory behaviour is strongly influenced by weather conditions (Agostini et al. 2007; 2016; Panuccio 2011). This species is a soaring bird but it is also able to use flapping flight while crossing wide stretches of sea with tailwind assistance (Agostini et al. 2016; Panuccio et al. 2016b). Thus, this species shows a high plasticity in its flight behaviour and as such it constitutes a well suited model species for studying the ecology of soaring bird migration (Vansteelant et al. 2015; Panuccio et al. 2016a).

2. METHODS

2.1 Study area and data collecting

We analysed radar data collected in Southern Italy during the springs of 2014 and 2016 with 12 kW and 24 kW, X-band radars (9.1 GHz), with an open array 7.1 feet antennas set horizontally (Bruderer 1997a) and 38 RPM rotation frequency (GEM, Italy, http://www.gemrad.com/). The radar range was approximately two kilometres and the detection area was limited towards a 230° sector in the direction of the migratory flow, while the remaining sector was blank due to ground clutter. The radar was positioned in Aspromonte, Calabria, on the continental northern side of the Strait of Messina, an area that is well known for its importance as migratory bottleneck for many species of birds and in particular for the European Honey Buzzard (Zalles and Bildstein 2000; Panuccio 2011). Site location (Fig. 1; 38° 13’ 50.7"N, 15° 47’ 58" E) was at an edge of a flat highland at about 1000 m above sea level (Fig. 1), an area frequently exposed to fog. Fog and low clouds are created in this area because humid air is trapped between the coast (about 5 km away) and the highland.

Figure 1 - The Strait of Messina where radar data were collect during the springs of 2014 and 2016. The red star indicates the position of the radar station. Points indicate watchpoints used to count raptors.



Radar measurements of migrating birds were carried out daily during the study period and continuously between 8:30 and 17:30 (solar time, UTC+1), interrupted only occasionally by the onset of heavy precipitation. Each monitoring day was divided into three time slots: morning (8:30-11:29), midday (11:30-14:29) and afternoon (14:30-17:30). Hourly weather data were recorded by a meteorological station positioned close the radar station (Fig. 2). The weather data were automatically recorded in the middle of every hour (i.e. 12:30).

Figure 2 - The radar station at the Strait of Messina (spring 2016).

2.2 Data analysis

As a first step we assessed if fog influenced the diurnal passage rate of birds detected by the radar. For this aim we used Generalized Linear Models (McCullagh and Nelder 1989; Dobson 1990) (hereafter GLM) with the hourly number of tracks used as dependent variable and the following as predictors:

1. Fog – categorical variable (presence/absence). The presence of fog banks and low clouds was visually assessed by the radar operators and recorded assigning a presence/absence value every hour when visibility was lower than 0.3 km. The presence value was assigned when extensive fog banks and/or low clouds were observed at the site for at least fifteen consecutive minutes, while disregarding isolated passing clouds.

2. Air temperature – continuous variable (° C).
3. Air humidity - continuous variable (%).
4. Wind direction – categorical variable of three classes (A. Tailwind, when the wind was blowing from the following sectors: S-SSW-SW-WSW; (B. Headwind, when the wind was blowing from the following sectors: N-NNE-NE-ENE; and (C. Crosswind when the wind was blowing from either eastern sectors: SSE-SE-ESE-E, or western sectors: W-WNW-NW-NNW).
5. Wind velocity (m/s).
6. Time of day – categorical variable of three classes (morning, midday, afternoon). Since the migration of birds is known to vary throughout the day (Kerlinger 1989; Mateos-Rodriguez and Liechti 2011), we added the time of the day to our models to account for the possible influence of this factor on bird density.

To avoid autocorrelation of variables we examined the correlation between the independent variables using Spearman's correlation tests, with a critical α of 0.05. Then, we used GLM with negative binomial error distribution using MASS package in R software (R software version 2.11.2) to investigate their effects on bird passage rate in Aspromonte, as calculated from the number of radar tracks. We selected variables using step function on R software based on their AIC values (Akaike 1973). We furthermore tested the significance of each variable in the selected, most parsimonious model, using ANCOVA.

As a second step we used data from spring 2016 comparing flight speeds of migrating birds under different conditions of visibility (fog vs. without fog). In particular we compared air-speed, ground speed and cross-country speed. These parameters were calculated after the radar tracks that were processed by the radR packcage in R were geographically positioned using a GIS software. We compared these values by using Mann-Witney U-tests.

3. RESULTS

-Variation of bird passage rate-

During spring 2014 data were collected during 267 hours of simultaneous radar tracking and visual observations. Fog was recorded during 65 hours (24.3% of the fieldwork time). We analysed 18,909 tracks recorded by the radar after processing by the radR package. The commonest observed species was the European honey buzzard, with 16,415 counted individuals (87% of the total). We run all possible GLMs with any combination of independent variables, we compared AIC values of each model and selected the most parsimonious one. The outcome of this procedure suggested that the selected model consists of the following three explanatory variables: Fog, Time of the day and Wind direction. AIC of this model is lower

(ΔAIC > 3.5) than that of the full models. The ANCOVA results suggest that the presence/absence of fog and low clouds was the most important variable explaining the variation in the hourly number of diurnal migratory birds that were recorded by the radar (Tab. 1). In particular, foggy conditions drastically decreased the number of echoes detected by the radar (estimated values for the effect of fog was -1.3 ± 0.2; Fig. 3). In addition, wind direction significantly influenced the hourly number of radar tracks with the lowest number recorded when tailwind was blowing (estimated value was -1.3 ± 0.7).

Table 1 - Results of the ANCOVA testing the effects of different independent variables on the hourly number of birds. This model was selected based on its lowest AIC score. Asterisks indicate significance.

Explanatory terms	**F**	***P***
Fog Banks	34.8	>0.001*
Time of the day	2.0	0.13
Wind direction	4.6	0.004*

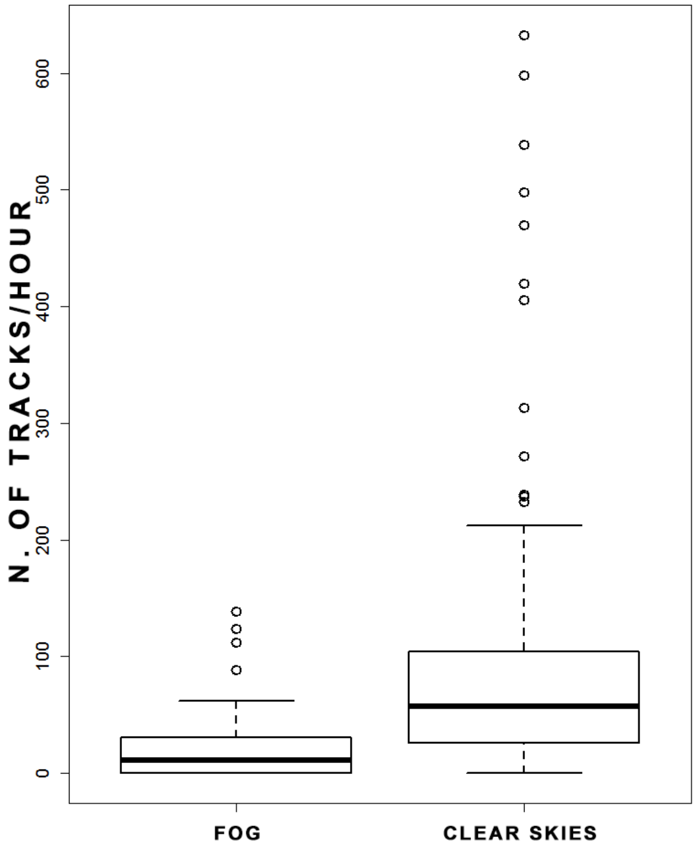


Figure 3 - Number of tracks per hour recorded during spring migration 2014 under the two different weather conditions (fog vs. clear skies).

-Variation of flight parameters-

During spring 2016 a total of 591 hours of simultaneous radar tracking and visual observations were made. Fog occurred during 62 hours (10.5% of the fieldwork time). We considered for this part of the analysis 37,629 radar tracks, of which 1,868 were collected during foggy time. Also during this data collection season the commonest species was the European honey buzzard with 7,678 counted individuals. We found that the different flight parameters varied in relation to the presence of fog (Tab. 2). In particular, flight speeds were faster under fog than under conditions of good visibility (Fig. 4).

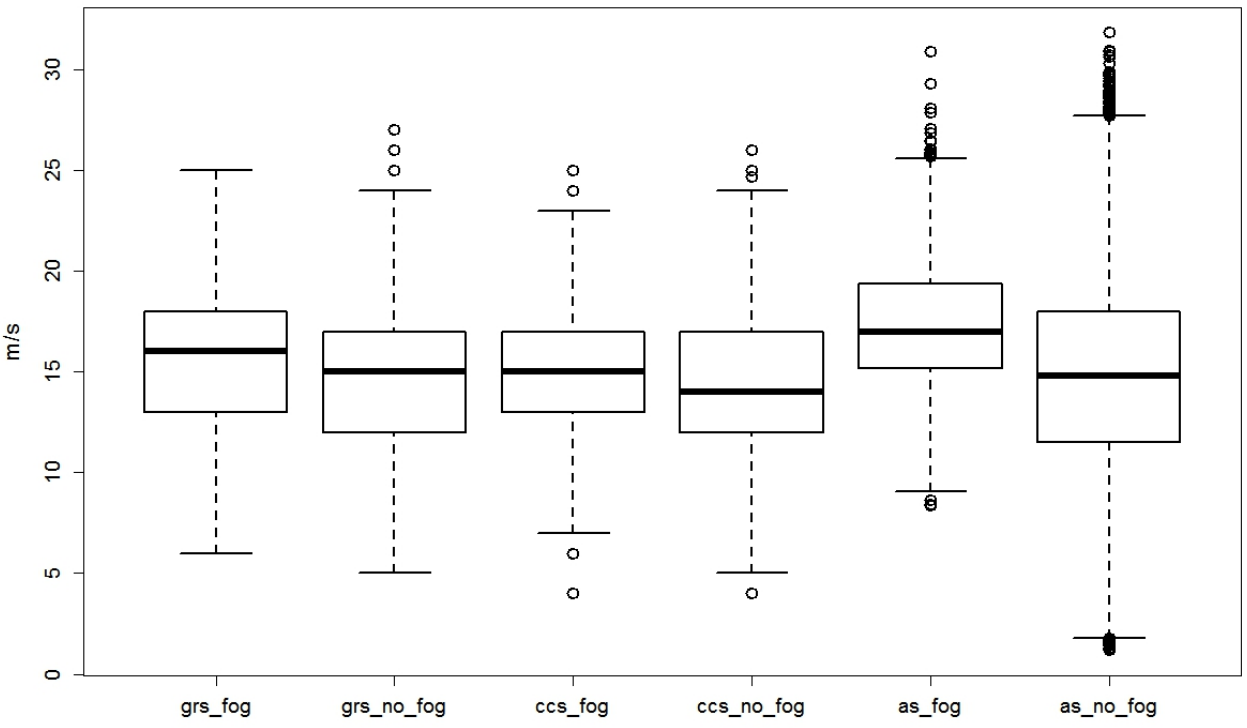
Table 2 - Flight speeds of migrating birds under the two tested weather conditions (fog vs. clear skies), with the results of Mann Witney U-tests.

	Fog Mean ± SE	No fog Mean ± SE	Mann Witney U-Test	*P*
Ground-speed	15.46 ± 0.08	14.57 ± 0.02	W = 38450000	< 2.2e-16
Air-speed	17.47 ± 0.07	14.69 ± 0.02	W = 45332000	< 2.2e-16
Cross-country speed	15.08 ± 0.08	14.27 ± 0.02	W = 38103000	< 2.2e-16

4. DISCUSSION

The results of our analysis show that, during foggy hours, numbers of birds flying in the area drastically decreased providing evidence that diurnal migrants avoid flying through fog and low clouds. Moreover, when flying across fog banks birds show higher flight speeds probably because they try to go as fast as they can outside an area with bad visibility. The European Honey Buzzard is a species that is known to modulate its migratory behaviour according to weather and topographical conditions (Fig. 5). A previous research made in the same area showed that these raptors actively select areas where their migratory flight will benefit by exploitation of updrafts and reduction of wind drift (Panuccio et al. 2016a). Also, it has been shown for other migrating raptor species that they actively select to fly over areas that allow a more efficient exploitation of thermals and ridge lifts (Kerlinger 1989; Bildstein 2006), therefore we can suggest that migrating raptors avoid flying through fog banks outflanking them or stopping and waiting for better conditions of visibility. Richardson (1990) suggested that soaring birds rarely fly in dense fog because their migration mostly occurs under sunny conditions and with strong updraughts. Soaring birds can avoid flying through fog because of low visibility or because fog and low clouds prevent the formation of convective updrafts necessary for migration using soaring flight. However the two explanations are not mutually exclusive.

Figure 4 - Flight speeds of migrating birds under fog and under good visibility conditions (grs = ground speed, ccs = cross-country speed, as = air speed).



The results of this study highlight once more the importance of using radars to study bird migration (Bruderer 1997b; Buler and Dawson 2014). Since under bad visibility conditions visual observations are mostly useless (Hall et al. 1992), the use of radars may allow measuring the intensity of bird migration as well as calculating different flight parameters. Yet, in most cases it is not possible to identify the specific bird species using radar. Our findings may also be used to investigate the impact of human-built structures on birds, particularly during migration and other movements, which is of crucial importance for bird conservation (Hüppop et al. 2006; Lambertucci et al. 2015). In particular, collision risks of birds with man-made structures like wind turbines depends on different factors, among which are weather conditions, and it is known that collision prevalence increases when visibility is poor (Drewitt and Langston 2006). Future research may focus on soaring vs. flapping migrants under different visibility conditions because these two groups may employ different behavioural responses to weather and may consequently have different collision risks with wind turbines.

Figure 5 - European Honey Buzzard flying through a fog bank.

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