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Fog and rain lead migrating White storks *Ciconia ciconia* to perform reverse migration and to land

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Abstract – Weather is one of the main factors affecting the migratory behaviour of birds. Rain and fog negatively influence bird flight, forcing animals to make long detours or to stop, waiting for better conditions, leading also in extreme cases to mortality events. We monitored spring and autumn bird migration on the continental side of the Strait of Messina, which is the main bottleneck along the Central Mediterranean flyway, in particular for soaring birds. Fieldwork integrated visual observations and radar monitoring. The radar station was located on a mountain highland close to the seacoast, where fog and rain often occurred. During autumn 2016 a flock of White Storks detected by the observers disappeared into an extended fog bank. We could track with the radar the movement of the birds into the fog and the analysis of the trajectories revealed an extremely circuitous flight until the birds stopped. The radar also detected the departure, with birds trying to find a way out of the fog bank. We compared track measurements of this flock with storks tracked during good visibility conditions. Ground-speed and straightness of the tracks showed a marked difference highlighting how fog deeply influenced their flight behaviour.

Key-words: White Storks, fog, rain, radar, reverse migration.

INTRODUCTION

Weather is one of the main factors affecting the migratory behaviour of birds (Newton 2008, Richardson 1991). The wind has a major effect on migration (Alerstam 1979, Green & Alerstam 2002, Safi *et al.* 2013), e.g. wind during migration has been found to determine apparent survival, breeding timing and productivity of the Neotropical migrant Yellow Warbler *Setophaga petechia* (Drake *et al.* 2014). Weather conditions during migration, influencing arrival date, can affect populations parameters more than weather during wintering or breeding period. Soaring migrants such as Osprey (*Pandion haliaetus*), Marsh Harrier (*Circus aeruginosus*) and Montagu's Harrier (*Circus pygargus*) showed a daily mortality rate six times higher during migration than during stationary periods (both breeding and wintering) (Klassen *et al.* 2014). Nevertheless, mortality during migration accounted for 55% of annual mortality, because the higher migration's daily mortality rate was compensated by the shorter period of risky migration compared to longer safe stationary ones. Unfavourable weather was likely one cause of mortality, which mainly occurred during Sahara's crossing in spring (Klassen *et al.* 2014, Eurasian Spoonbill *Platalea leucorodia*: Lok *et al.* 2015, Strandberg *et al.* 2010). Desert's sandstorms have been found to be a cause of mortality for many species, also larger one as White Stork (Newton 2007). Rain and fog negatively influence bird flight (Kirsch *et al.* 2015), compromising visibility and therefore navigation (Newton 2007). Newton (2007) reviewed birds' mass-mortality events due to weather divided into three main groups: during the travel, after arrival in breeding grounds and before departure of fall migration. Rain, fog, and cold temperatures were the main causes of mortality. Terrestrial birds appeared to be especially vulnerable to bad weather if this occurred over water surface (see references in Newton 2007). Soaked plumage increases wing loading and therefore energy expenditure, forcing birds to land if possible or leading to exhaustion if animals are forced to keep on flying. Wet plumage increases also heat dispersion, causing a further metabolic energy consumption (Newton 2007).

Impacts of songbirds on tall structures as communication towers (Gehring *et al.* 2011) increase in frequency in low visibility condition, especially if tower lighting produces an illuminated halo due to low clouds (Avery *et al.* 1976, Longcore *et al.* 2013). Here we report a case of a flock of White Storks *Ciconia ciconia* flying in dense fog tracked by radar and we compare the flight parameters with those of flocks of White and Black Storks *Ciconia nigra* migrating in good visibility conditions.

MATERIALS AND METHODS

We monitored bird migration on the continental side of the Strait of Messina, the main bottleneck along the Central Mediterranean flyway, in particular for soaring birds (Agostini 1992, Panuccio *et al.* 2005). Fieldwork was carried on in spring (radar station: 38°13'50.80"N, 15°47'58.26"E) 2015, 2016 and 2017 from March 15th to May 30th, while in autumn (radar station: 38°12'54.50"N, 15°49'24.17"E) migration was monitored from 2014 to 2016 between August 15th and September 30th.

The monitoring activity combined visual observations and radar tracking, using 12-kW and 24-kW, X-band (9.1 GHz) marine surveillance radars with a 7.1-foot open array antenna set horizontally for one radar (hereafter horizontal radar) and vertically for the other one (vertical radar), rotating at 38 RPM. The deployment of two radars allowed collecting both the trajectories and flight heights of birds (Panuccio *et al.* 2016). Visual observations were carried out simultaneously to radar operation by two experienced ornithologists, using binoculars (10x42) and spotting scope (20–60x). Fieldwork was carried on from sunrise to sunset. Radar echoes were associated with species and flock size by the observers, following methods used in previous studies (Kerlinger & Gauthreaux 1985a, 1985b, Dokter *et al.* 2013).

The site was located on the Aspromonte Plains, a flat highland a few kilometres inland of the Strait of Messina, on the western side of the Apennines ridge. The highland is between 1000 and 1200 m a.s.l., with the landscape shaped by human activities, mainly agriculture and ovi-caprine pastures. This site is an important migratory bottleneck for migrating soaring species, in particular raptors (Panuccio 2011, Panuccio *et al.* 2016), but also storks (Bobek *et al.* 2008).

In spring one horizontal radar was set with 2 km radius while two radars were used in autumn, with 2 km radius for both horizontal and vertical settings. Birds were tracked using a new Java application developed for this purpose: Hipatia-TrackRadar (Capotosti & Scacco 2017). This application works like a virtual transparent sheet overlapped on the radar screen, allowing to track echoes by clicking on them and assigning information gathered via visual observation to each track, such as bird species, age, sex, and flock size. Therefore, each track consists of a variable number of fixes, each one with X-Y coordinates in respect to the radar centre. The application computes the following flight parameters: Euclidean distance (distance between first and last points of the track), track length, ground speed, cross-country speed (Euclidean distance/track's time length), straightness (Euclidean distance/track length) for radar's horizontal setting. With radar's vertical setting the application computes birds' altitude above ground and above sea level. A left or right click of the mouse allows to assign gliding or soaring flight to the echoes.

RESULTS

On September 3rd 2016, weather was foggy on the highland, with low clouds coming from SW. Visibility was limited to few tens meters, improving sometimes to hundreds meters.

10:39 (CEST, Central European Summer Time) A flock of six White Storks detected by the observers flew just above the radar station and disappeared into an extended fog bank SW from the radar station. The radar followed the movement of the birds into the fog revealing an extremely circuitous flight (Fig. 1).

10:51 The flock performed reverse migration and disappeared from our screen 870 m from the radar station moving toward NW.

11:20 - 13:20 Rain, after that visibility improved.

14:18 During a foot transect we spotted the flock of six White Storks perched on a power line's tower, 2390 meters NW from radar station, still on the highland. Birds flew away in the fog bank.

14:34 Radar tracked the flock again, while trying to find a way out from the fog.

14:41 White Storks flew south-westward.

The limited visibility forced the flock to perform reverse migration, find an emergency perching site and suspend migration. The radar lost the flock probably due to very low flight's altitude, maybe because birds were looking for perch. It started raining after a short time.

The highland is flat, lacking of tall structures or isolated big trees. A new electric power line of Terna Rete Italia S.p.A. crosses the highland, whose possible impact on migrating birds was the aim of our monitoring activity. The power line's towers are dominant features on the landscape. Likely for this reason the storks chose to perch on it.

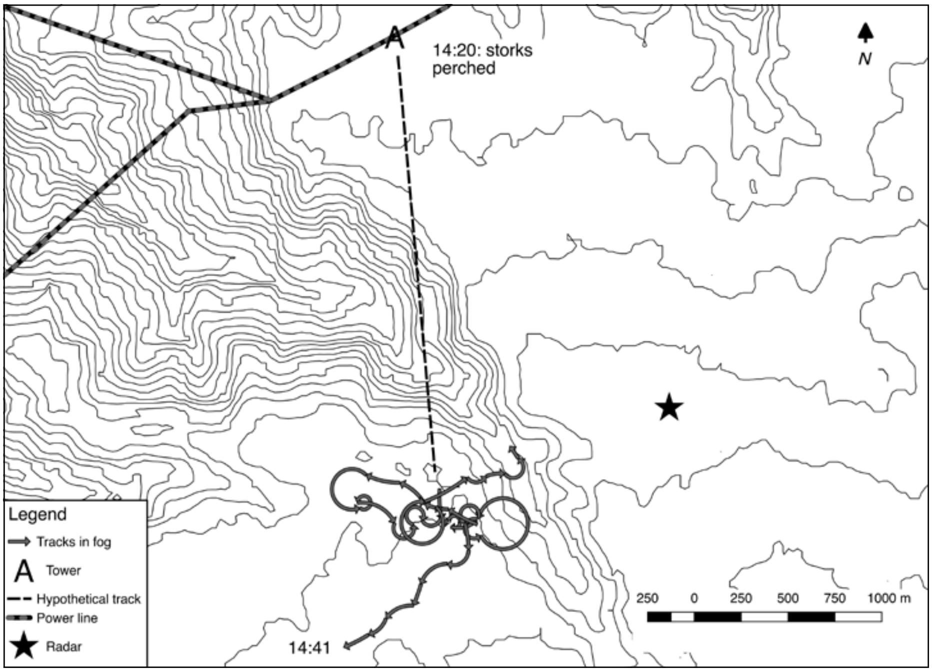

Figure 1. Detailed flight trajectories of White Storks in fog. Two hours of rain occurred between the first and the second track. Radar altitude was 1185 m a.s.l.

The application Hipatia-TrackRadar computed ground speed, cross-country speed, straightness of tracks and flight altitude. We compared track measurements of this flock with storks tracked during good visibility conditions during both spring and autumn (Fig. 2). With the horizontal radar we could track White Storks five times during our study period, four tracks were collected during autumn and one in spring. We included in comparison also tracks of Black Stork, tracked four times in spring. Altitudes were computed seven times, five times for flocks of White Storks, two for Black Storks (Fig. 3).

Storks flying in dense fog showed an extremely circuitous path, a slower ground and cross-country speed, as well as lower flight altitude. Ground speed was 19.9 and 24.1 km/h for the first and the second tracks of the flock respectively. Flocks flying in favourable weather showed ground speed mean ± SE of 46.22 ± 2.96 km/h (N=9). Cross-country speed (i.e. speed between the first and the last points of the track) was 2.6 and 11 km/h, respectively before and after rain, while the other flocks showed mean ± SE overall migration speed of 33.31 ± 4.79 km/h (N=9). The radar did not track the flock immediately after departure from the tower, 13 minutes occurring between the departure from the perch to the starting of radar tracking. Overall cross-country speed of the second track was therefore even lower.

Flight altitude of the flock was 120 m while mean ± SE height of the other flocks was 320.2 ± 25.7 m (N = 28 individuals of seven flocks, five of White Storks, two of Black Storks).

DISCUSSION

Despite the consistent literature available on migration of both White Stork (Liechti *et al.* 1996, Berthold *et al.* 2002, Shamoun-Baranes *et al.* 2003, Chernetsov *et al.* 2004, Vergara *et al.* 2007, Vaitkuvienѐ *et al.* 2015, Flack *et al.* 2016, Rotics *et al.* 2016, 2017) and Black Stork (Jiguet & Villarubias 2004, Bobek *et al.* 2008, Chevallier *et al.* 2010), to the best of our knowledge, no study has ever described in detail the behaviour of a flock migrating in low visibility condition. In our study we could detect with the radar that the birds flew into the fog showing a very circuitous path, at low altitude, likely trying to find a way out from the fog bank and eventually landed on an electric tower moving in an opposite direction than the migratory one. In coastal areas birds often reorient their migration flight showing reverse direction in order to find suitable places to refuel and rest (Alerstam 1978). This storks' flock perched on the tower of the high voltage power line probably because it was the only tall structure available

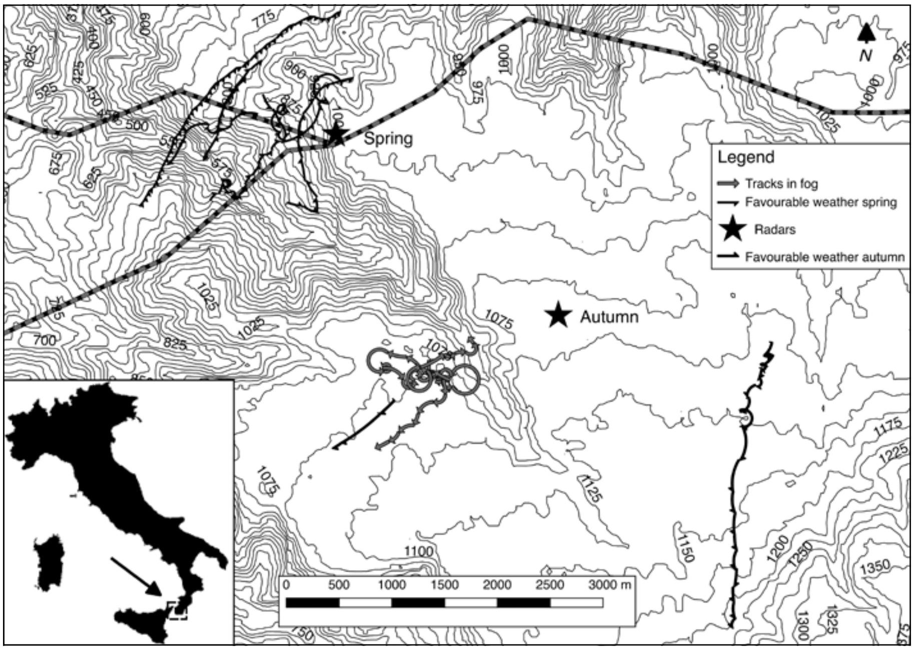

Figure 2. Comparison between tracks of storks flying in favourable weather condition and the flock observed flying in fog.

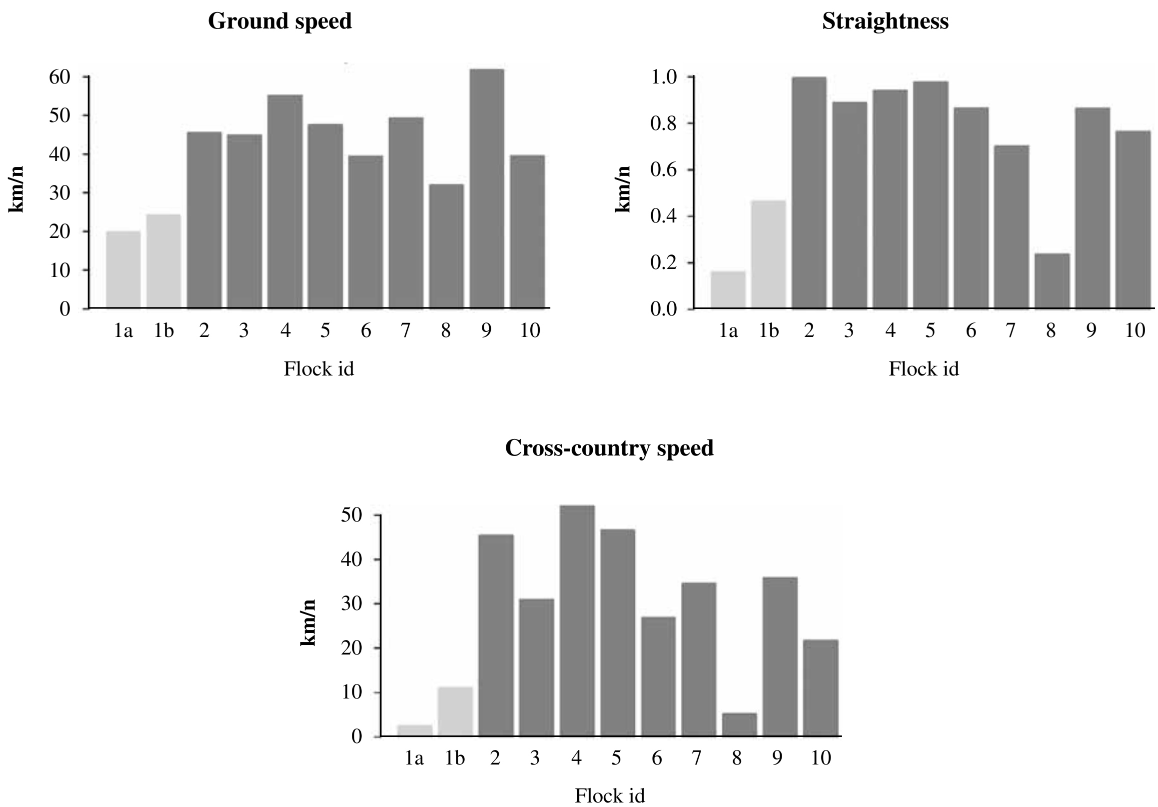

Figure 3. Flight parameters of storks tracked in fog (light grey: 1a = first track, 1b = second track) and storks tracked in good visibility conditions (dark grey, 9 flocks).

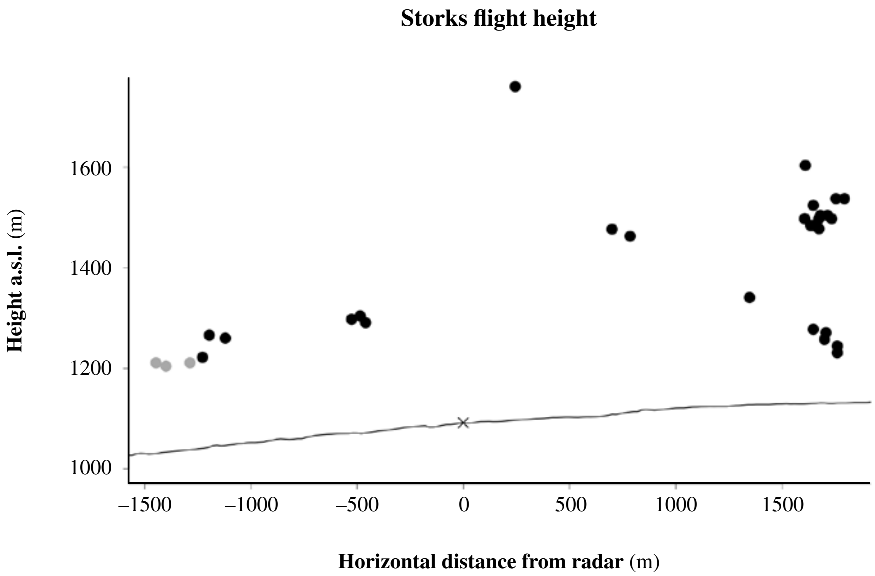

Figure 4. Flight altitudes a.s.l. of storks (grey = fog; black = good visibility conditions) during autumn migration. The black line is the ground profile. Radar (black cross) altitude was 1185 m a.s.l.

and visible in the fog. Instead of proceeding in the original direction of their flight the birds preferred to discontinue their migration and to land on a safe place to wait probably for the return of good visibility conditions. Therefore when faced with the decision to continue towards an unknown and possible risky route they preferred to take a safer decision and return to a known, or at least visible, position. After three hours during which rain occurred, visibility improved and the flock departed from the tower, resuming migration. Fog stopped them again but eventually visibility improved and they succeed in flying southward.

This may be explained by a risk-averse strategy due to low visibility conditions (Newton 2007). Furthermore thermal uplift is prevented in fog, thus thermal soarer as storks and raptors have to switch from energetically cheap soaring-gliding flight to a much more expensive flapping one. Energy cost of flapping flight increase as exponential function of body mass (Pennycuick 1975), therefore it represents a huge energy expenditure if large birds are forced to use this flight mode for long time (Bildstein *et al.* 2009). Orography of the Aspromonte plateau (Fig. 2), with steep slopes forming the southern and western edges, may be a kind of "trap" during autumn migration, because in events of fog coming from SW the entire southern and western edges of the highland are usually enveloped by low clouds. Therefore fog can completely stop the direction of migration for the birds once they have crossed the highland from N to S and have reached the southern edge.

Sandhill Cranes *Grus canadensis* flying in thick fog after departing from night roost showed a flight pattern similar to the one we observed (Kirsch *et al.* 2015). They indeed performed a very circuitous path, an increase in frequency of flight calls and lower altitude compared to cranes flying in favourable conditions. During inclement weather Sandhill Cranes showed to remain in the roost or to fly to a short distance from it (Lovvorn & Kirkpatrick 1982 in Kirsch *et al.* 2015) and they could also leave later in the morning (Lewis 1974, Melvin & Temple 1981, Norling *et al.* 1992 in Kirsch *et al.* 2015). In that area, the threat represented by a wind farm 3.2 km from the cranes' roost could increase due to weather condition, as shown in other studies (Brown *et al.* 1985, Drewitt & Langston 2008 in Kirsch *et al.* 2015). The radar allowed to track birds flying in low visibility, otherwise undetectable by direct observations (Kirsch *et al.* 2015, Larkin & Frase 1988).

Newton (2007) highlighted how weather condition during migration can represent a severe mortality factor for birds, likely shaping migration routes. On the other hand weather conditions shortly after arrival in the breeding grounds or shortly before departure after the breeding season could drive the timing of migration (Newton 2007). Rotics *et al.* (2016) found higher mortality rates for juveniles than for adult White Storks during migration, in some cases due to juvenile higher energy consumption in flight, leading to exhaustion and starvation. Previous studies found a higher sensitivity to adverse weather in juvenile than adult birds (Owen & Black 1989, Thorup *et al.* 2003, Sergio *et al.* 2014). Another study highlights the strong ef-

Table 1. Numbers of observed Accipitriformes and storks migrating through the Aspromonte plateau. Spring fieldwork was carried on from March 15th to May 30th (2015 and 2016, until May 25th in 2017). Autumn fieldwork was carried on from August 11th to September 30th all years.

Season	Year	Total	Raptors	White Stork	Black Stork
Autumn	2014	11417	11372	11	34
Spring	2015	15046	14995	9	42
Autumn	2015	15181	14997	157	27
Spring	2016	8830	8629	183	18
Autumn	2016	11569	11380	158	31
Spring	2017	13946	13877	30	39
	Totals	**75989**	**75250**	**548**	**191**

fect of migration on mortality, comparing migrant juvenile white storks with juvenile birds wintering in Europe (Rotics *et al.* 2017), the latter showing a higher survival rate.

This storks' flock used the tower without consequences, but influence of adverse weather on birds' behaviour may increase risk of collision or electrocution against utility structures (Avery *et al.* 1976, Longcore *et al.* 2013). White Storks were frequently found dead below power lines in the past (Riegel & Winkel 1971 in Bevanger 1998, Schaub & Pradel 2004). During our study period we performed 3-km of daily transects below power lines for one month in each season (2014-2016), but we could not find carcasses of collided or electrocuted soaring birds.

A high number (Accipitriformes and storks, all years and seasons combined: 75989, Tab. 1) of soaring birds crossed the highland during the entire study period in variable weather conditions, but we have never observed collisions with the wires or found carcasses of those birds during the transects. This is consistent with one study carried out in seven areas in Italy, comprised the Strait of Messina, which showed a generally low number of collisions (Costantini *et al.* 2016). Impacts have never been observed either during a study on the potential impact of a new power line crossing the Kittatinny Ridge in the USA, which is a corridor for raptor's autumn migration (Luzenski *et al.* 2016). Raptors increased their flight altitudes compared to the heights computed before the construction, in order to avoid the line (Luzenski *et al.* 2016). In our study area collisions should have occurred where the power line crosses deep valleys originating from the highland, whose intricate vegetation did not allow transects to be performed. Nevertheless we could observe several kilometres of wires above one of that valley from our spring watchpoint, but we have never observed collisions, even if days with impeded visibility for the observers are also those with higher risk of collision of birds with utility structures (Avery *et al.* 1976, Longcore *et al.* 2013). For all these reasons we should have missed some events of collision but this number should still be very low compared to numbers of migrating birds (Tab. 1). This could also suggest migrants avoiding to fly in low visibility condition like the flock of White Stork we observed. Birds should prefer to land and wait for better visibility conditions to reduce risks or perform reverse migration in order to find a path with better visibility condition.

A time-minimising strategy could lead birds to keep on flying (Kokko 1999, Mellone *et al.* 2012, Duerr *et al.* 2015) while a risk-averse strategy could force birds to perform reverse migration or to land, suspending migration and waiting for better conditions (Newton 2007).

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