Bird Study

ISSN: 0006-3657 (Print) 1944-6705 (Online) Journal homepage: https://www.tandfonline.com/loi/tbis20

Migrating raptor counts: the need for sharing objectives and field protocols, and the benefits of using radar

Michele Panuccio, Nicolantonio Agostini, Giuseppe Bogliani & Giacomo Dell’Omo

To cite this article: Michele Panuccio, Nicolantonio Agostini, Giuseppe Bogliani & Giacomo Dell’Omo (2018) Migrating raptor counts: the need for sharing objectives and field protocols, and the benefits of using radar, Bird Study, 65:sup1, S77-S84, DOI: 10.1080/00063657.2018.1506423

To link to this article: https://doi.org/10.1080/00063657.2018.1506423

BIRD STUDY
2018, VOL. 65, NO. S1, S77–S84
https://doi.org/10.1080/00063657.2018.1506423

OPEN ACCESS Check for updates

Migrating raptor counts: the need for sharing objectives and field protocols, and the benefits of using radar

Michele Panuccio [a,b,c], Nicolantonio Agostini[b], Giuseppe Bogliani[a,d] and Giacomo Dell'Omo[b,c]

[a]DSTA (Department of Earth and Environmental Science), University of Pavia, Pavia, Italy; [b]MEDRAPTORS (Mediterranean Raptor Migration Network), Rome, Italy; [c]Ornis italica, Rome, Italy; [d]CISO, Centro Italiano Studi Ornitologici, Palermo, Italy

ABSTRACT

Capsule: Raptor migration attracts the interest for different reasons, but not all raptor counts achieve the goal of repeatability through the use of standardized field protocols, and this does not allow comparisons of data to be made across years and sites.

Aims: We analysed migrating raptor count activities in Italy to verify the interest on this phenomenon by identifying organizers of such counts, and we ascertained the use of a minimum repeatable field protocol (MRFP), and the implications of using it or not. Moreover, we tested the use of radar to support field monitoring.

Methods: We analysed 298 migrating raptor counts carried out between 1984 and 2016 by considering characteristics of raptor counts at migratory bottlenecks (number of years covered, use of MRFP, numbers of raptors counted, etc.). In addition, we analysed two case studies using radar to evaluate the effectiveness of raptor counts.

Results: There is a growing interest in raptor migration, as well as an increasing use of a MRFP, although differences between counts emerged, probably due to the different aims of the promoting organizations. At sites not using MRFP, more raptors were counted than at other sites, probably because of a greater bias in the data collected. Radar is able to clarify the water-crossing behaviour of raptors at coastal sites, and allows the proportion of birds passing undetected by observers to be evaluated. It also provides data on the spatial density of migrants across a sample area.

Conclusions: The use of MRFP is important to harmonize data collection and is necessary to allow comparisons across years and sites. Moreover, the use of radar can be recommended for optimizing raptor monitoring schemes.

ARTICLE HISTORY
Received 22 June 2017
Accepted 15 May 2018

Before the twentieth century, the interest in raptor migration was the prerogative of a very small number of erudite people. However, from the 1930s interest in this phenomenon grew in the eastern United States as part of anti-shooting campaigns. At that time, raptors were considered vermin, and a large number of them were shot along traditional flyways (Bildstein 2006). Interest in counting migrating raptors also emerged in other countries as a stand against raptor slaughter; this was the case with some Mediterranean countries, such as Italy and Malta (Sultana & Gauci 1982, Giordano 1991, Panuccio 2005). Today, long-term projects of raptor counts are considered a valuable tool for detecting population trends at regional and continental scales (Agostini *et al.* 2007, Martin *et al.* 2016), but also to investigate the influence of climate change on the ecology of raptors, especially with respect to migration timing (Filippi-Codaccioni *et al.* 2010, Jaffré *et al.* 2013, Panuccio *et al.* 2016a). This method is considered to be cost-effective, because birds of prey are usually secretive and at low densities when breeding and therefore are difficult to survey at that time, in particular over large spatial scales, while soaring species concentrate along definitive flyways during migration (Bildstein 2006, Farmer *et al.* 2007, 2010). Moreover, ornithologists have used visual counts of raptors to study their behavioural ecology and in particular their flyways, phenology, flocking behaviour, differential migration (i.e. by age or sex), and water-crossing tendencies (Bildstein *et al.* 2007, 2009). Raptor counts at migratory bottlenecks are carried out not only for research but also for education, conservation and recreation, and can involve a wide audience that sometimes reaches impressive numbers, such as at the Hawk Mountain Sanctuary (USA) where

CONTACT Michele Panuccio panucciomichele@gmail.com DSTA (Department of Earth and Environmental Science), University of Pavia, via Adolfo Ferrata 9, Pavia 27100, Italy
Supplemental material for this article can be accessed at http://dx.doi.org/10.1080/00063657.2018.1506423

the number of visitors is comparable to that of important art museums (Brett & Bildstein 2014). This interest and differentiation in motivation has led to a growing number of activities relating to raptor migration worldwide (Kerlinger 1989). However, due to the diversity of reasons for counting raptors, data collected in the field do not always fulfil the minimum standard of repeatability based on the use of fixed watch points and continuous observations across the season and day, as needed for migration counts and monitoring (Bildstein *et al.* 2007). The lack of a standardized method for data collected by volunteers, local institutions and environmental associations represents a limitation when comparing data across years and across different sites, and is a missed opportunity, given all the stakeholders involved. We analysed raptor counts made at Italian sites from 1984 to 2016 in relation to the minimum standard protocol proposed for counts of migrating raptors (Bildstein *et al.* 2007). We also discuss the use of radar equipment as an aid to raptor monitoring. We selected the European Honey Buzzard *Pernis apivorus* as a case study because it is the most common raptor migrant at Palaearctic bottlenecks (Zalles & Bildstein 2000).

Methods

A data set on activities carried out during raptor migration counts in Italy was collated from published papers, communications at conferences, technical reports and books (listed in online Appendix S1), and the Infomigrans bulletin published by the Maritime Alps Natural Park and available at http://en.parcoalpimarittime.it. The database included: site, year, season of activity, number of counted European Honey Buzzards, number of watch points per site, hour of observations, dates and protocol used. A generalized linear model (GLM) was used to investigate factors influencing the duration of the activity across years, using the number of years of observations as dependent variables, and as covariates: the average number of counted European Honey Buzzard per year/season, the season of the passage (spring, autumn), the latitude of the site (decimal degrees), and whether the site was included inside a protected area (categorical). Additionally, we used a binary logistic regression analysis (BLRA) using a binary dependent variable (yes/no) if for each season/site of activity a Minimum Repeatable Field Protocol (MRFP) was used. We defined MRFP as a protocol that included the use of fixed watch points and continuous observations across the season and day (Bildstein *et al.* 2007). As explanatory variables, we used the year of observation, season (spring/autumn), the number of counted individuals and the type of organization promoting the activity (categorical). In this last variable, we included the following categories: environmental associations (i.e. Lega Italiana Protezione Uccelli-BirdLife, World Wildlife Fund), local authorities managing protected areas, birdwatchers' associations and ornithological associations. We distinguish between these last two categories that have a large overlap between each other by considering ornithological associations as those organizations publishing at least one paper on the migration of European Honey Buzzards in Institute for Scientific Information-indexed journals. For both sets of models, we tested if a model selection based on the second-order Akaike Information Criterion corrected for small sample sizes (AICc, Akaike 1973) helped to find more parsimonious models than the full models containing all the variables (Burnham & Anderson 2002). We evaluated the model fitness of the GLM by visual inspection of the model residuals and examination of their distribution. While we tested the ability of the BLRA model to distinguish between 'used MRFP' and 'non-used MRFP' by means of the area under the curve of the receiver operating characteristic (ROC) plot (Pearce & Ferrier 2000, Boyce *et al.* 2002, Fawcett 2006). This area provides a measure of discrimination ability, varying from 0.5 for a model with a 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; 0.50–0.00 = fail.

Radar applications

We show two different applications for radar equipment that can be useful for gathering information on raptor migration at bottlenecks. We used a 12 kW X-band (9.1 GHz) marine surveillance radar with 7.1 foot open array antenna set horizontally and vertically rotating at 38 revolutions per minute (Nilsson *et al.* 2018). We used the radar during autumn 2014 to investigate the spatial displacement of migrating European Honey Buzzards when passing through a highland area several kilometres inland of the Strait of Messina. To verify the homogeneity of raptor distribution across the highland we divided the study area into five sectors of 1.2 km each, and we used a Kruskal–Wallis test to compare numbers of European Honey Buzzards tracked by radar in each slot. At this site, we compared the flight altitude of migrating raptors tracked by radar and detected by the observers with the flight altitude of those passing undetected by observers. Moreover, we used the radar during spring 2013 to detect raptors leaving an island (Ustica) in the Tyrrhenian Sea. In all the reported study cases, radar echoes corresponded to bird species and flock sizes identified by observers, as suggested by previous studies (Kerlinger & Gauthreaux 1985a, 1985b, Dokter *et al.* 2013, Panuccio *et al.* 2016b, Pastorino *et al.* 2017).

Results

The data set included 298 records in which every season in each monitored site is a record (number of monitored sites per season/year). The first activities were carried out in 1984, and there was a steep increase in the number of observation sites starting during the late 1990s (Figure 1). We found 19 spring and 20 autumn sites that were active at least for one single season (Figure 2). For spring sites, there was a mean (± se) of 3173 ± 973 European Honey Buzzards counted per season, while for autumn, the mean was 3497 ± 1309. Observations were performed by protected areas (32.9%), followed by birdwatchers' associations (29.9%), environmental associations (28.9%), and finally by ornithological associations (8.4%). Universities were involved only in a limited number of cases. We found that MRFP was clearly used in 64.9% of the cases. Conversely, in 35.1% of the cases, observers unpredictably changed the used watch points during the same season and/or did not cover a significant (95%) part of the migration period of the target species and/or did not carry out monitoring continuously during the season. Considering the organizations promoting the fieldwork, MRFP was clearly used with the following percentages: 83.7% with protected areas, 100% when promoted by ornithological associations, 54.5% by birdwatchers' associations, and 44.7% by environmental associations.

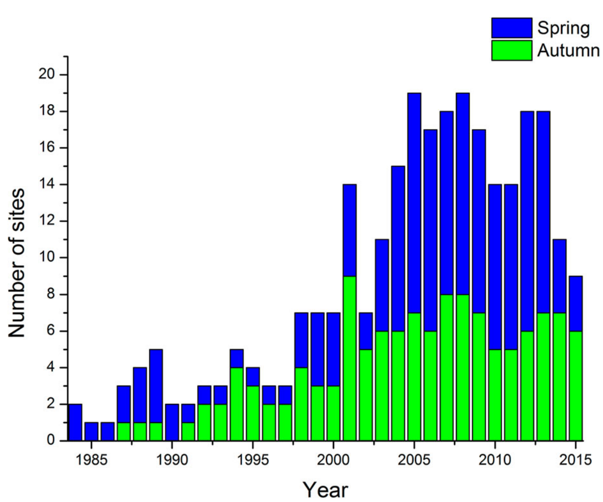

Figure 1. Number of sites per season/year where counts of migrating European Honey Buzzards were made in Italy between 1984 and 2016.

The model selection for both models showed that the full model with all the variables included is the most parsimonious one or the ΔAICc is less than 2 (Tables 1 & 2). Therefore, we show the results of the two full models. The results of the GLM explaining the number of monitoring years per site show that the number of birds counted per year/season was the most important variable determining the continuation of monitoring on that site with a positive estimate value ($F = 9.3$, df = 1, $P < 0.001$, $\beta \pm se = 0.0001 \pm 0.00001$). Moreover, the latitude of the site was marginally important, also in this case with a positive estimate value, sites at higher latitudes had more years of monitoring ($F = 4.0$, df = 1, $P = 0.05$, $\beta \pm se = 0.09 \pm 0.02$), and the other terms were not significant. The residuals of the model were distributed normally, implying a good model fit. The results of the BLRA model indicate that the three significant variables were: the year of the observations (Wald = 23.8, df = 1, $P < 0.001$, $\beta \pm se = 0.1 \pm 0.002$), the number of counted individuals (Wald = 24.3, df = 1, $P < 0.001$, $\beta \pm se = -0.0001 \pm 0.00002$), and the organization type (Wald = 11.4, df = 3, $P < 0.01$). In this last case, the estimate values (± se) of protected areas ($\beta = 1.3 \pm 0.4$), environmental ($\beta = 0.4 \pm 0.5$) and ornithological associations ($\beta = 18.5 \pm 7.6$) were positive in comparison with the birdwatchers's associations that was used as the comparative category in the analysis. The AUC of this model was 0.82, suggesting good accuracy of the model.

Radar

During the autumn migration in 2014, we collected 636 echoes of European Honey Buzzards that were identified by raptor counters, while in the case of 95 radar records (the 13% of the total stored echoes) echoes were not visually identified, but they were likely to be migrating raptors because of their behaviour and size. The mean (± se) flight altitude of European Honey Buzzards was 450.8 ± 8.6 m above ground level, while the mean flight altitude of non-identified echoes was 547.6 ± 15.8 m above ground level. The difference between the two categories was significant (Mann–Witney U-test, $U = 22496$, $P < 0.0001$). The lowest recorded flight altitude was 87 m above ground level. Raptors flying at lower altitudes were missed by radar due to ground clutter (blind areas due to trees, houses, infrastructure). Moreover, it was possible to verify the spatial displacement of raptors migrating across the highland, showing that European Honey Buzzards tended to move mostly in its eastern sector closer to a mountain chain (Figure 3). Numbers of tracked raptors in the five spatial slots was significantly different ($H = 4.6$, df = 4, $P < 0.001$).

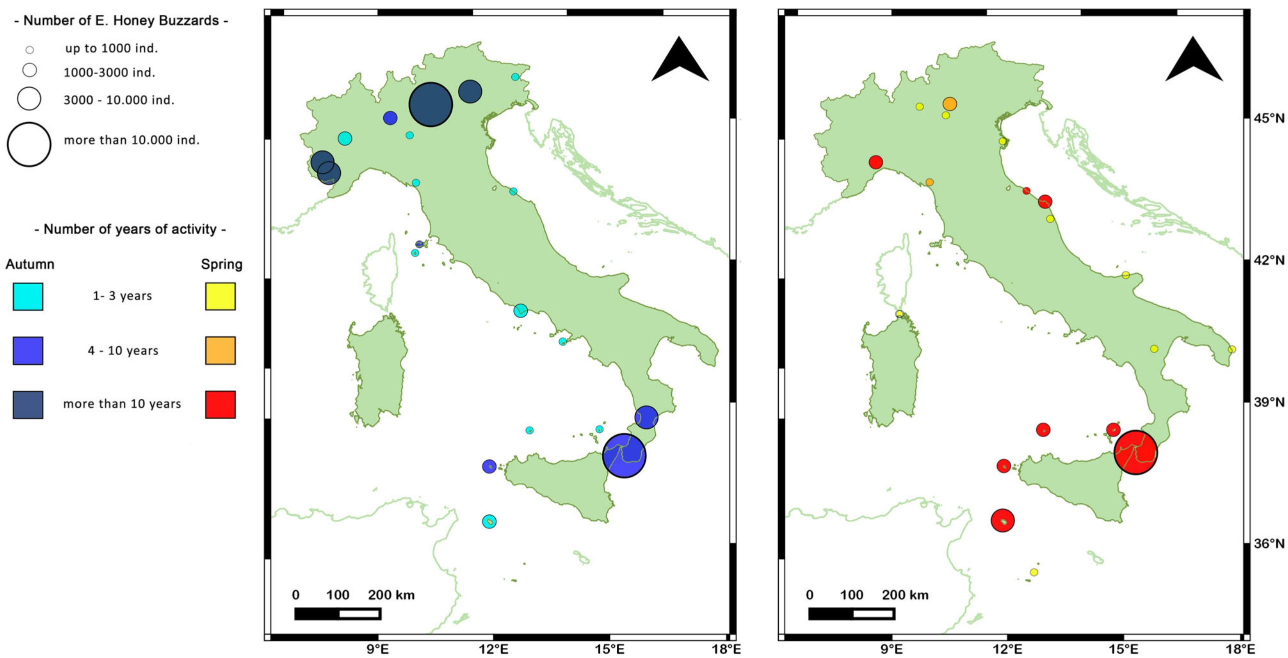

Figure 2. Sites where at least one survey of migrating European Honey Buzzards was made in Italy. Dot size indicates the magnitude of the passage while colours indicate the number of years of activity. Left panel: autumn migration, Right panel: spring migration.

At the island of Ustica, about half (47.6%) of the tracked European Honey Buzzards leaving the island flew back, showing a reverse direction of migration. Here we report a case of a flock of 67 European Honey Buzzards tracked on 6 May 2013. After passing over the watch point, raptors began to cross the Tyrrhenian Sea, and after 2 km past the watch point they flew back changing the direction. At that moment, the flock was out of sight from the observers, because the raptors were flying at a very low altitude over sea (Figure 4).

> 16:50:22 – The flock passed over the radar station situated on the shoreline at about 250 m from the watch point located at the highest point of the Falconiera Promontory.

> 16:51:52 – The flock appeared on the radar screen, and after a phase of soaring flight, started crossing the Tyrrhenian Sea moving toward northeast.

> 16:57:01 – At about 1750 m from the radar station, the flock changed the flight direction moving toward southeast.

> 17:05:07 – The flock split, and five individuals flew back toward the island, while the main part of the flock disappeared from the radar screen toward south-southeast at about 2 km from the island.

Discussion

The increasing interest in raptor migration in Italy is highlighted by the remarkable increase of activities related to this phenomenon, and the same positive trend is occurring almost worldwide (Zalles & Bildstein 2000, Bildstein 2006). As expected, sites with higher numbers of observed migrants are those attracting an enduring interest. Sites located in northern Italy are those that have been monitored for a longer time, probably due to the historical gap between northern and southern Italy in

Table 1. Generalized linear model analysis for the duration of raptor count per site. In bold the full model for which is reported the deviance values in relation to the degrees of freedom.

Model	AIC_c	ΔAIC_c
Average numbers of counted Honey Buzzard	216.82	0
Average numbers of counted Honey Buzzard, Latitude of the watchsite	217.08	0.26
Average numbers of counted Honey Buzzard, Latitude of the watchsite, Season	217.66	0.84
Average numbers of counted Honey Buzzard, Latitude of the watchsite, Season, Protected Area (Null deviance: 233.61 on 37 d.f. Residual deviance: 141.29 on 33 d.f.)	**218.28**	**1.46**

Table 2. Binary Logistic Regression Analysis (BLRA) for the use of MRFP (Minimum Repeatable Field Protocol). In bold the full model for which is reported the deviance values in relation to the degrees of freedom.

Model	AIC_c	ΔAIC_c
Year, number of counted Honey Buzzards, Organization type, Season (Null deviance: 367.2 on 286 d.f., Residual deviance: 259.65 on 280 d.f.)	**273.65**	**0**
Year, number of counted Honey Buzzards, Organization type	275.17	1.52
Year, number of counted Honey Buzzards	305.28	31.63
Year	362.98	89.33

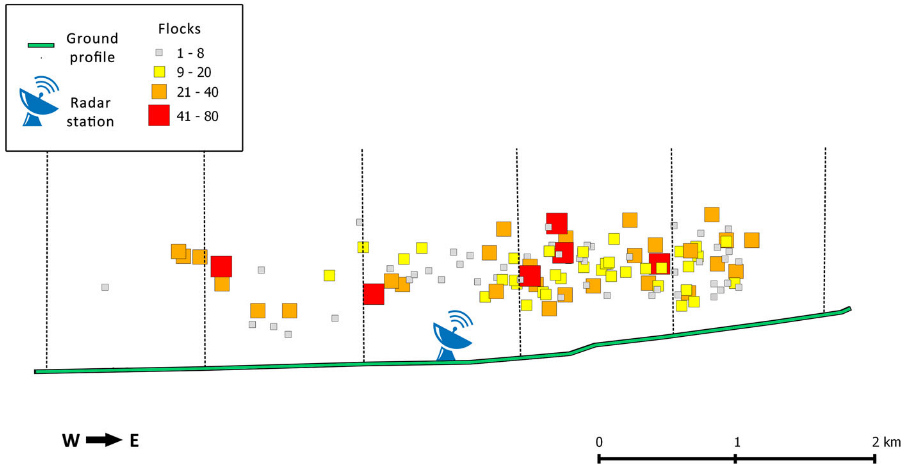

Figure 3. Flocks of European Honey Buzzards tracked by radar during autumn 2014 at an Apennine highland some kilometres inland of the Strait of Messina. The radar beam was oriented perpendicular to the migration direction, covering the whole extension of the highland. Here are indicated the five slots used for comparing densities of migrating raptors.

terms of economic, social and infrastructural background. Protected areas play a role of paramount importance in promoting raptor counts by guaranteeing a use of MRFP in most cases. Differently from protected areas and ornithologist associations, birdwatchers and environmental associations gave less attention to the use of MRFP, probably due to the different aims of their effort, which are more oriented towards anti-poaching activity, such as in the case of the Strait of Messina (Giordano 1991, Agostini *et al.* 1994, Panuccio 2005), or because people involved in such observations enjoy raptor migration without facing the complexity of standardized monitoring programs. This lack of a common protocol among the many involved in raptor counts is a missed opportunity for different reasons. Firstly, in several cases, with a bit more commitment it would be possible to collect data that are comparable across years, rather than giving 'an idea' of raptor passage at the site. Secondly, data stored without the use of MRFP are reported on the web or in bulletins, and this information might not be as reliable as suggested by the results of the BLRA analysis indicating that sites not using MRFP count, in general, more migrants than sites using MRFP. In our experience, this is a result of pooling data from observation posts used simultaneously in a watch site without standardizing the methods. In addition, the lack of MRFP, such as the use of changeable observation posts, prevents the collection of data that could be used for comparing data across the years or to investigate the effects of weather conditions, also making it difficult, if not impossible, to quantify the extent of the monitoring bias. However, as highlighted in this study, the number of sites using MRFP in Italy is increasing over time, underlining that there is a growing understanding about the importance of adopting a more rigorous method. Bird monitoring data are most valuable when the methods are repeatable and used consistently during the field season and across the years (Bibby *et al.* 2000). In the case of raptor counts, it has been proposed that a proper field protocol must (i) be based on the use of fixed watch points, (ii) cover 95% of timing of the target species with daily observations, (iii) be carried out for a fixed number of hours per day (weather permitting, i.e. excluding heavy rainfall) covering at least the whole central part of the day (i.e. 8 hours per day) using binoculars and scopes and scanning the sky searching for migrating raptors. In any case, the sampling scheme should be consistent and easily repeatable across years (Bibby *et al.* 2000, Bildstein *et al.* 2007). The Hawk Migration Association of North America already promotes networking and the use of a common sampling scheme across more than 50 active raptor watch sites that have collected migration count data for at least 10 years (Zalles & Bildstein 2000). The promotion of a similar networking activity, not only at a national scale, but along the Afro-Palaearctic migration system, could strongly improve raptor monitoring activity through shared training, sampling methods and objectives, guidance and standardization of data collection and storing procedures (Bildstein *et al.* 2009).

The use of surveillance radar equipment to monitor raptor movements at bottlenecks was applied for the first time in the 1980s in the southern United States (Kerlinger & Gauthreaux 1985a, 1985b). Those pioneering studies led us to begin using surveillance radar in recent years, thanks to innovations due to the digital era that allow reductions in time and costs of data collection, and also allows more accurate data collection than with analogical equipment. The radar

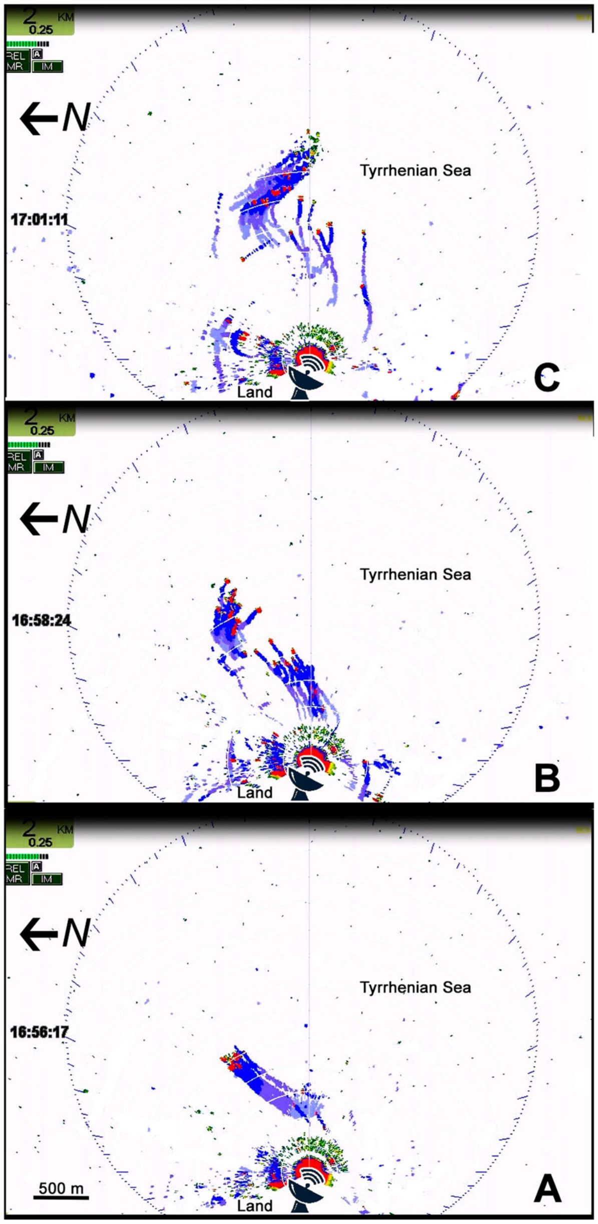

Figure 4. Flock of European Honey Buzzards leaving the island of Ustica (6 May 2013) and showing reversed migration. (A) the flock left the island moving northeast after flying over the watchpoint; (B) the flock changed direction at about 1750 m from the radar station and another smaller flock joined the main one; (C) the main part of the flock disappeared from the radar screen heading south-southeast at about 2 km from the island.

outputs that we show here highlight the usefulness of radar to evaluate the following issues:

(1) the proportion of raptors passing undetected from the observers because of their flight altitude (see also Schmidt *et al.* 2017);
(2) the spatial displacement of migrating raptors in a study area and
(3) the behaviour of migrating raptors when facing an ecological barrier or adverse weather conditions.

Our results suggest that radar is useful when starting a monitoring programme. Only a limited number of watch sites were designed for a long-term monitoring program for migrating raptors based on preliminary research (De La Cruz *et al.* 2011). As shown from the first radar application, radar can evaluate the proportion of raptors that migrate out of sight from the observers. In our study case, the number of raptors that passed undetected was only the 13% of the total number of European Honey Buzzards. However, this proportion can be much higher depending on variables influencing the flight altitude of migrating raptors. Topography, temperature and season can determine which air layer raptors use to fly, as well as the ability of each species in the use of updraughts (Kerlinger 1989, Bruderer *et al.* 1994, Spaar & Bruderer 1996, Spaar *et al.* 2000, Dinevich & Leshem 2008, Panuccio *et al.* 2013). The second radar application shows how, in sites without landmarks, such as across flat areas, radar may identify points of higher densities of migrating birds allowing the localization of useful watchpoints, if any. At several coastal sites, raptor counts are very uncertain due to their flying behaviour (Bildstein *et al.* 2007); therefore, it is usually not possible to determine by eye if raptors really undertake a water-crossing, as shown by our case study at the island of Ustica (Figure 4). Counting migrating raptors at coastal watch sites is likely to produce biased data, and also in this case, the extension of this bias can be very large depending upon different elements, such as the length of the crossing, the time of day, the age of birds, and the morphology of the target species (Kerlinger 1989, Agostini 2005, Agostini & Panuccio 2003, Panuccio & Agostini 2010, Panuccio *et al.* 2011). In this last study case, the use of radar can determine the behaviour of migrants and the proportion of individuals that do not undertake the sea crossing, as well as identify the variables influencing the water-crossing behaviour.

In conclusion, we suggest that promoting networking activity and the use of a common MRFP across Afro-Palaearctic watch sites will strongly improve the efficiency of raptor migration monitoring along with integrating field observations with the use of new technologies (Bildstein *et al.* 2008, 2009, Inzunza 2009).

Acknowledgements

We thank Al Vrezec for his effort, as well as all the EURAPMON staff. We thank also Luca Giraudo for helping us in the references search and Kelsey Horvath for language editing. We are grateful to Keith Bildstein for his suggestions across the years and Terna Avian Team for support in 2014. We thank Carlo Catoni, Viviana Stanzione, and Mauro Santini who participated as fieldworkers at the Aspromonte Mountain and at the island of Ustica, respectively. Finally, we would like to thank all the people who collaborated for raptor research and conservation in the Mediterranean area.

Funding

M.P. was partially financed through a grant from Crowdfunding Platform 'Universitiamo' of the University of Pavia for the project 'Wings Over the Straits' and by Ornis italica.

ORCID

Michele Panuccio http://orcid.org/0000-0003-0315-8930

References

Agostini, N. 2005. Are earlier estimates of Accipitriformes crossing the Channel of Sicily (Central Mediterranean) during spring migration accurate? *J. Raptor Res.* **39**: 184–186.

Agostini, N. & Panuccio, M. 2003. Analysis of the spring migration of Honey Buzzards *Pernis apivorus* and Marsh Harriers *Circus aeruginosus* at two sites of Central Italy. *Avocetta* **27**: 203–205.

Agostini, N., Malara, G., Neri, F. & Mollicone, D. 1994. Spring migration of European Honey Buzzard, *Pernis apivorus*, at the Strait of Messina: conservation issues. *Riv. ital. Orn.* **63**: 187–192 (in Italian).

Agostini, N., Panuccio, M., Mellone, U., Lucia, G., Wilson, S. & Ashton-Booth, J. 2007. Do migration counts reflect population trends? A case study of the Honey Buzzard, *Pernis apivorus*. *Ardeola* **54**: 339–344.

Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. In Petrov, B.N. & Csaki, F. (eds) *Second International Symposium on Information*, 267–281. Akademiai Kiado, Budapest.

Bibby, C., Burgess, N., Hill, D. & Mustoe, S. 2000. *Bird Census Techniques*, 2nd edn. Academic Press, London.

Bildstein, K.L. 2006. *Migrating raptors of the world: their ecology and conservation*. Cornell University Press, Ithaca, NY.

Bildstein, K.L., Smith, J.P. & Yosef, R. 2007. Migration counts and monitoring. In Bird, D.M. & Bildstein, K.L. (eds) *Raptor Research and Management Techniques*, 101–116. Raptor Research Foundation, Blaine, WA.

Bildstein, K.L., Smith, J.P. & Ruelas Inzunza, E. 2008. The future of raptor migration monitoring. In Bildstein, K.L., Smith, J.P., Ruelas Inzunza, E. & Veit, R.R. (eds) *State of North America's Birds of Prey*. Series in Ornithology 3: 435–446. Nuttall Ornithological Club and American Ornithologist's Union, Cambridge, MA and Washington, DC.

Bildstein, K.L., Farmer, C.J. & Yosef, R. 2009. Raptor population monitoring: examples from migration watchsites in North America. In Fornasari, L. & Tellini Florenzano, G. (eds) *Bird Numbers 2007 – monitoring for conservation and management*. Proceedings of the 17th International EBCC Conference, Chiavenna, 17–22 April 2007. *Avocetta* 33: 43–51.

Boyce, M.S., Vernier, P.R., Nielsen, S.E. & Schmiegelow, F.K.A. 2002. Evaluating resource selection functions. *Ecol. Modell.* **157**: 281–300.

Brett, J.J. & Bildstein, K.L. 2014. *Hawk Mountain: a conservation success story*. Hawk Mountain Sanctuary, Kempton, PA.

Bruderer, B., Blitzblau, S. & Peter, D. 1994. Migration and flight behaviour of Honey Buzzards *Pernis apivorus* in southern Israel observed by radar. *Ardea* **82**: 111–122.

Burnham, K.P. & Anderson, D.R. 2002. *Model selection and multimodel inference: a practical information theoretic approach*, 2nd edn. Springer-Verlag, New York.

De La Cruz, A., Arroyo, G.M., Onrubia, A., Barrios, L. & Muñoz, A.R. 2011. Spring migration of soaring birds at the Strait of Gibraltar. Design of a long-term monitoring program. *Migres* **2**: 79–88 (in Spanish).

Dinevich, L. & Leshem, Y. 2008. Some characteristics of daytime bird migration in Israel: radar monitoring data. *Ring* **30**: 3–17.

Dokter, A.M., Baptist, M.J., Ens, B.J., Krijgsveld, K.L. & van Loon, E. 2013. Bird radar validation in the field by time-referencing line-transect surveys. *PloS One* **8**: e74129.

Farmer, C.J., Hussell, D.J.T. & Mizrahi, D. 2007. Detecting population trends in migratory birds of prey. *Auk* **124**: 1047–1062.

Farmer, C.J., Safi, K., Barber, D.R., Newton, I., Martell, M. & Bildstein K.L. 2010. Efficacy of migration counts for monitoring continental populations of raptors: an example using the Osprey (*Pandion haliaetus*). *Auk* **127**: 863–870.

Fawcett, T. 2006. An introduction to ROC analysis. *Pattern Recognit. Lett.* **27**: 861–874.

Filippi-Codaccioni, O., Moussus, J.P., Urcun, J.P. & Jiguet, F. 2010. Advanced departure dates in long-distance migratory raptors. *J. Ornithol.* **151**: 687–694.

Giordano, A. 1991. The migration of birds of prey and storks in the Strait of Messina. *Birds of Prey Bull.* **4**: 239–250.

Inzunza, E.R. 2009. Monitoring with a conservation goal: principles and practice of raptor migration monitoring. In Rich, T.D., Arizmendi, C., Demarest, D. & Thompson, C. (eds) *Tundra to Tropics: connecting birds, habitats and people*. Proceedings of the 4th International Partners in Flight Conference, 13–16 February 2008, McAllen, Texas. University of Texas-Pan American Press, Edinburg, TX.

Jaffré, M., Beaugrand, G., Goberville, É., Jiguet, F., Kjellén, N., Troost, G., Dubois, P., Leprêtre, A. & Luczak, C. 2013. Long-term phenological shifts in raptor migration and climate. *PLoS ONE* **8**: e79112.

Kerlinger, P. 1989. *Flight strategies of migrating hawks*. University of Chicago Press, Chicago, IL.

Kerlinger, P. & Gauthreaux, S. 1985a. Seasonal timing, geographic distribution, and flight behaviour of broad-winged hawks during spring migration in South Texas: a radar and direct visual study. *Auk* **102**: 735–743.

Kerlinger, P. & Gauthreaux, S. 1985b Flight behaviour of raptors during spring migration in South Texas studied with radar and visual observations. *J. Field Ornithol.* **56**: 394–402.

Martin, B., Onrubia, A., de la Cruz, A. & Ferrer, M. 2016. Trends of autumn counts at Iberian migration bottlenecks as a tool for monitoring continental populations of soaring birds in Europe. *Biodivers.Conserv.* **25**: 295–309.

Nilsson, C., Dokter, A.M., Schmid, B., Scacco, M., Verlinden, L., Bäckman, J., Haase, G., Dell'Omo, G., Chapman, J.W., Leijnse, H. & Liechti F. 2018. Field validation of radar systems for monitoring bird migration. *J. Appl. Ecol.* doi:10.1111/1365-2664.13174

Panuccio, M. 2005. Protection of migratory raptors in the Mediterranean. *Sustain. Medit.* **35**: 13–14.

Panuccio, M. & Agostini, N. 2010. Comparison of the water-crossing behavior of Western Marsh Harriers (*Circus aeruginosus*) and European Honey Buzzards (*Pernis apivorus*) during autumn migration. *Chin. Birds* **1**: 30–35.

Panuccio, M., Agostini, N., Baghino, L. & Bogliani, G. 2013.Visible migration of Short-toed Snake-Eagles: interplay of weather and topographical features. *J. Raptor Res.* **47**: 60–68.

Panuccio, M., Gustin, M. & Bogliani, G. 2011. A comparison of two methods for monitoring migrating broad-winged Raptors approaching a long water crossing. *Avocetta* **35**: 13–17.

Panuccio, M., Martin, B., Morganti, M., Onrubia, A. & Ferrer, M. 2016a. Long-term changes in autumn migration dates at the Strait of Gibraltar reflect population trends of soaring birds. *Ibis* **159**: 55–65.

Panuccio, M., Stanzione, V., Catoni, C., Santini, M. & Dell'Omo, G. 2016b. Radar tracking reveals influence of crosswinds and topography on migratory behavior of European honey buzzards. *J. Ethol.* **34**: 73–77.

Pastorino, A., Ramirez, J.R., Agostini, N., Dell'Omo, G. & Panuccio, M. 2017. Fog and rain lead migrating White storks *Ciconia ciconia* to perform reverse migration and to land. *Avocetta* **41**: 5–12.

Pearce, J. & Ferrier, S. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. *Ecol. Modell.* **133**: 225–245.

Schmidt, M., Aschwanden, J., Liechti, F., Wichmann, G. & Nemeth, E. 2017. Comparison of visual bird migration counts with radar estimates. *Ibis* **159**: 491–497.

Spaar, R. & Bruderer, B. 1996. Soaring migration of Steppe Eagles *Aquila nipalensis* in southern Israel: flight behaviour under various wind and thermal conditions. *J. Avian Biol.* **27**:289–301.

Spaar, R., Liechti, F. & Bruderer, B. 2000. Forecasting flight altitudes and soaring performance of migrating raptors by the altitudinal profile of atmospheric conditions. *Proceedings of XXVI OSTIV Congress in Technical Soaring XXIV* **2**: 49–55.

Sultana, J. & Gauci, C. 1982. *A New Guide to the Birds of Malta*. Ornithological Society, Valletta.

Swets, K.A. 1988. Measuring the accuracy of diagnostic systems. *Science* **240**: 1285–1293.

Zalles, J. & Bildstein, K.L. 2000. *Raptor watch: a global directory of raptor migration sites*. BirdLife International Conservation Series No. 9. BirdLife International, Cambridge.