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Bats in a Mediterranean Mountainous Landscape: Does Wind Farm Repowering Induce Changes at Assemblage and Species Level?

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Abstract We reported data on flying bat assemblages in a Mediterranean mountain landscape of central Italy on a 5-year time span (2005–2010) where a wind farm repowering has been carried out (from 2009, 17 three-blade turbines substituted an a priori set of one-blade turbines). In 4 yearly based surveys, we calculated a set of univariate metrics at species and assemblage level and also performing a diversity/dominance analysis (*k*-dominance plots) to evaluate temporal changes. Nine species of bats were present (eight classified at species level, one at genus level). Number of detected taxa, Margalef richness, and Shannon–Wiener diversity apparently decreased between 2005–2007 (one-blade turbine period) and 2009–2010 (three-blade turbines period). We showed a weak temporal turnover only between 2007 and 2009. In *k*-dominance plots, the occurrence curves of the years before the new wind farming activity (2005 and 2007) were lower when compared to the curves related to the 2009 and 2010 years, suggesting an apparent stress at assemblage level in the second period (2009 and 2010). *Myotis emarginatus* and *Pipistrellus pipistrellus* significantly changed their relative frequency during the three-blade wind farming activity, supporting the hypothesis that some bats may be sensitive to repowering. Further research is necessary to confirm a possible sensitivity also for locally rare bats (*Miniopterus schreibersii* and *Plecotus* sp.).

Keywords Bat assemblage · *k*-Dominance plots · Diversity · Margalef index · Time species turnover · Wind farm · Central Italy

Introduction

Wind turbines and the associated power lines often present considerable threats to wildlife (Crawford and Baker 1981; Arnett et al. 2005, 2009; Barclay et al. 2007; Baerwald et al. 2008). Bats (Mammalia, Chiroptera) can be differently impacted by wind farm utilities, both directly (for direct collision or barotrauma; Korner-Nievergelta et al. 2011; Rollins et al. 2012; Rodrigues et al. 2008) or indirectly (for habitat change and disturbances linked to wind farms; e.g., Dürr and Bach 2004; Rydell et al. 2010; Cryan and Barclay 2009). The negative impact of wind farms to resident bat communities may depend on ecological, biological, and sensitive traits of species, as well as location, type, and activity regime of the turbines (Horn et al. 2004; Arnett et al. 2008; Barclay et al. 2007; Rodrigues et al. 2008; Kunz et al. 2007).

To assess the level of impact, researchers searched for bat carcasses under the turbines (e.g., Korner-Nievergelta et al. 2011) or carried out a sampling to assess the bat assemblages before and after the construction or repowering of wind turbines. The latter type of study highlighted the joint consequences of both collision mortality and habitat changes and disturbances leading to decreased use of the wind farm area by some species (Rodrigues et al. 2008). Although the knowledge on the impact of wind facilities on bat populations and assemblages have increased in the last decade, researches are actually skewed towards North American and North European temperate contexts (e.g., Johnson et al. 2003; Barclay et al. 2007;

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Arnett et al. 2008, Kunz et al. 2007; Korner-Nievergelta et al. 2011), while researches in Mediterranean landscape and on long-term study of bat assemblages are still scarce (e.g., Roscioni et al. 2013) (e.g., Kingston et al. 2003; Winhold et al. 2008). Finally, although the effects of change in activity regimes of bats have been tested (Barclay et al. 2007; Arnett et al. 2011), studies on the effects related to wind farm facility repowering are still scanty.

Bats are highly mobile individuals which tend to congregate in partly unpredictable roosts out of the breeding season, and exhibit strong interspecific variation in activity patterns, flight, and foraging behaviors (Stebbing and Griffith 1986; Thomas and West 1989; Rodrigues et al. 2008), making their monitoring difficult. Moreover, a high variety of turbine models are available for use at wind farms, and little information is available that compares multiple turbine types at the same site.

In this work, we report a between-year structure of bat assemblages occurring in a wind farm located in the Apennine mountains of central Italy, an area that is undergoing considerable wind farm development where a set of older one-blade turbines (here located in 2005) was removed in 2009 (Ferri et al. 2011). As part of a long-term post-construction monitoring effort, we conducted field surveys with bat detection techniques (Weller and Baldwin 2012). We used the *k*-dominance plots to compare cumulative frequencies obtained from occurrences of flying bat individuals to evaluate the level of disturbance in the bat assemblages before and after the erection of new type of turbines (i.e., with three-blades). In particular, we hypothesized that the repowering of wind turbines (i.e., from one-blade to three-blades) may have changed the bat assemblage structure in terms of frequency of occurrences and other univariate metrics. The implications of wind farm repowering will be discussed in the final sections.

Methods

Study Area

The study area is located near the Fucino Valley and the Sirente-Velino Natural Regional Park, along the southern slopes of the Sirente Massif, with an altitudinal range of 900–1200 m above sea level (a.s.l.) and on a surface of about 35 km^2 (Municipalities of Cerchio, Collarmele, Pescina; Province of L'Aquila; central Italy; WGS 84, F33 coordinates: top left—X 381.985, Y 4.663.406; bottom right—X 397.520, Y 4.653.612).

As initially constructed (1992–2005) the facility contained 44 one-bladed turbines (Riva Calzoni 1992, rated power output of 250 and 350 kW; Cerchio–Collarmele–Pescina wind farm or CCP). In 2007, the older turbines were removed and repowered with 17 three-bladed turbines (Vestas V80 rated for 2.0 MW; ENECO Power Station). Two meteorological towers were also present from 2007 and 2009 with one having a height of 30 m and the other at a height of 50 m. Rotor diameter of each three-blade turbine is 80 m and spans over an area of 5072 m^2 with a tubular steel tower 78 m high. Each turbine reaches a maximum height, at the tip of the blades, of 117 m from ground level.

The Vestas turbines in CCP wind farm were located at altitudes between 970 and 1160 m a.s.l. in a heterogeneous mosaic characterized by hemicryptophytic pastures (*Brachypodium rupestre* dominant) with nitrophilous phyto-coenoses and sparse brushes (for cattle presence) (Pirone and Tammaro 1997; see also Guarrera and Tammaro 1996). For their uniformity at landscape scale, we considered this study area as a unique sampling area. Nearby (>15 km far away) another wind farm ("Cocullo") is present (from 2005: 38 wind turbines with rated output of 850 kW, managed by Gamesa and the Municipality of Cocullo). After 2005, about 10 km of new service roads have been built.

Climate is cold temperate. We did not observe significant changes between mean temperatures and rainy regimes in the studied periods (ENECO Meteorological Station, Collarmele; www.meteo.it: Valle del Fucino—Avezzano).

Field Methods and Data Analysis

Interspecific differences in flight morphology and echolocation behavior lead to differences in foraging behaviors and habitats, which in turn affect our ability to detect them with ultrasonic bat detectors (Kunz and Kurta 1988; Barclay 1991). Consequently, we used multiple techniques to arrive at our estimates at level of whole community structure (Thomas and LaVal 1988; Kunz and Fenton 2003; Rodrigues et al. 2008; Therkildsen et al. 2012).

We carried out a comparative research effort (23 surveys in 2005, 27 in 2007, 29 in 2009, 28 in 2010) using ultrasonic detectors on multiple nights, which produced an index of relative flight activity for the different species (Britzke et al. 2013). Individuals were recorded in the wind farm area with bat detectors used with a comparable effort in each year: (i): by frequence division mode sampling with 1 AnaBat II (Titley Scientific), (ii) by time expansion mode sampling with 2 D240X Petesson, and (iii) by direct ultrasound sampling with 2 D1000X Pettersson (Pettersson Elektronik AB, Uppsala, Sweden) and recorders (2 Edirol R09 and 1 ZCAIM unit Titley).

Bat activity was monitored at wind farm areas using automatic bat monitoring units (ABMs; O'Donnell and Sedgeley 1994) placed within and around turbines in a comparable number in the different habitat types of the landscape mosaic (scrublands, pastures, roads) to obtain representative data at landscape mosaic level, here considered as a single heterogeneous sample unit. Ten monitoring sites were selected in each habitat type for each year. Sites in each habitat type were at least 50 m apart, and sites in different habitat types were at least 100 m apart. Each site was monitored for one night each month, with the order of monitoring being randomly selected. ABMs were placed on the ground or deployed approximately 30 m above ground level on a meteorological tower, facing upwards at an angle of approximately 45° to increase the likelihood of detecting bats. Calls and bat passes were recorded from approximately sunset to sunrise (08.00 p.m.–05.00 a.m.), so covering approximately the entire night. ABMs detect echolocation calls produced by bats as they pass within a distance of approximately 50 m of the unit, and calls are automatically recorded; activity is then quantified as the number of echolocation calls (or passes) recorded per hour. A pass is defined as a series of two or more calls separated from other calls by a period of silence lasting at least one second (Thomas and LaVal 1988; Tupinier 1997). As bats approach a potential prey item, the rate at which they call begins to increase, culminating in the production of a rapid series of calls immediately prior to attempted capture ("feeding buzz"; Griffin 1958). The number of buzzes detected by the ABMs was used as an index of attempted feeding activity.

A walk-through survey (O'Donnell and Langton 2003) was also conducted using the line-transect method and handheld 1 bat detector D1000X Pettersson: around 5 transects of 1000 m per night within the first 2 h after sunset, in the wind farm and control areas. Each transect takes about 20 min to walk (walking speed = about 3 km/h). The start and end points of each transect have been defined using a GPS Garmin E-trex. Sampling was repeated in different seasons (spring, summer, autumn; each year from May to September), and the total number of bat passes per sampling unit were recorded. Fifty transects were conducted yearly.

Data Analyses

Analysis for bat species recognition was carried out using ANALOOK software, for AnaBat files, that displays ultrasonic activity in a format similar to a sonogram (e.g., frequency versus time), and FFT analysis using BatSound PRO 4.03 (Pettersson Elektronik AB, Uppsala, Sweden) for bat passes registered with Pettersson units. Echolocation calls were identified by applying the classification functions described by Russo and Jones (2002) and comparison with reference recordings (Barataud 1996, 2012); social calls were identified according to Russo and Jones (1999, 2000) and Russo and Papadatou (2014). As methods for diagnosis identification, we referred to Ahlén and Baagøe (1999), Ahlèn (2003), and Lanza (2012).

To assess the flying bat assemblage structure, we calculated for each year and on the whole of records: (i) the total number of taxa recorded (at species or genus level, when taxonomical diagnosis at species level were not possible), as a measure of not normalized taxa richness (S); (ii) the Margalef index (Dm), as simple taxa richness index that attempts to compensate for sampling effects by dividing S by N, i.e., the total number of records in the sample (i.e., $\mathrm{Dm} = [S - 1]/\ln N$, Clifford and Stephenson 1975); (iii) the Shannon–Wiener diversity index as $H' = -\Sigma \mathrm{fr}_N \ln \mathrm{fr}_N$, were fr_N are the flying occurrence frequencies.

Comparing the species assemblages between years, we obtained a temporal turnover index (Brown and Kodric-Brown 1977) calculated as: $t = b + c/S_1 + S_2$, where b is the number of taxa present only in the first year, c is the number of species present only in second year, S_1 is the total number of taxa in the first year, and S_2 is the total number of taxa in the second year.

Analyzing species assemblages, large datasets on occurrence and abundance can be analyzed using different approaches (e.g., Lambshead et al. 1983; Warwick 1986; Wiens 1989; Krebs 1999, 2001; Magurran 2004; Santoro et al. 2012). All these approaches may be useful to detect differences among assemblages (e.g., in diversity and evenness), expliciting the frequency ratio (or dominance) among species. More particularly, k-dominance plots provide general information on the natural or anthropogenic stress that might affect the assemblages (Magurran 2004). To develop the k-dominance plot, we used the fr_N values: for each species in the bat assemblage, we additionally obtained two values related to number of passage rates (flying occurrences: N) and for their relative and cumulative frequency (i.e., relative proportion; fr_N). In this representation, we made explicit the progressively cumulated fr_N values (y-axis) in relation to log species rank (x-axis). Under this approach, more elevated curves represent less different assemblages (Lambshead et al. 1983; Magurran 2004).

To compare the relative frequencies among years, we performed a χ^2 test. To check data reliability (standardization, independence, replication, detectability), we followed Battisti et al. (2014). We performed all statistical analyses, two-tailed and with alpha set at 5 %, using SPSS version 13.0 (SPSS Inc. 2003).

Results

We sampled 1779 flying bat occurrences. Among 1483 occurrences that are identified at species level, we obtained evidences for nine taxa of bats (eight at species level, one at genus level). *Pipistrellus kuhlii, Hypsugo savii*, and *Pipistrellus pipistrellus* were the dominant species in all years ($\mathrm{fr}_N > 0.05$; Table 1). Considering the whole study period (2005–2010), we observed significant changes in relative frequency of flying occurrences for *Plecotus* sp. and *Miniopterus schreibersii* ($P < 0.01$; both of them detected only in 2005 and 2007), *Myotis emarginatus,* and *P. pipistrellus* ($P < 0.05$).

Absolute number of detected taxa changed from 9 (2005 and 2007) to 7 (2009 and 2010). We observed a weak decrease of normalized Margalef richness index between the 2005–2007 and 2009–2010 periods , and Shannon–Wiener diversity indices were also decreased. Temporal turnover indices showed a value of 0 between 2005 and 2007 and between 2009 and 2010 and a higher value (0.125) between 2007 and 2009 (Table 2).

In *k*-dominance plots, the curves of the years before the wind farming repowering (2005 and 2007) are lower when compared to the curves related to the 2009 and 2010 years (Fig. 1), for both flying occurrence and biomass.

Discussion

Bat fatalities and their impact may imply a consequential effect both at assemblage- and species level with effects on species occurrence, abundance, relative frequency, richness, and diversity (e.g., Erickson et al. 2002; Johnson et al. 2003). The best known effect of wind farms on bats is the mortality caused by collision with blades (direct impact; Osborn et al. 1996). Nevertheless, there are other indirect effects of wind farm facilities induced by habitat changes and disturbances related to these infrastructures that are much less studied. Here, we have obtained explorative data on an apparent indirect impact of wind farm repowering in a Mediterranean mountainous landscape along a 5-year time span.

At assemblage level, *k*-dominance plot shows a shift in cumulative lines after the start of three-blade wind farming activity (2007), suggesting an apparent stress induced by this repowering. Moreover, all the structural parameters of bat assemblages (number of detected taxa, Margalef, and Shannon–Wiener indices) decreased following the erection of the new three-blade wind turbines. A temporal species turnover (>0) occurred only between 2007 and 2009 in coincidence with the repowering of the wind turbines. Therefore, although not conclusive, our data may support our hypothesis that the repowered farming activity (i.e., from turbines with one blade and turbines with three blades) may have a role in changing the flying bat assemblage structure. This change may be due to a higher rate of direct collision of bat individuals against three-blade wind turbines (when compared to one-blade turbines) and/

Table 2 Structure of flying bat assemblages in the study area

Assemblage metrics	2005	2007	2009	2010
N	381	367	370	365
S	9	9	7	7
Dm	1.35	1.35	1.01	1.02
H'	1.61	1.7	1.42	1.43

N passage rates, *S* number of taxa detected, *Dm* Margalef's diversity index, H' Shannon–Wiener diversity index

Table 1 Bat flying assemblage in Collarmele study area before (2005 and 2007) and during (2009 and 2010) the start of wind farming repowering with three-blade turbines

	Before 3-blade wind farming activity				During the 3-blade wind farming activity						
	2005		2007		2009		2010			χ^2	*P*
	n	frN	*n*	frN	*n*	frN	*n*	frN	Ntot		
Rhinolophus hipposideros	5	0.013	8	0.022	3	0.008	2	0.005	18	1.294	0.999
Myotis emarginatus	12	0.031	23	0.063	9	0.024	11	0.03	55	8.454	0.048*
Myotis myotis	22	0.058	14	0.038	21	0.057	15	0.041	72	2.302	0.699
Pipistrellus kuhlii	148	0.388	134	0.365	98	0.265	147	0.403	527	9.303	0.033
Pipistrellus pipistrellus	79	0.207	67	0.183	111	0.3	93	0.255	350	10.228	0.021*
Hypsugo savii	88	0.231	91	0.248	124	0.335	86	0.236	389	7.795	0.065
Plecotus sp.	3	0.008	7	0.019	0	0	0	0	10	13.148	0.005**
Miniopterus schreibersii	6	0.016	11	0.03	0	0	0	0	17	19.676	0.000**
Tadarida teniotis	18	0.047	12	0.033	4	0.011	11	0.03	45	8.092	0.057
Total	381	1	367	1	370	1	365	1	1483		

frN relative frequency on total flying occurrences, *n* number of bat passes (before and during the wind farming activity), *Ntot* total number of bat passes, χ^2 test values and probability values are reported (* $P < 0.05$; ** $P < 0.01$)

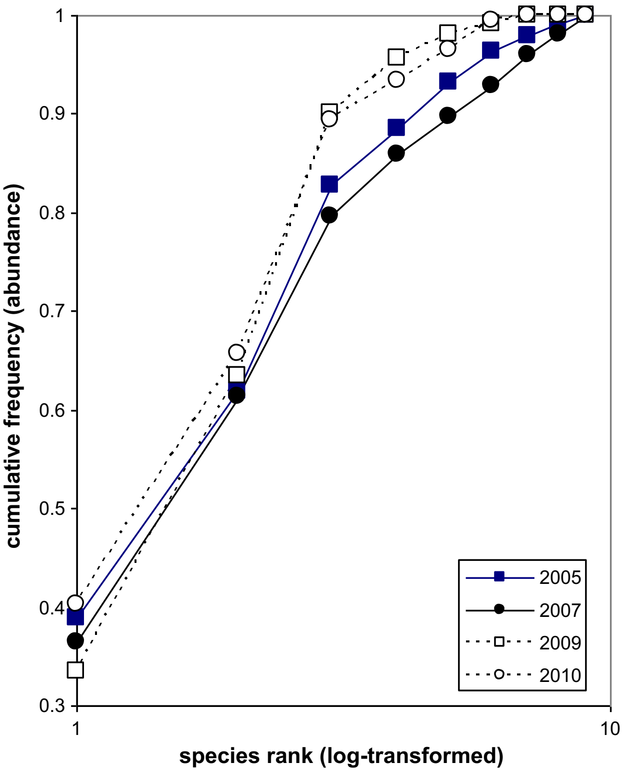

Fig. 1 *k*-Dominance plots (log-transformed species rank vs. cumulative frequency calculated on occurrences) for the flying bat assemblages. *Continuous lines* before the start of three-blade wind farm activity (2005, 2007); *dashed lines* during the wind farm activity (2009, 2010)

or an indirect impact of wind farming activity (disturbance by noise, change in habitat suitability for species due to different type of turbines, presence of roads and noise; Dürr and Bach 2004).

At species level, we observed significant changes in relative frequencies of *Miniopterus schreibersii* and *Plecotus* sp. (not detected during the 3-blade wind farming activity), and of *M. emarginatus and P. pipistrellus* (this last one apparently increasing their frequency after the 2007). Because of the low number of records for the first two locally rare species (see Agnelli et al. 2004; Gruppo Italiano Ricerca Chirotteri—GIRC 2004), these results are not conclusive to detect a possible sensitivity for these bats and further research are necessary. Differently, for *M. emarginatus* and *P. pipistrellus,* we suggest they may be sensitive to wind repowering, corroborating previous evidences on the attraction of bats toward larger, taller turbines (Barclay et al. 2007; Cryan and Barclay 2009; Cryan et al. 2014; “high risk species” in Rodrigues et al. 2015). This is an important result and could have potential significance in bat conservation and wind farm management.

However, we highlight some intrinsic and extrinsic point of weaknesses. First, other stochastic or deterministic factors (e.g., natural change in vegetation cover and in regime of inter-annual meteoclimatic events) may also indirectly affect the metric used for our flying bat assemblages (Arnett et al. 2005, 2009; Baerwald et al. 2008, 2009; Cryan and Barclay 2009). However, local vegetation is represented by secondary prairies (mountain scrublands with nitrophilous phyto-coenoses and sparse brushes) having a low dynamism (Mazzoleni et al. 2004): consequently, we may assume that this factor might not have significantly affected bat assemblages during our study period. Moreover, data from local meteorological station did not show significant changes in seasonal regimes of the main parameters during this time span (source: www.meteo.it and ENECO Meteorological station).

Secondly, in this study, we have only captured the indirect information related to two associated phenomena: (i) the change in a wind farming activity, and (ii) the change in relative flying occurrences in different years. Therefore, the cause–effect relationship between these phenomena should be more directly tested in future studies.

Finally, ultrasonic acoustic detectors can be useful in obtaining data on the occurrence of a species in a study area, and this information directly relates only to the different flying activity of individuals and species while may be considered only a weak proxy of their relative abundance. Despite these caveats, to our knowledge, this paper is the first study that compares the indirect effects due to two different types of turbines at assemblage level over a multi-year period in a Mediterranean mountainous context, also using a stress-sensitive bivariate metric of diversity (*k*-dominance plot).

Although preliminary, our data suggest a precautionary approach (see Keith 2009) in areas of concurrent presence of repowered wind farm infrastructures and bat assemblages of high conservation concern.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval This article does not contain any study with human participants or animals performed by any of the authors.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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