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# Bat activity in intensively farmed landscapes with wind turbines and offset measures

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ABSTRACT

Compensation measures are needed to counteract some of the negative impacts of wind energy facilities on bat populations. To advise developers, we studied farming landscapes and compared bat activity at impacted sites (crops with wind turbines), sites without compensation measures (crops) and a set of sites with potential compensation measures: fallows, hedgerows, bushes, grass strips, and grass strips with bushes. Each site type was sampled twice in 2013, once during the reproductive period and once during the migratory period. Each sample consisted of at least eight nights of ultra-sound recordings. Bat species were separated into three groups: *Pipistrellus* sp., *Eptesicus-Nyctalus* sp. and *Plecotus-Myotis* sp. The results demonstrated that the three groups responded differently to the different potential compensation measures and that responses were season-dependent. These results lead to further questions regarding strategies to mitigate the negative impacts of wind farms.

## 1. Introduction

Today, it is well known that the human population demands more and more energy, which increases the emissions of greenhouse gases and reduces the availability of natural habitat. Due to this alarming situation, following the Kyoto conference, a global objective has been to reduce emissions of greenhouse gases (GHG). Among the possible solutions, the production of electricity from renewable energy sources has been identified as a priority (Kuvlesky et al., 2007). Wind turbines are a part of alternative energy production that does not contribute to greenhouse gas emissions (Barclay et al., 2007; Kuvlesky et al., 2007). Worldwide, between 2001 and 2009, wind energy increased 6.5-fold in installed capacity (WWEA, 2010). In Europe, onshore wind is expected to be the largest contributor to achieving 20% renewable electricity by 2020 in Europe (Directive 2009/28/EC). Although the impact of wind turbines on the ground is not great compared to other development projects, the growth of the wind energy industry does not come without concerns. Indeed, bird and bat fatalities induced by wind turbine blade rotation are regularly described in Europe (Rodrigues et al., 2008) and North America (Baerwald and Barclay, 2009; Erickson et al., 2002; Johnson et al., 2003; Kunz et al., 2007a; Kuvlesky et al., 2007). In addition, wind turbines may cause non-lethal impacts, such as disturbance of commuting and migration routes, displacement and local habitat loss (Hötker et al., 2006; Kuvlesky et al., 2007; Roscioni et al., 2014).

Wind farm developers are obligated to provide effective avoidance, reduction, on-site restoration and offset measures (EC, 2007) in order to achieve no net loss of biodiversity or a net environmental benefit. Offsetting, the last step of the avoiding-reducing-offsetting sequence, consists of implementing measures that counteract the residual loss of biodiversity and generate gains through management measures (e.g., restoration or creation of habitats on offset sites, land acquisition and/or the legal protection of areas) (McKenney and Kiesecker, 2010; Maron et al., 2012). This produces the so-called ecological equivalence between biodiversity losses (i.e., residual effects after avoidance and reduction measures) and biodiversity gains through the implementation of offset measures (Quétier and Lavorel, 2011; Regnery et al., 2013a). Mitigation policies explicitly stated that "in-kind compensatory mitigation is preferable to out-of-kind" (US EPA and DA, 1990; McKenney and Kiesecker, 2010); that is, offset frameworks should be spatially and ecologically as close as possible to the impacted area (McKenney and Kiesecker, 2010). This obligation has resulted in legislation that allows for derogation from strict protection to licenses allowing activities with the obligation to mitigate any potential negative effects (see for Stone et al., 2013 for England or

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Regnery et al., 2013a for France). In England, a recent study (Stone et al., 2013) concluded that it was unclear whether the licensing process meets EU obligations concerning bats.

A particularly interesting situation, which is far from trivial, is wind turbines installation in intensive agricultural landscapes, and the associated research on offset measures for biodiversity. Indeed, due to constraints resulting from cultural or natural heritage (e.g., the Landscape Act Coastal Act Areas of Conservation (SACs) and protected areas) and the reluctance of local people to install wind turbines near their homes, project developers often attempt to install wind energy facilities on agricultural land, particularly in arable land dominated by open fields. However, intensive agriculture is recognized as one of the greatest current threats to worldwide biodiversity (Benton et al., 2003; Hole et al., 2005) even without wind turbines. Thus, there is a great need to find measures that have positive impacts on biodiversity in order to improve biodiversity-friendly farming and counteract the negative impacts of wind turbines close to impacted areas. Today, agri-environment schemes (AES) are implemented in Europe when farmers subscribe to environmental commitments related to the preservation of the environment, such as hedgerows, bushes or grass strips (Kleijn and Sutherland, 2003). However, their positive impacts on biodiversity are discussed (Kleijn et al., 2006; Kleijn and Sutherland, 2003; Wittingham, 2011). Implementations of both offset measures and AES in farming landscapes have the common goal of bringing about biodiversity gains and it would be wise to assess the additionality of these two managements.

Therefore, we proposed to evaluate the non-lethal impacts of wind energy facilities on bat populations (i.e., reductions in availability and attractiveness of foraging habitat) and to assess the consequences of setting up vegetation structures which are aimed at ecological mitigation of wind turbines in intensively farmed landscapes. We decided to focus on bat populations for the following reasons. First, European bats are endangered throughout much of their range (Stebbings 1988; UICN, 2011). Numerous threats and causes of this decline have been identified and include the availability of suitable foraging habitat (Walsh and Harris, 1996; Kunz and Fenton, 2003), agricultural intensification, which has resulted in an increase in pesticide use (Dunsmore et al., 1974; Jones et al., 2009; Swanepoel et al., 1999; Wickramasinghe et al., 2003), land use changes (Stebbings, 1988; Battersby, 2010), roost destruction and disturbance (Mitchell-Jones et al., 2007); artificial lighting (Rydell, 2006; Stone et al., 2012), global climate change (Jones et al., 2009) and wind energy fatalities (Kunz et al., 2007b; Racey 2009; Rodrigues et al., 2008). Most bats killed at wind energy facilities across Europe belong to the genera *Pipistrellus* and *Nyctalus* (Amorim et al. 2012; Hötker et al., 2006) and to a lesser extent genus *Eptesicus* and *Vespertilio* have also high fatality rates (Rydell et al., 2010). Despite numerous and recent published studies relating bat fatalities due to wind turbine, quantification of this impact on mortality and population dynamics remain difficult. High rates of bat fatalities are worrying because bats have slow life-histories (Barclay and Harder, 2003). Second, to the best of our knowledge, very few studies have been carried out on the indirect impacts of wind farms (i.e., disturbance, displacement, reduction of availability and attractiveness of foraging habitat) on bat populations (Bach, 2002). This knowledge gap renders our study highly valuable because such impacts should also be included when calculating equivalence. Third, bats are considered to be bio-indicators, and based on the importance of common species for ecosystem functioning, offset measures are necessary to counteract the negative effects on those species as well (Regnery et al., 2013b; Jones et al., 2009). Fourth, few studies have been carried out on bat populations or their prey in intensively farmed landscapes (Boughey et al., 2011; Jennings and Pocock, 2009; Lentini et al., 2012; Merckx et al., 2009; Rainho, 2007; Taylor and Morecroft, 2009). For instance, most studies on the impacts of AES concerned birds, insects and plants (Kleijn et al., 2006; Kleijn and Sutherland, 2003; Wittingham, 2011).

Our analysis focused on a comparison of bat activity at impacted sites (crops with wind turbines), sites without compensation measures (crops) and sites with a set of potentially compensation measures (crops with agricultural fallows and crops with semi-natural elements linked to local farming practices, such as hedgerows, bushes, grass strips, etc.). We did not limit our study to threatened species but considered the whole bat community, focusing on three groups (*Pipistrellus* sp, *Eptesicus-Nyctalus* sp and *Plecotus-Myotis* sp).

## 2. Methods

### 2.1. Study area

Our study was conducted from May to September, 2013 in Champagne-Ardenne in northeast France (Fig. 1); this region is predominantly rural, with agricultural land covering 68% of the territory, urban areas 3% and woods and natural land less than 29%, as calculated from Corine Land Cover data. The agricultural fields are mainly used for intensive cropping, especially for cereals, sugar beet and rapeseed. The region is ranked fourth in France for wheat production (INSEE, 2012), and 32% of its utilized agricultural land is dedicated to cereal production (AGRESTE, 2012). In 2012, the Champagne-Ardenne region was ranked second in France for producing electricity from wind and was able to produce the equivalent of almost 70% of its domestic consumption this way (ENR, 2012).

### 2.2. Bat inventory

Fieldwork was carried out during two visits, corresponding to seasonal peaks in bat activities, as recommended by the French Bat Monitoring Program (FBMP, 2012). The first visit occurred during the period in which females give birth and feed their offspring (late May to early July). In contrast, bats that were a few months old and already hunting and migratory adults were expected to be contacted during the second visit (middle of August to end of September). We sampled bats using standardized echolocation recordings on stationary points, which is a robust method to assess the relationship between bat activities and the corresponding habitat (Stahlschmidt and Brühl, 2012). For more technical details on bat monitoring see Supplementary material A_1.

At each sampled time point, we recorded all sounds higher than 12 kHz throughout the entire night, from 30 min before sunset to 30 min after sunrise. Three ultra-sound detectors with identical settings were used each night. We used Scan‘R (Binary Acoustic Technology, 2010) to isolate each bat vocalization and automate the measurement of relevant parameters (Barataud 2012; Gannon et al., 2004; Obrist et al., 2004; see Supplementary material A_2). Ambiguous call patterns were analyzed call by call by authors using Syrinx software version 2.6 (Burt, 2006). Due to the lack of general consensus for some species about the acoustic criteria and some overlap between acoustic repertoires, it was not possible to assign the exact species with certainty for all calls; thus, we constructed three groups: *Pipistrellus* (*Pipistrellus kuhlii*, *P. nathusii*, *P. pipistrellus* and *P. pygmaeus*), *Eptesicus-Nyctalus* (*Eptesicus serotinus*, *Nyctalus leisleri* and *N. noctula*) and *Plecotus-Myotis* (*Myotis bechsteinii*, *M. daubentonii*, *M. myotis*, *M. nattereri*, M. species, *Plecotus auritus* and *P. austriacus*). For more details on the composition of each group, see Supplementary material A_4.

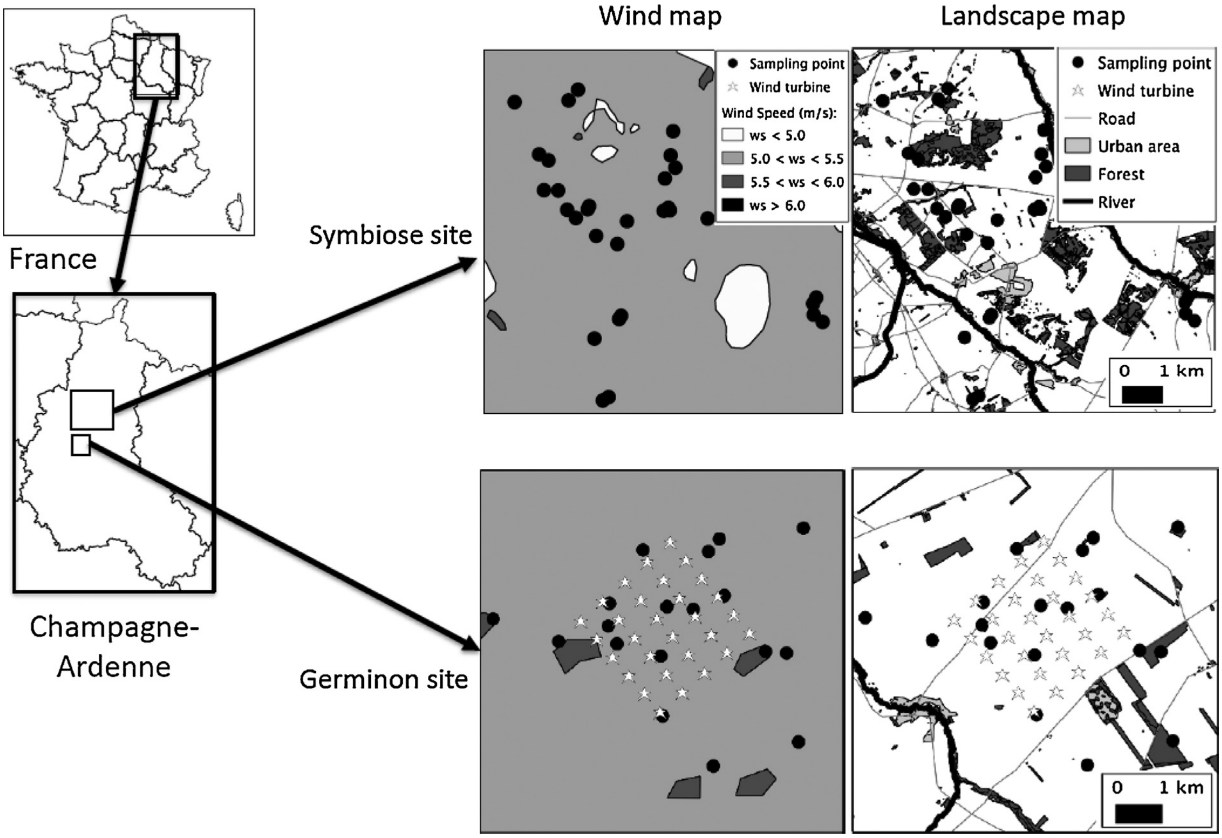

**Fig. 1.** Sampling design map.

Note that some species included in the same group may have different ecology, however, from a foraging behavior perspective, these groups have some convergences. The *Plecotus-Myotis* group primarily included species considered to be gleaners, which capture the majority of their prey from substrates in cluttered environments (Arlettaz et al., 2001). These species eat mainly diurnal *Brachyceran Diptera* and non-volant arthropod such as weevils, lepidopteran larvae, harvestmen and spiders (Swift and Racey, 2002; Dietz et al., 2007). In contrast, the *Pipistrellus* and *Eptesicus-Nyctalus* groups primarily included species considered to be aerial hawkers, which forage mostly on flying prey in open spaces (Dietz et al., 2007; Schnitzler et al., 2003; Holderied and Von Helversen, 2003). These two groups can be distinguished according to their flight height: *Pipistrellus* ssp. forage on average at a lower altitude than *Eptesicus* ssp and *Nyctalus* ssp (Rydell, 2006). These groups also exhibited consistency with respect todetection distance; the *Plecotus-Myotis* group included mainly species detected from 5 to 15 m, the *Pipistrellus* group from 20 to 25 m and the *Eptesicus-Nyctalus* group from 30 to 100 m (Barataud, 2012). Finally, some species having been recorded on too few sites, their statistical analysis would not have been satisfactory and required to be grouped.

As it is impossible to know the exact number of individuals foraging in the areas, we used a bat activity metric instead (bat passes), calculated as the number of contacts per night per group. For each group, a pass was defined as a single bat call or several bat calls emitted during a 5 s interval; if the calls were emitted for longer than 5 s, they were counted as two passes. Because the absolute length of a bat pass mainly depends of the detection distance, some species are recorded for longer time than other (e.g., *Nyctalus* ssp versus *Pleocotus* ssp and *Myotis* ssp). However, data from the FBMP indicate the 5 s interval is quite a good compromise (see Supplementary material A_3).

### *2.3. Sampling design*

To assess the potential disturbance of wind energy facilities, bat activity was compared between impacted sites (crops under wind turbine, CWT, $n = 12$) and non-impacted areas (crops without wind turbine, C, $n = 12$). Second, to evaluate potential offsets of wind turbine settlement in an agricultural landscape, we compared bat activity in areas with alternative agricultural practices such as fallows (Fa, $n = 8$) and in agricultural landscape elements such as a representative set of hedgerows (H, $n = 8$), grass strips (GS, $n = 8$), bushes (B, $n = 8$) and grass strips with bushes (GSB, $n = 8$). All sample sites were located more than 200 m from each other.

#### *2.3.1. Characteristics of sites*

Crops under wind turbine were located in a 7 km$^2$ park containing 30 wind turbines (the “Germinon” site). Wind turbines had a 100 m high tower and 50 m long blades and were located in crop fields. Some crops without wind turbine were located in the area surrounding the 30 wind-turbine park (at a minimum distance of 880 m and a maximum distance of 2.4 km from the closest wind turbines). The others crops without wind turbine were located in the “Symbiose” site (at 35 km from “Germinon”), an area where alternative agricultural practices and landscape elements have been commonly implemented.

Fallows were areas that were mowed at most twice a year. Their average surface was 3 ± 1 ha, and they were 0.87 ± 0.07 m high. Hedgerows were composed of approximately 15 shrub species, including usually tree species, mostly broad-leaved species (6 ± 0.7 m high). Hedgerows also included double rows of trees. On average, the sampled hedgerows were 537 ± 97 m long and 6.5 ± 1.6 m wide. Grass strips were 6.5 ± 1 m in width and 600 ± 66 m long. They were either sowed or left to natural growth and mowed at most twice per year to avoid fallow land encroachment. Bushes consisted of a mix of six broad-leaved shrub species planted in the middle or at the edge of the crops; they were 7 ± 0.8 m long, 2.6 ± 0.2 m high and 2.8 ± 0.3 m wide. Similar bushes but in longer stretches (18.5 ± 2.7 m long, 2.1 ± 0.13 m high and 2 ± 0.25 m wide) were planted inside grass strips at, on average, 100 m intervals. The grass strips with bushes were 5.6 ± 0.3 m wide and 757 ± 56 m long; they received the same management protocol as the grass strips. In total, 60 sampling sites were identified. Due to changes in farming management during the season, 7 of the 8 fallows and 7 out of 8 hedgerows were present at the second visit. For technical reasons, only 6 bushes were the same at both the first and second visits. The results demonstrated herein thus consist of a smaller sample size from the second visit than the first (only 56 sampling points). However, extra sites were added at the second visit to maintain 8 hedgerows, 8 bushes and 10 fallows. We obtained similar results from this data set (see Supplementary material B).

### 2.3.2. Habitat and local field characteristics

Because bat activity could depend on landscape structure beyond the focal compensation measure of interest, the position of the 60 sampling points was chosen according to the surrounding habitat. Distances to the nearest forest, river or urban area, as a proxy for landscape characteristics, were checked to ensure homogeneity among site types (see Supplementary material C_1); landscape data were provided by the National Institute of Geography (from BD TOPO for data on forests and urban areas and from BD Carthage for river data (www.ign.fr); distance and areas were calculated using ArcGIS 10.1). Only the fallows were, on average, too close to forests during the first visit, rendering the distribution of this variable heterogeneous among site types ($ks = 14.9$, $p = 0.0214$, see Supplementary material C_1**)**. However, this is also representative of what is found in farming practices in the area; fallows are usually implemented close to forests because those areas are generally less accessible.

In addition to large scale habitat structure, local field characteristics within a 100 m buffer area were also taken into account; the crops' mean height was noted in addition to the number and type of crops in the fields and the presence of farming trails and marginal strips of spontaneous herbaceous. Because those variables reflected the local landscape's heterogeneity, they might have had an effect on species' abundances. Only variables describing local field characteristics, which did not correlate with site type, were selected (see Supplementary material C_2). To avoid over-parameterization, only three among them were included in the statistical models. We used hierarchical partitioning of variance (HP, R package hier.part) to choose the ones that explained the largest portion of the variance. This method is an analytical method using multiple regressions that allows us to identify the most likely causal factors while alleviating multicollinearity problems (Mac Nally, 2000).

### 2.3.3. Meteorological variables and material used

Because we assumed that bat activity might be affected by weather conditions (Ciechanowski et al., 2007), recordings were only performed when weather conditions were favorable, i.e., no rain, low wind speed (<7 m/s) and temperatures, if possible, higher than 12 °C half an hour after sunset (FBMP, 2012). To reduce statistical effects of meteorological variables, the three ultra-sound detectors were used as much as possible on different site types during the same night. In addition, we also recorded precipitation, wind speed, temperature at 8 PM and luminosity during the night (for more details concerning this last variable, see Supplementary material C_3). The date were also noted and transformed into a numeric variable, i.e., a Julian date. To avoid a correlation between the sampling dates and site types, the sampling design included alternating among sampled site types over time. Among the meteorological variables most likely to affect bat activity, two were included in the models. The choice of variables was made after having checked their distribution among site types, assessed the correlation between them and performed a hierarchical partitioning of variance (R package hier.part, see Supplementary material C_4 and C_5).

Finally, to avoid a correlation between the material used and the site type, the three detectors were used to sample all site types in quasi-equal numbers. The detector used (serial number) and the lengths of the recording time were noted. Among those two last variables, one was chosen to be included in the models after the hierarchical partitioning of variance (see Supplementary material C_6).

## 2.4. Statistical analyses

Because each visit represents two different periods of bat activity, analyses were performed separately for each visit. In the first step, each group's number of calls was analyzed. In the second step, a dataset including all groups was analyzed, but each group was distinguished. At the species group level, during each visit, we assessed variations in bat activity (i.e., the response variable) as a function of site type, local field characteristics, weather conditions and material variables (i.e., explanatory variables) using generalized linear models (GLM). The effect of site type was adjusted to the other explanatory variables using an Anova type II (R package car). Because of the nature of the data (i.e., count data), we performed GLMs with a Poisson error distribution. Following Faraway (2006), *p*-values were corrected for potential overdispersion using a dispersion parameter. For the analyses of the full dataset, we used mixed generalized linear models for each visit, which included the group of species as a random effect (R package lme4).

All selected variables (local field characteristics, meteorological variables and material variables) were included in the first model. We removed the ones that did not have a significant effect one by one. Our final models included the variable site type in addition to the others variables that had a significant effect (see Supplementary material D to know the list of the selected variables and their explanatory power, plus the AIC of the final models). In addition to the selection procedure for the variables, which aimed to select variables of interest, avoid over-parameterizations and avoid including correlated explanatory variables, we evaluated multicollinearity in the explanatory variables of our final models by calculating variance-inflation factors (VIF) on the full models (Fox and Monette, 1992). All variables had VIF < 2. Because recordings could be from the same night but different site types (i.e., for 85% of the nights), another type of statistical analysis was used that considered data from the same date as paired and thus allowed removal of the meteorological variables by including an adjustment for date, taken as a factor. Similar results were found (see Supplementary material E).

We explored data for potential spatial autocorrelation using a variogram tool (R package spatial, Bivand et al., 2008). According to the slight spatial trend detected for the *Pipistrellus* group at the first visit ($p$-value = 0.019) and the *Eptesicus-Nyctalus* group at the 1st visit ($P$-value = 0.00013), we added an autocovariate (i.e., a distance-weighted function of neighboring response values, here weights by the square of inverse distance; Dormann et al., 2007; Penone et al., 2013) with the autocov dist function in R for those two group's analysis and the mixed generalized linear models for the 1st visit (package spdep, Roger Bivand).

Bat activity in crops without wind turbine was used as the reference (i.e., intercept) in our models. This permitted us to easily assess the impact of wind turbines in agricultural landscapes on bat activity. Moreover, it permitted us to determine the gain or loss incurred from changing agricultural practices or adding landscape elements to intensively farmed landscapes. All analyses were performed using R statistical software v.3.0.2 (The R foundation for Statistical Computing, 2013).

## 3. Results

### 3.1. Species registered

In total, more than 9900 bat passes were recorded, 3926 during the first visit and 5985 during the second. The majority of them were from species in the *Pipistrellus* group (Table 1). For more details on the composition of each group, see Supplementary material A_4.

### 3.2. Effects of wind turbines

Bat activity was, on average, lower in crops under wind turbine than in crops without wind turbine for all groups and all visits (Table 2). This was confirmed with significant results in the analysis of the total dataset (Fig. 2, see Supplementary material F).

Because some of the crops without wind turbine were not in the area surrounding the wind turbine farm at the Germinon site, we performed analyses on a subset of the data that included crops under wind turbine and crops without wind turbine from the Germinon site. The variables used were the same as in the models with all the data. A significant difference was again found for the second visit ($\beta = -2.09 \pm 0.11$, $p$-value $< 0.0001$). However, for the first visit, we did not detect any significant effect ($p$-value $= 0.29$).

### 3.3. Effects of offsets and farming practices

During the first passage, at the species group level, at least one farming practice or landscape element resulted in a gain in each group (Table 2). The *Pipistrellus* group was slightly positively impacted by the presence of hedgerows, the *Eptesicus-Nyctalus* group by hedgerows and grass strips, and the *Plecotus-Myotis* group by fallows. When taking into account all groups, fallows and hedgerows resulted in a significant gain ($\beta = 0.54 \pm 0.06$, $p$-value $< 0.0001$ and $\beta = 0.70 \pm 0.05$, $p$-value $< 0.0001$, respectively, Fig. 2, see Supplementary material F). During the second visit, at the species group level, fallows resulted in an increase in *Pipistrellus*, whereas the grass strips and grass strips with bushes induced a significant decrease in *Pipistrellus* and *Eptesicus-Nyctalus* (Table 2). When considering all groups in the same analysis (Fig. 2, see Supplementary material F), fallows induced a significant positive effect ($\beta = 0.85 \pm 0.05$, $p$-value $< 0.0001$), accompanied by bushes ($\beta = 0.18 \pm 0.04$, $p$-value $< 0.0001$). Hedgerows were associated with a decrease in bat activity at the end of the summer ($\beta = -1.22 \pm 0.07$, $p$-value $< 0.0001$). Grass strips had no impact during the first visit ($p$-value $= 0.538$) but induced a significant decrease during the second visit ($\beta = -0.93 \pm 0.06$, $p$-value $< 0.0001$). Grass strips with bushes had a significant negative effect during both the first ($\beta = -0.32 \pm 0.07$, $p$-value $< 0.0001$) and second visits ($\beta = -0.93 \pm 0.06$, $p$-value $< 0.0001$).

**Table 1**
Number of bats passes per group and per visit (in parentheses: the % of the total number of contacts per visit).

| Group | *Pipistrellus* | *Eptesicus-Nyctalus* | *Plecotus-Myotis* | Total |
|---|---|---|---|---|
| First visit | 3587 (91%) | 173 (5%) | 166 (4%) | 3926 |
| Second visit | 5611 (94%) | 195 (3%) | 179 (3%) | 5985 |
| Sum of the two visit | 9198 (93%) | 368 (4%) | 345 (3%) | 9911 |

## 4. Discussion

Bat activity was, on average, lower in crops under wind turbine than in crops without wind turbine for all groups and whatever the season considered. But the three groups of bats showed different responses to compensation measures: during the reproductive season, *Plecotus-Myotis* group was positively impacted by fallow, whereas *Pipistrellus* and *Eptesicus-Nyctalus* responded positively to hedgerow. This latest bats group responded also positively to grass strips. In addition, we also detected season-dependent responses to compensation measures: significant changes of responses were observed for hedgerow and bushes, for which bats responses were the opposite according to season.

### 4.1. Limits

*A*n approach targeted to feeding buzzes would most likely be more appropriate because it would be more tightly linked to resources that are vital to bats. However, due to the limited observations of feeding buzzes collected, we used the total number of bat passes per night as a proxy for bat activity. Additionally, data were only collected during one year. Multi-annual dynamics were therefore not taken into account. Finally, the site types that were sampled were different in size and age, which could explain some of the observed differences. However, we tried to choose older sites for this study to limit the heterogeneity but the differences are also representative of what is actually implemented in farming landscapes (Fallows, Hedgerows, Grass strips, bushes, grass strips with bushes). Further analyses and sampling could determine the size that would be most effective.

### 4.2. Effects of wind energy facilities

Many studies have highlighted the impact of wind turbine on bat through bat fatalities (Johnson et al., 2003,b; Kunz et al., 2007a, b; Kuvlesky et al., 2007). However to our knowledge, this study is one of the first to demonstrate that wind energy facilities can have a negative impact on bat activity through a measure of bats activity in intensive agricultural sites which differ by the presence or not of wind turbine. This sampling (points outside a wind turbine park with those inside of it) permitted us to avoid a temporal bias that exists when comparing data from before versus after the implementation of a wind turbine park. However, the sampling design used did not permit us to completely avoid a site bias because the sampling was conducted on two sites, Germinon and Symbiose. To counteract this bias, we performed an analysis on a restricted dataset that included only the site with the wind farm (Germinon) to compare bat activity with and without wind turbines. Those results showed that a negative effect of wind turbines, which was found during the first visit, was not detected. However, the negative impact during the second period was still detectable, suggesting that individuals avoided the wind turbine park during this period. This difference between the two visits when focusing only on the site with a wind farm could be linked to a sample effect (i.e., smaller sample size), but a non-exclusive hypothesis could also indicate a real difference in bat behavior. Indeed, during the first visit (late May to early July), sites are expected to be used by reproductive individuals present in the region, with high fidelity between years; there is thus the possibility of a behavioral adaptation to use this habitat without being injured by turbines. This is consistent with a previous study that showed that *Pipistrellus pipistrellus*, the most abundant species in our study, became habituated to wind turbines (Bach, 2002). In contrast, during the second visit (from the middle of August to the end of September), populations are expected to include non-local individuals such as migrating bats. This avoidance behavior may

**Table 2**
$\beta$ parameters ± standard errors (SE) and *p*-values from a generalized linear model of bat activity with a distance-weighted function for the *Pipistrellus* group (1st visit) and the *Eptesicus-Nyctalus* group (1st). Crops without wind turbine (C) provides the intercept (i.e., the variable for which the parameter = 0). A positive parameter (respectively, negative) indicates that the modality presents a higher (respectively, lower) abundance than C.

| Group | First visit | | | Second visit | | |
|---|---|---|---|---|---|---|
| | *Pipistrellus* | *Eptesicus-Nyctalus* | *Plecotus-Myotis* | *Pipistrellus* | *Eptesicus-Nyctalus* | *Plecotus-Myotis* |
| Modality | | | | | | |
| CWT | | | | | | |
| $\beta$ ± SE | −0.59 ± 0.64 | −1.08 ± 1.15 | −0.22 ± 0.49 | −0.56 ± 0.69 | −0.55 ± 0.39 | −0.03 ± 0.56 |
| *p*-value | 0.355 | 0.346 | 0.656 | 0.414 | 0.156 | 0.962 |
| Fa | | | | | | |
| $\beta$ ± SE | 0.37 ± 0.51 | 0.35 ± 0.67 | **1.25 ± 0.39** | **1.09 ± 0.56** | 0.12 ± 0.36 | 0.86 ± 0.51 |
| *p*-value | 0.465 | 0.597 | **0.00137** | **0.052** | 0.742 | 0.088 |
| H | | | | | | |
| $\beta$ ± SE | 0.79 ± 0.41 | 0.32 ± 0.75 | 0.35 ± 0.45 | −1.33 ± 0.99 | −0.11 ± 0.37 | 0.50 ± 0.54 |
| *p*-value | 0.055 | 0.675 | 0.431 | 0.177 | 0.768 | 0.353 |
| GS | | | | | | |
| $\beta$ ± SE | −0.13 ± 0.55 | **1.63 ± 0.49** | −1.00 ± 0.78 | **−1.47 ± 0.74** | 0.14 ± 0.37 | 0.33 ± 0.57 |
| *p*-value | 0.805 | **0.000811** | 0.199 | **0.0449** | 0.715 | 0.565 |
| B | | | | | | |
| $\beta$ ± SE | −0.98 ± 0.72 | −0.15 ± 0.89 | −0.25 ± 0.59 | 0.11 ± 0.51 | −0.29 ± 0.42 | 0.20 ± 0.62 |
| *p*-value | 0.177 | 0.864 | 0.677 | 0.835 | 0.499 | 0.746 |
| GSB | | | | | | |
| $\beta$ ± SE | −0.29 ± 0.64 | −0.29 ± 0.69 | −0.11 ± 0.54 | −1.02 ± 0.70 | **−1.93 ± 0.83** | −0.41 ± 0.73 |
| *p*-value | 0.639 | 0.673 | 0.842 | 0.145 | **0.019** | 0.571 |

CWT, crops under wind turbine; Fa, fallows; H, hedgerows; GS, grass strips; B, Bushes; GSB, grass strips with bushes. Significant effects are in bold.

seem contradictory to some studies that showed that bats were attracted by wind turbines for roosting or foraging (Northrup and Wittemyer, 2013) or link to mating behavior (Cryan, 2008). This difference in results may indicate that there are two effects of wind turbines, one repulsive at the scale of the wind farm (30 wind turbines over 7 km$^2$) and one attractive at the scale of the turbine itself (tree-roosting bats mistake wind turbines for roost trees while engaging in mating behaviors, insectivorous bats feed on insects that might be attracted by wind turbines or other bat species might be attracted by the swishing sounds produced by the rotating blades (Cryan, 2008; Cryan and Barclay, 2009; Cryan et al., 2014; Horn et al., 2008; Kunz et al., 2007b; Rydell et al., 2010).

### *4.3. How to define offset measures*

Many previous studies were not designed to directly test management strategies that could be used as mitigation measures (Northrup and Wittemyer, 2013). This study was designed to evaluate the effects of offset measures in order to advise developers. We expect that by offering a choice of offset measures

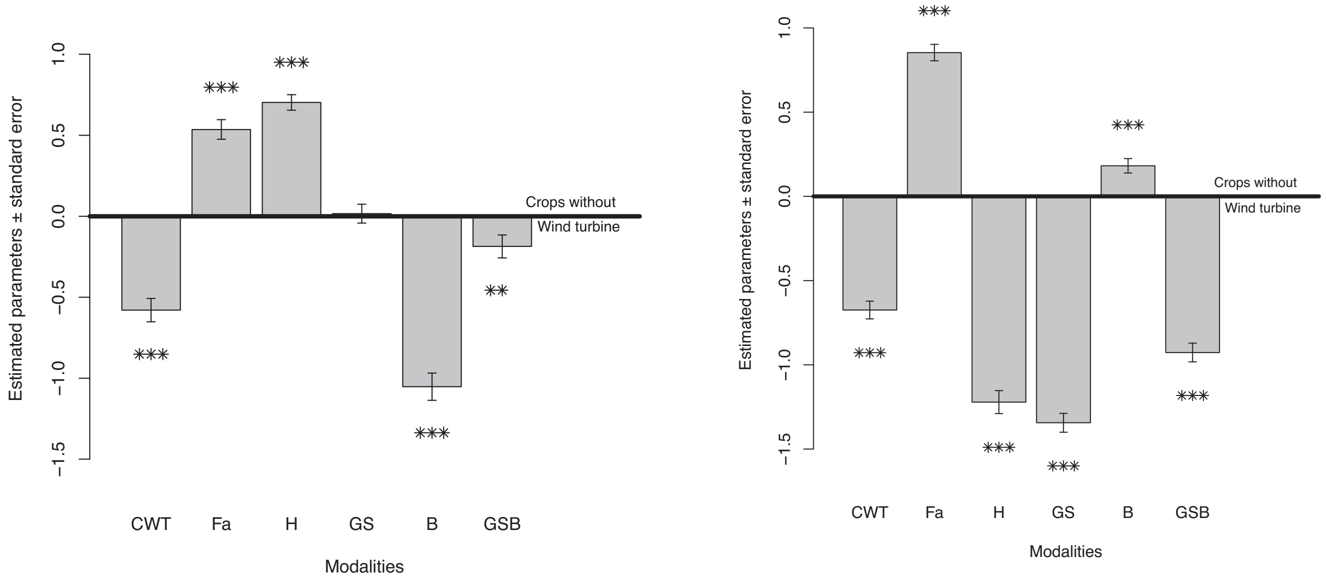

**Fig. 2.** Results from the mixed generalized linear models of bat activity for the first visit (respectively, second) on the left (respectively, on the right), with a distance-weighted function for the 1st visit. Crops without wind turbine (C) provided the intercept (i.e., the variable for which the parameter = 0, bold black line). A positive parameter (respectively, negative) means that the site type presents a higher (respectively, lower) abundance than C. CWT, crops under wind turbine; Fa, fallows; H, hedgerows; GS, grass strips; B, bushes; GSB, grass strips with bushes. The number of stars indicates the significance level (***$p$-value < 0.001, **0.001 < $p$-value <0.01 and *0.01 < $p$-value < 0.05).

with explicitly equivalent outcomes, we place the agricultural stakeholders in the center of the offsetting process; this would undoubtedly contribute to the successful implementation of compensation measures. In addition, the research on offset measures based on field metrics of biodiversity with sound and transparent sampling designs, using the same methods to assess the losses caused by the operation of wind farms and the potential gains from some agricultural practices may reduce the opposition to the proposed offsets.

It has been hypothesized that agriculture intensification is a major cause of bat population declines (Stebbings, 1988). Some studies showed that bat activity was higher on organic farms than on conventional ones (Wickramasinghe et al., 2003), but we cannot know if this was due to a reduction in agrochemical use in organic farms or a larger amount of hedgerows (Jones et al., 2009). Lentini et al. (2012) proved that, in farming landscape, larger linear remnant with intact native vegetation supported higher bat activity. Fuentes-Montemayor et al. (2011) compared the effects of Agri-Environmental Scheme (AES) interventions on *Pipistrellus pipistrellus* and *Pipistrellus Pygmaeus* with similar interventions that were not implemented as an AES. They found that both food availability and bat activity were lower on farms with AES interventions. Here, the effects of agricultural fallows and different landscape elements on the activity of three groups of bats were compared with conventional farming practices. We showed that those site types could have a significant positive impact on bat activity (Table 2, Fig. 2).

We identified that fallows and hedgerows, especially in spring and early summer, could bring about gains and therefore be used to achieve the no-net-loss objective within the framework of “like-for-like” offsetting practices for protected species. At the landscape scale, the establishment of fallows and hedgerows could help to conserve the impacted species by improving ecological conditions outside of the impacted site. However, we showed that those groups responded differently to the different site types and that responses were period dependent (Table 2, Fig. 2). Farm management could cause the difference between the two visits. Indeed, most of the crops were mowed when the second visit occurred, making the site types more disconnected from the landscape elements. We believe that hedgerows were the site type that became the most disconnected, leading to a positive effect in the first visit and a negative one in the second (Fig. 2). This observation is congruent with a study by Boughey et al. (2011) that emphasized that landscape context may influence the use of linear features. Fuentes-Montemayor et al. (2011) results highlighted that the management of implementations, such as an AES or an offset measure, should be carefully designed in order to have an effective positive impact on bat populations.

## 5. Conclusion

These results highlighted the facts that wind energy facilities have a negative impact on bat activity, proving that a repulsive effect at the scale of the wind does exist. This loss of habitat is rarely taken as a serious threat (Lloyd, 2010) and mitigation strategies are usually only based on bat fatalities. We showed here that the loss of foraging habitat has to be taken into account when assessing offset measures to counteract the negative impacts of wind energy facilities.

These results lead also to further questions regarding strategies for mitigating the effects of wind turbines: (i) How can we take into account the ecological needs of species that do not respond in the same way throughout the year? Should we promote priority site types that are favorable for the breeding season? Should we perform a mix of site types at the landscape scale? (ii) How can we take into account the entire bat community despite the fact that the species do not thrive on the same features? Should we promote priority species whose local population trends are declining fastest or species identified to be the most impacted by wind farms? (iii) How can we propose an offset based both on mortality and loss of habitat attractiveness, knowing that wind farm facilities kill bats from near and far (Lehnert et al., 2014)?

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoleng.2014.11.050.

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