How to mitigate impacts of wind farms on bats? A review of potential conservation measures in the European context

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Introduction

In the last 20 years, wind energy became the fastest growing source of power generation in the world and it is expected to continue growing in Europe, North America and in the developing markets of China and India. There is also a growing trend in Latin America, new Asian and Eastern European markets and in some African countries (Ledec et al., 2011; WWEA, 2013), though in the past three years, due to the global economic crisis, the rate of growth has slowed down (WWEA, 2013).

In Europe, during the last 30 years, wind energy has grown from 100 MW to over 100,000 MW (EWEA, 2012). Among European countries, Germany, Spain, Italy, France, UK and Portugal have shown an extraordinary growth in wind energy in the last decade (WWEA, 2013). In fact, energy produced from renewable sources is a priority in the European Union (EU) agenda, especially after the implementation of the Renewable Energy Directive in 2009 (2009/28/EC) and subsequent amending acts. This directive establishes mandatory targets for the European Union (EU) agenda, especially after the implementation of the Renewable Energy Directive in 2009 (2009/28/EC) and subsequent amending acts. This directive establishes mandatory targets for 2020, imposing a 20% share of energy from renewable sources by 2020 in all member states. As a consequence, several member states have seriously invested in the development of wind energy, as a crucial way to attain this goal.

This goal shift towards a more sustainable production of energy to reduce the emission of greenhouse gases is certainly desirable, but the development of wind energy facilities does not come free of risk of negative impacts on biodiversity (Voigt et al., 2012), as well as noise and visual impacts for local human communities (Leung and Yang, 2012).

Among vertebrates, bats are pointed out as one of the most affected groups (Arnett et al., 2011; Barclay et al., 2007; Johnson et al., 2003; Rydell et al., 2010). In the last few years, the concern about the negative impact of wind farms on bat assemblages has significantly increased...
among the scientific community. Since the implementation of the first wind farms in Europe and the USA, it was assumed that bats could be affected by collision with the moving turbines. However, this group only became a research focus when bat fatalities were documented as potentially higher than bird fatalities (Cryan and Barclay, 2009; Rodrigues et al., 2008; Rydell et al., 2010).

Bat fatalities result from direct collision or from barotrauma, i.e., experiencing rapid pressure changes that cause severe internal organ damage, especially in the lungs (Baerwald et al., 2008; Grodsky et al., 2011; Rollins et al., 2012). Bat fatality rates show significant variation among sites and years and although there are general recommendations from EUROBATS for the monitoring and estimation of fatalities (e.g. Rodrigues et al., 2008), the lack of standardised methods to estimate these rates hinders comparisons (EUROBATS, 2012). Nonetheless, significant fatality rates have been recorded in both the USA and Europe. In a review of the patterns of bat fatalities at wind energy facilities in North America (USA and Canada), Arnett et al. (2008) present as many as 69.6 bat fatalities per turbine per year. In Europe although a global study has not been done yet, it is known that fatality rates vary largely among sites and high numbers were also reported especially from Hohe Eck wind farm in southern Germany, where rates of 41.1 bat fatalities per turbine per year occurred (Rydell et al., 2010).

In the European Union all wind energy developments that are likely to have a significant impact on environment should be subjected to an environmental impact assessment (EIA) (Article 2, Directive 85/337/EEC). That is the formalised procedure that ensures that the likely effects of a new wind farm on the environment are fully understood (Jay et al., 2007) and taken into account before the proposed project is given development consent. For that reason they are a good decision-making tool on project viability (Rajvanshi, 2008; McKenney and Kiesecker, 2010) and should identify and, if possible, quantify impacts on biodiversity, confirm the need for mitigation and set out the mitigation required for the identified impacts (BBOP, 2009a; Marshall, 2001). The negative impacts are mitigated through the implementation of measures that aim at the reduction of those impacts to the point where they have no adverse effects (BBOP, 2012a). Within the EU there are regulations that consider population effects and also regulations focusing on individual specimens of species that are strictly protected. Ultimately, both focus on negative effects that will occur at the population level, though considering that, in threatened species, these effects are more severe, so even a reduced number of fatalities is of great concern.

Mitigation involves any process, activity or action designed to avoid, reduce or compensate those significant adverse impacts (Marshall, 2001). The mitigation measures are categorised according to their goals and following the mitigation hierarchy: (a) avoid, (b) reduce/moderate/minimise, (c) offset/compensate (Fig. 1) (BBOP, 2012d; Darbi et al., 2009; PricewaterhouseCoopers, 2010). This hierarchy implies that avoidance strategies have priority over remedial solutions (Marshall, 2001) and that those impacts that cannot be avoided or minimised must be addressed through biodiversity offsets or compensatory measures (BBOP, 2009a; PricewaterhouseCoopers, 2010). Strictly following the mitigation hierarchy, it is important to underline that offsets or compensatory measures are the “last resort” and must not provide a justification for proceeding with projects for which the residual impacts on biodiversity are unacceptable. This means that the “no go” option has to be considered seriously and applied in cases where the destruction of unique habitats, or irreversible loss would otherwise occur (BBOP, 2012c; Bishop, 2006).

The last step of the mitigation hierarchy, the offset or compensation, has been acquiring importance and popularity among conservationists (McKenney and Kiesecker, 2010; Kiesecker et al., 2010). The clarification between those two concepts has been under discussion in recent years, and Biodiversity Offsets were defined by BBOP as “measurable conservation outcomes resulting from actions designed to compensate significant residual adverse impacts on biodiversity, after appropriate prevention and mitigation measures have been taken”. The offset measures should “achieve no net loss and preferably a net gain of biodiversity taking into account species composition, habitat structure, ecosystem function and people’s use and cultural values associated with biodiversity” (BBOP, 2013; ten Kate et al., 2011). To demonstrate no net loss or a net gain, conservation action outcomes must demonstrate that biodiversity conserved is sufficient and of the same kind as the biodiversity lost or degraded due to the project’s impacts, and that biodiversity persistence is not compromised, or if possible enhanced (BBOP, 2013; ten Kate et al., 2011). For compensation, there is no clear definition set by BBOP, and the edge between these two concepts is mainly related with the capacity of a project to demonstrate that the conservation outcomes are enough to guarantee “no net loss or a net gain” (BBOP, 2013; ten Kate et al., 2011).

Offsets are a relatively recent field of investigation (Hayes and Morrison-Saunders, 2007), and the Business and Biodiversity Offsets Programme has developed and introduced the Standards on Biodiversity Offsets. These standards are based on 10 principles that provide a framework for the design and implementation of biodiversity offsets and to verify its success (BBOP, 2009a): (1) adherence to mitigation hierarchy, (2) limits to what can be offset, (3) landscape context, (4) no net loss, (5) additional conservation outcomes, (6) stakeholder participation, (7) equity, (8) long-term outcomes, (9) transparency and (10) science and traditional knowledge.

The compliance with these principles helps to ensure that adequate offset programmes are created and implemented. However, there are several conservation programmes that, for a variety of reasons, are simply unable to follow all these principles, which is more evident in the case of principle 4 – no net loss/a net gain. For some projects it is not possible to prove no net loss because i) pre-impact data is lacking and it is impossible to know what was lost as a result of the project, and/or ii) gains achievable by the conservation actions are not easily quantified. If so, the programme in question should not be considered as an offset but as a compensation programme. Fig. 2 illustrates the continuum from a very basic form of compensation to the type of compensation that is a full offset and may realistically be expected to achieve no net loss or even a net gain.

Despite the recommendation to follow the mitigation hierarchy, monitoring programmes in several European wind farms have revealed that, in some situations, significant impact over bat populations may be occurring (EUROBATS, 2013). So, it is essential to guarantee that, for each wind energy facility, the mitigation hierarchy is followed from the beginning and that this sensitive group is taken into account in all steps. In that context, the implementation of the mitigation hierarchy should start during the planning and design phase, in order to avoid any important area, such as breeding, hibernating areas and/or foraging habitats of threatened bat species (EC, 2010). However, identifying potential impacts during the planning phase may be a difficult task, unless it is made in extreme circumstances with easily predictable impacts or in the predictable absence of impacts (e.g. near an important roost or at a hostile, windy and cold site). Furthermore, in some cases
the real effects are only indentified during the monitoring of the post-construction phase (e.g. Hein et al., 2013). So, an adaptive management approach should be followed in order to reconsider the mitigation hierarchy during the construction and/or exploration phase based on monitoring results, to continually improve its performance (BBOP, 2009c). For unavoidable impacts, minimisation measures for bat populations usually include on-site efforts to remedy the effects of short-term damage. Research on this subject has been significantly increasing in the last few years, especially on ultrasound emissions as a way to deter bats from approaching wind turbines (Arnett et al., 2013; Horn et al., 2008; Johnson et al., 2012; Spanjer, 2006; Szewczak and Arnett, 2006a, b, 2007). Radar emissions also seem to negatively affect bat activity (Nicholls and Racey, 2007, 2009). However, to our knowledge, until now, no device was successfully developed or commercialised. Nevertheless, as bat mortality rates seem to be higher during low wind nights (Amorim et al., 2012; Kerns et al., 2005; Rydell et al., 2010) the most effective mitigation measure seems to be the increase of wind turbine cut-in speed (the velocity at which turbines start producing electricity) and changes in blade feathering (altering the angle of the blade preventing it from rotating on low wind situations). This measure has been proven to reduce bat fatalities from 30% to 90% (Arnett et al., 2008, 2011; Baerwald et al., 2009).

If an adverse effect on the assemblage of bats cannot be definitely eliminated or even reduced to acceptable levels through the above-mentioned measures and thus residual adverse effects on biodiversity still remain, offset or compensatory measures should then be considered (BBOP, 2009a; Darbi et al., 2009; PricewaterhouseCoopers, 2010). The acceptable levels of impact referred above may vary between European member states: in some countries the death of any individual bat of a protected species is strictly forbidden, while in others a reduced number of fatalities is tolerated and evaluated on a case by case basis. However, despite that recommendation, to our knowledge and to date, no offset or compensatory measures have been taken in Europe aimed at bat mortality compensation (personal information obtained through inquiries done to the focal points of the EUROBATS Intersessional Working Group on Bats and Wind Farms). It should be underlined, however, that the avoidance of mortality must always be the first option while compensation/offset of the acceptable impacts that remain after the implementation of the mitigation hierarchy should be seen as the last resort.

The lack of such measures is probably related to the lack of baseline knowledge on bat populations (e.g. Walters et al., 2012) making it hard to assess the population affected, and especially difficult with migrating species (Voigt et al., 2012). Actual knowledge on bat migration and migratory paths is still scarce (e.g. Popa-Lisseau and Voigt, 2009). European bat species are classified into three migratory categories according to the distances recorded — long distance (>500 km), regional (100–500 km), and sedentary (<50 km); however, not all populations of known migratory species perform complete migrations and some may even be sedentary along the range of occurrence of the species (Fleming and Eby, 2003).

In this paper we reviewed a set of conservation measures that may be applied and assessed in the context of compensation or offsetting the impacts of wind farms on bat populations, in particularly sedentary or non-migrant species. Although these measures were analysed under the European land-use and policy context and considering the ecological requirements of the bat species that show higher mortality rates at European wind farms, the guidelines presented here are surely appropriate elsewhere. This review should be seen as a first approach to the subject, as in some cases the potential of the presented measures is mostly theoretical, and it is crucial to investigate in more detail their efficiency in different populations and regions.

Review methodology and scope

Using a broad range of monitoring reports and other official documents published between 2003 and 2013 we gathered information on the species, number of fatalities per species and seasonal trends in fatalities in European wind farms.

To our knowledge, no publication has addressed specific compensatory measures for bats at European wind farms, so we investigated a wide range of studies describing bat activity patterns, taking into account macro-, meso- and micro-scale habitat features, such as landscape characteristics, habitat, forestry/agricultural regime, vegetation structure, and water and prey availability.

Based on the review of i) the ecological requirements of the most affected bat species, ii) the main threats to bat populations, and iii) conservation strategies focused on bat populations, we identified several measures that could be used to compensate wind farm impact on bat assemblages. We focused on forest management actions to be implemented mostly in the surrounding area of the wind farms but distant enough to avoid the attraction of bats into their area of influence, so that by any means, preventing an increase in fatalities numbers.

Bat mortality in European wind farms

Presently only a few countries have published guidelines for the monitoring of bat fatalities at wind farms in the context of EIA (EUROBATS, 2013). In most countries, this monitoring is mandatory only in some situations and according to the potential impacts of the wind farm in question. Even when monitoring schemes are in place, the results of those surveys are often not available or open to review or public access (Rydell et al., 2010), which makes the evaluation of the patterns of bat fatalities in European wind farms quite difficult.

The Intersessional Working Group on Wind Turbines and Bat Populations (EUROBATS) has, however, compiled information on this subject in the European context. Between 2003 and 2012, 5139 dead bats were detected, either located accidentally or during post-construction monitoring studies. The report underlines that these numbers by no means reflect the real extent of bat fatalities at wind farms, even because many
infrastructures are not consistently monitored. However, these data probably represent the overall tendency in Europe (EUROBATS, 2013).

The majority of the fatalities occurred in Germany, Spain, France and Portugal, but again this may be a consequence of the monitoring schemes being carried out in each country. Between 2003 and 2012, wind turbines in Europe killed at least 27 species, of which the most affected were Pipistrellus pipistrellus (965 fatalities), Nyctalus noctula (704), P. pipistrellus/Pipistrellus pygmaeus (597), Pipistrellus nathusii (593) and Nyctalus leisleri (383). These are all Least Concern (LC) species according to the IUCN Red List of Threatened Species, although the conservation status varies among the European countries. For example, in those four countries, P. pipistrellus and P. pygmaeus are considered least concern species, except in Germany where P. pygmaeus is data deficient; N. noctula is considered rare in Spain, near threatened in France, least concern in Germany and data deficient in Portugal; and P. nathusii is considered near threatened in France and least concern in Germany. These differences in regional or national conservation status of bat species imply that some measures may be priority in some areas but not in others, and that compensatory programmes, even if following the general guidelines presented in this paper and elsewhere (e.g. Boye and Dietz, 2005; Entwistle et al., 2001; Meschede et al., 2001), should be designed according to the regional and temporal context in which they are to be implemented.

Ecological requirements of the most affected species

Table 1 summarises the ecological requirements of the five bat species most affected by wind energy facilities in Europe. Information about their distribution, preferred foraging habitats, flight paths, and prey items, as well as breeding and hibernation requirements is presented. Those species that are rare or more threatened regionally, such as N. noctula, N. leisleri, and P. nathusii depend on wetlands and mature forests of deciduous trees to forage or roost, indicating that the destruction or degradation of these areas through cutting, replacement by production forests, or forest fires, poses a negative impact for them.

Potential offset and compensatory measures

In this work we bring together several measures that may be implemented to compensate the residual adverse effects of wind farms on bat populations. These measures are intended for the improvement of ecological conditions towards the increase of the carrying capacity for bat assemblages, specifically for breeding and roosting conditions and the increase of prey availability and accessibility. These actions are mainly thought to be implemented in the surrounding area of wind power infrastructures but far enough to avoid the attraction of bats into the wind farm area of influence. Therefore, measures related with roost and food availability have potentially larger scope and will benefit both sedentary and migratory species; others will mostly benefit sedentary populations that use the vicinity of wind farms all year around. Whenever there is bibliographic support of an increase in bat numbers or bat activity, references are presented.

As explained above bat populations are poorly known, and present several sampling constraints. For instance, for migratory bat species it is difficult to understand which populations are being affected and evaluating the effects of the present measures for those species is an extremely difficult task. Despite the referred, improving bats’ ecological requirements in habitats that present limitations will certainly benefit those populations, at least at a local level. So, it is urgent to start studying this topic, as it could be an important tool to mitigate residual impacts of human infrastructures on bat populations.

Management of autochthonous forests

Most native European forests are extremely important for a wide spectrum of bat species, especially ancient forests, as opposed to even-aged and mono-specific plantation forests, due to their higher structural complexity. Bats usually prefer those habitats to forage and roost (Rainho, 2007; Ruczyńska et al., 2010; Russ and Montgomery, 2002; Russo and Jones, 2003; Waters et al., 1999), though the specific structure of each forest is closely linked to the array of bat species present (Ford et al., 2005).

The maintenance and preservation of the existing conditions in mature autochthonous forests and the acceleration of the ecological succession of younger formations are crucial for bat conservation. In mature forests, bats often use large trees and snags as roosts (Crampton and Barclay, 1998; Hutson et al., 2001; Kunz and Lumsden, 2003; Russo et al., 2004). Simple actions, such the preservation of older trees with cavities and well developed branches, and the non-removal of standing or fallen dead trees should be adopted. These actions are mostly relevant for the protection of tree-roosting bat species, and in the context of those more negatively affected by wind farms in Europe, particularly N. noctula and N. leisleri. Still, besides providing roosts for bats, these structures contribute to the enhancement of insect abundance and diversity, increasing the availability of potential prey for bats (Dietz and Pir, 2009; Guldin et al., 2007; Russo and Jones, 2003). However, in some forest types, branch thinning may occasionally be necessary in order to create flight corridors for bats with less manoeuvrable flights (e.g. Guldin et al., 2007; Loeb and O’Keefe, 2006; Obrist et al., 2011), creating vertical heterogeneity and promoting the creation of niches that may be used by different species (Collins and Jones, 2009; Plank et al., 2012). Branch thinning may also contribute towards healthier tree development.

Well-developed riparian galleries usually harbour great plant diversity and are frequently used as foraging grounds by many bats, including species most affected by wind turbines in Europe (Table 1). Riparian galleries act as a shield from the wind and are simultaneously home to great diversity and abundance of arthropods (Peng et al., 1992; Russo and Jones, 2003; Warren et al., 2000), thus management actions aiming the preservation or the restoration of those sites are fundamental. In many areas these actions must include the removal of exotic invasive plants, because they override autochthonous vegetation, together with the plantation of native species (Guil and Moreno-Opo, 2007; Marchante et al., 2005). Changes in trophic structures have already been shown for spiders in response to invasive plants (Petillon et al., 2005). Some exotic plants, like Australian acacias, which are among the most significant invaders worldwide (Richardson and Rejmánek, 2011), have an aggressive invasive behaviour forming dense forest stands. These dense stands block the development of native species (Marchante et al., 2005), may change river-flow (Richardson et al., 2007) and fire regimes (Kull et al., 2011), and may also preclude the access of foraging bats to these areas due to high clutter. For the waterline itself, management actions should promote additional heterogeneity of the water flow. The creation of backwater areas that endorse vegetation accumulation favours i) species directly affected by wind farms as P. pipistrellus (Warren et al., 2000), ii) species least affected that hunt in smooth water such as Myotis daubentoni (Warren et al., 2000), and iii) species apparently not affected by wind farms such as Myotis capaccini, considered vulnerable by IUCN (Biscardi et al., 2007), which may result in an additional positive outcome in a compensatory scheme for a wind farm. Promoting rapid areas that allow water oxygenation favours breeding sites for several species of arthropods, potentially increasing prey availability for bat species (Capinera, 2010; Entwistle et al., 2001).

In traditional agro-forestry European ecosystems such as Montados or Dehesas (extensive silvo-pastoral agro-forestry systems consisting of grasslands with a tree cover of holm oak Quercus rotundifolia or cork oak Quercus suber) and extensive olive groves (Olea europaea) in the Mediterranean, and woodland pastures in Central and Northern Europe, management actions should aim at the maintenance of typical extensive farming, promoting the complexity of the vertical structure of the vegetation. Rotational grazing, fruit harvesting, branch thinning
Table 1
Ecological requirements of the five most affected bat species by wind farms in Europe.

<table>
<thead>
<tr>
<th>Species</th>
<th>Common pipistrelle Pipistrellus pipistrellus</th>
<th>Soprano pipistrelle Pipistrellus pygmaeus</th>
<th>Nathusius' pipistrelle Pipistrellus nathusii</th>
<th>Leisler's bat Nyctalus leisleri</th>
<th>Common noctule Nyctalus noctula</th>
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<tr>
<td>Distribution</td>
<td>Distributed through Europe up to southern Scandinavia and Baltic countries. Occurring also in some parts of Northwest Africa and Southwest Asia to Central and Eastern Asia. P. pipistrellus is one of the most common species in many areas of its distribution range. (1, 2, 3)</td>
<td>All over Europe from Scotland and southern Scandinavia to Iberia and Turkey, but records are missing from some regions like the northern Balkans and southernmost Italy. (1, 4)</td>
<td>P. nathusii is a migratory species. Occurs in Eastern, Central and Southern Europe. (1, 3, 5, 6)</td>
<td>Distributed all over Europe, but absent from Scandinavia, Estonia and Northern Russia. Missing in southern Italy, Sicily and Crete. Ranging to South-western Asia and also present in North-western Africa. (1, 5, 7)</td>
<td>All over Europe except for Ireland, Scotland, northern Scandinavia and Southern parts of Greece and Italy. Mostly absent from the Mediterranean Islands. Ranging to Asia to southern Siberia, north Vietnam, Myanmar, and Taiwan. (1, 3, 5, 8)</td>
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<td>Foraging preferred habitat</td>
<td>Hunts in several habitats, although more common in wetlands and urban areas. (3, 5, 10, 11)</td>
<td>Hunts in several habitats from forest areas to wetlands, agricultural and urban areas. Riparian areas and ponds with trees or hedgerows in their margins seem to be preferred, especially during the breeding season. (9, 10, 11, 12, 13)</td>
<td>Frequently found in riparian habitats and wetlands. Hunts 4–15 m above ground, on paths and woodland edges, also over water. (3, 9, 11, 13, 14, 15)</td>
<td>Forest species, uses preferentially deciduous forests, but can also be found on resinous forests and urban parks, hunting above tree tops; forest roads and open areas are also used to hunt. Feeding areas seem to change according to season, age, sex and geographical area. (11, 16, 17)</td>
<td>Mostly a forest species, hunts in open areas in forest and also frequent in large urban parks and gardens, frequently using artificial illuminated areas as feeding grounds. (3, 11, 13, 17, 18)</td>
</tr>
<tr>
<td>Usual commuting routes</td>
<td>Linear landscape elements such as hedgerows, forest edges and tree lines but also open spaces. (11, 19, 20, 21)</td>
<td>Linear landscape elements such as hedgerows, forest edges and tree lines but also open spaces. (11, 20, 21)</td>
<td>Follows landscape structures, as forest edges, hedges, roads or forest aisles, but also across open fields. (11, 14, 20)</td>
<td>Little is known, but seems to fly above tree tops directly and fast to the feeding grounds, reaching up to 40 km/h. (11, 16, 20)</td>
<td>Fast flying species, known to travel as far as 20 km to reach preferred foraging grounds, although individuals in maternity colonies predominantly forage within 2 km of the roost. (11, 20)</td>
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<tr>
<td>Breeding and hibernation</td>
<td>Uses virtually all kinds of natural and artificial structures as roosts, though not common in caves. Hibernate and breed in colonies that can reach thousands of individuals. (3, 11, 17, 20)</td>
<td>Uses virtually all kinds of natural and artificial structures as roosts. Hibernate and breed in colonies that can reach thousands of individuals. (11, 20, 24)</td>
<td>Roosts in trees, bat boxes and sometimes in buildings. Hibernate in crevices, cliffs, buildings, and caves. (5, 11, 15, 14, 20, 26)</td>
<td>Seldom uses anthropogenic structures as shelter, choosing preferably tree cavities as roosts. Migratory species hibernate in relatively large groups, also aggregating in the roosts during the breeding season. (11, 16, 17, 20)</td>
<td>Roosts and hibernates in trees, crevices in rocks, buildings and bridges in colonies that can reach thousands of individuals during hibernation. (3, 7, 11, 17, 20, 21)</td>
</tr>
<tr>
<td>Migration category</td>
<td>Most populations are considered sedentary, but there is evidence of long distance migratory behaviour. (26, 27)</td>
<td>Evidence of long distance migratory behaviour. (26, 27)</td>
<td>Long distance. (5, 27)</td>
<td>Long distance. (5, 27)</td>
<td>Long distance. (5, 27)</td>
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and the creation of small clearings generate potential flight corridors for bat species with low manoeuvrable flight as *N. leisleri* and *N. noctula* and medium manoeuvrable flight as *P. pipistrellus* and *P. nathusii* (Obrist et al., 2011). It will also enable access to food resources located on the ground or in herbaceous vegetation which may benefit gleaning bats, e.g. genus *Myotis* and *Plecotus* (Rainho et al., 2010). Additionally, these actions also may represent additional conservation outcomes while contributing to the reduction of vegetative surface fuels, which is especially relevant in Southern Europe, where intensive and highly destructively summer fires are frequent (Guil and Moreno-Opo, 2007). Such actions, designed for bat population management that simultaneously reduce the risk of fire, represent examples of actions meeting BBOP recommendations on how to involve stakeholders in mitigation by showing how they can benefit with actions dedicated to biodiversity management and conservation.

Vegetation homogeneity may result in low availability of food resources for some bat species (Dodd et al., 2008). So, it may be necessary to create small clearings or agricultural plots, while avoiding pesticide treatments, in the surroundings of the wind energy facilities, allowing some diversification within the landscape and creating the conditions for greater diversity in food items (Wickramasinghe et al., 2004). This is particularly evident in Southwest Mediterranean where many wind farms are located at hilltops of mountainous areas, and where vast expanses of scrubland are common (Chauchard et al., 2007; Gallego Fernández et al., 2004). In fact, the creation of clearings, and the subsequent development of shoots and young plants, and vegetation heterogeneity may increase both the accessibility (Rainho et al., 2010) and the availability of food items to arthropods that constitute the diet of all European bats.

The studies referred above focused mainly on the evaluation of bat activity in different management scenarios. This means that there is still a lack of studies specifically designed to evaluate if those measures have promising results in bat population increase.

### Diversification of forest and agriculture monocultures

The diversification of agriculture and forest monocultures is closely associated with the measure described above. In Europe, intensive production forests are characterised by large areas covered with monocultures of the Pinaceae or *Eucalyptus* spp., regarded as areas of poor quality in terms of food and roost availability for bats (Ciechanowski, 2005; Kusch and Schotte, 2007; Rebello and Rainho, 2009; Salvo et al., 2009). These areas may also present higher susceptibility to fires than native forests (Moreira et al., 2009) so active management for fire restriction is essential, including the creation of shaded fuelbreak strips where fuel reduction occurs through the cutting and removing of vegetation (Agee et al., 2000; Asociación Columbares, 2009; Guil and Moreno-Opo, 2007) and controlled grazing (Ruiz-Mirazo et al., 2011). In specific cases, prescribed burns may also be considered as they promote fuel discontinuity and simultaneously maintain areas of vegetation regeneration, representing a significant decrease in fire occurrence (Montiel and Kraus, 2010); this is a high-risk activity and all precautionary measures should be implemented in conformity with established security and legislation rules. Prescribed burning and thinning have already been proved to benefit bats inhabiting forest pine stands in North America (Loeb and Waldrop, 2008).

Because different species of bats use forests in different conditions, the creation of spatial heterogeneity is desirable in those areas and can be attained by the creation of clearings within the forest. This will improve the area as feeding ground and will contribute to the regeneration of autochthonous understory vegetation (Guldin et al., 2007). In areas where this regeneration is difficult, the plantation of autochthonous deciduous trees and shrubs should be considered, in a long-term management perspective. At the same time, particularly dense understory areas may be managed through grazing. It should be underlined that there is no generic habitat for forest-dwelling bats and different habitats will favour different species (Guldin et al., 2007), so the selected measures must consider the species most negatively affected by wind farms in each region.

In intensively explored forests, clear cuttings in large areas are common, and this may represent the sudden loss of important foraging and roosting grounds for bats (Borkin et al., 2011; Hutson et al., 2001; Russo et al., 2010). Allowing some stands to grow older may attenuate such impacts, while increasing spatial heterogeneity and the potential development of roosting sites in cavities of bulkier older trees (Russo et al., 2010). The installation of bat-boxes in younger forests should also be taken into consideration (Ciechanowski, 2005) and is specifically relevant for species of the genus *Nyctalus* that present significant fatality numbers in European wind farms.

In areas of intensive agriculture, the planting of live fences and native trees and shrubs provides additional refuge and breeding habitat for many bat species. In systems like Bocage (a habitat typically composed of very small parcels of land separated by hedgerows and ditches found in western Portugal and France), shrubs and trees alternate with agricultural fields promoting greater floristic diversity, which potentially supports greater faunal diversity (Guil and Moreno-Opo, 2007; Haddad et al., 2001; Knops et al., 1999).

### Preservation of existing roosts

The occurrence of wildlife populations is limited by the availability of refuge and successful breeding places. As referred above, mature trees are prime roosts for forest bats all year long, and may be especially relevant during the maternity season (Betts, 1998; Carter and Feldhamer, 2005). So, the maintenance of old trees and snags, prime locations while natural shelters for forest bats, must also be provided (e.g. Ruczyński et al., 2010).

Roosts used by bats in the vicinity of wind farms, whether of natural or of anthropogenic origin, may be improved or protected to optimise roosting conditions. It is well known that bats that roost in caves, mines and buildings are particularly vulnerable to anthropogenic distress (Agosta, 2002; Hutson et al., 2001), and tend to abandon roosts when these are frequently disturbed (Thomas, 1995). Indeed, several important bat roosts are known to have been lost when caves were opened to the public as show caves or used for sporting activities too often (Ransome and Hutson, 1999). Restricting human access to roosts, either underground, crevices or trees may be recommended in some cases. For example, setting adequately designed gates or fences in the entrances of caves and mines may reduce human disturbance of important roosts (Rodrigues, 1996; Tuttle, 1977). Certainly, neglecting this type of maintenance or distress limitation may lead to the loss of local populations (Limpens et al., 2000; Ransome and Hutson, 1999).

The preservation of old buildings, bridges and other anthropogenic structures that are often used as roosts not only by *Pipistrellus* species, but also by species of the genus *Nyctalus*, among others (e.g. Amorim et al., 2013; BCT, 2012) is also a key issue to bat conservation, and can assume an important role in the wind farm context. Special attention should also be given to building restoration and demolishing, as disturbances made in critical times of maternity and hibernation may cause severe mortality in bat populations (Ransome and Hutson, 1999; Sherwin et al., 2000). Monitoring of any changes is important since access points to roosts used by bats may be blocked, as for example by nesting birds, or even destroyed by minor modifications (e.g. BCT, 2006; Kelleher and Marnell, 2006; Mitchell-Jones, 2004; Waring, 2011).

### Provision of new roosts

Native mature forests had been showing a significant decrease in Europe in the last three decades (Gibbs and Greig, 1997; Jung, 2009; Luisi et al., 1993; Oleksin and Przybyl, 1987; Santos and Martins, 1993; Szweczyk and Ufnalski, 1998; Sonesson and Drobshev, 2010; Szepesi, 1997; Thomas et al., 2002). As a consequence, many forest-
dwelling bats have lost their natural roosting habitats. Even bat species adapted to artificial structures (e.g. walls and stone houses, bridges, fences) had been losing potential roosts, as these structures fell into disuse and were gradually abandoned, presenting risk of collapse, or were entirely destroyed.

The creation of new artificial sites, such as bat-boxes built with long-lasting materials (e.g. maritime plywood), is then of crucial importance for European bats, and should be implemented in areas where the availability of natural roosts is low (Flaquer et al., 2006). In fact, Ciechanowski (2005) showed that the occupation of artificial roosts by P. nathusii and Plecotus auritus was significantly higher in pine monocultures than in deciduous forests, because in the latter the availability of natural roosts is much higher. The design and bat box placement-schemes should respect the ecological requirements and preferences of the target-species. For instance, N. leisleri and N. noctula, two of the most affected species by wind farms in Europe, are quite selective in their choice of natural roosts, preferring high-located cavities (ca. 19 m above the ground), in more open surroundings, with smaller entrances, that are consistently dry, and at a safe distance from martsens (Ruczyński and Bogdanowicz, 2005). While N. noctula seems to prefer cavities with wider inside cross section and with only one entrance, N. leisleri prefers cavities with more than one entrance (Ruczyński and Bogdanowicz, 2005). N. leisleri also seems to prefer roosts with entrances clear from dense vegetation, in areas close to water lines and low tree density (Spada et al., 2008).

Although bat boxes have been used for replacement of lost refuges, or even for the purpose of providing new roosts or even as way of facilitating studies about bat ecology, being one of the most adopted conservation measures, few studies have addressed the effectiveness of these structures (Arnett and Hayes, 2000; Brittingham and Williams, 2000; Flaquer et al., 2006; White, 2004). Occupancy rates of bat boxes seem to vary with factors such as geographic location, type of box and sunlight exposure (Mitchell-Jones, 2004). Studies in the United States suggest increasing occupancy rates along the years, which vary with the placement site of the box: trees — 20%, poles — 52%, and buildings — 64% (Kiser and Kiser, 2004). In any case, the occupation of bat-boxes by bats may take a while, so they may need monitoring for several years to assess their effectiveness.

Creation of ponds

Bats constitute a group with unique natural history traits, such as the ability to fly and echolocate that make them particularly susceptible to energy and water availability (Adams, 2010; Arlettaz et al., 2001; Barclay, 1994; Barclay and Harder, 2003). In fact, water availability represents a limiting factor to the occurrence and foraging habitat selection by many bats (Adams and Hayes, 2008; Rainho and Palmeirim, 2011, 2013), especially during the summer in drier regions of Europe. However, global climate change will result in increasing average annual temperatures and in a significant decrease in precipitation. So, water-limited environments are expected to increase worldwide (IPCC, 2008). By creating small ponds, water may be available for bats all year long. Ideally, to ensure the sustainability of these ponds in the long term, and to avoid the cost of artificially supplying water, these structures should be placed in areas where rainfall naturally accumulates, and/or take advantage of the proximity of other sources of water such as wells and fountains. Still, in times of severe water scarcity, ponds could be supplied artificially. A few studies provide support for the importance of artificial water sources for bats. For example, heliponds created for fire suppression in North American pine stands were considered important for bats to forage and drink (Vindigni et al., 2009); a similar trend was found for retention-ponds created in agricultural landscapes (Sirami et al., 2013; Stahlschmidt et al., 2012).

In addition to providing water for bats and other wildlife, ponds are fundamental systems for the emergence and development of some insect taxa (Cayrou and Cérégino, 2005) that can compose the diet of bats. Allowing and promoting the development of autochthonous vegetation in the margins of the ponds not only provide favourable foraging and shelter habitat for other animal groups (Biggs et al., 1994; Oertli et al., 2002), but also promote the development of diverse insect assemblages, while simultaneously offering bats, and other taxa for that matter, protection against natural predators (Gee et al., 1997). Pond characteristics may determine which bat species are privileged. There is evidence that ponds located in open areas may benefit species with low flight manoeuvrability (e.g. Nyctalus spp. and Eptesicus spp. Ciechanowski, 2002), while those integrated with connectivity elements such as treelines may favour species that follow linear landscape features (e.g. Pipistrellus spp. Downs and Racey, 2006). A comprehensive compilation of pond designs is available from the project Million Ponds (www.freshwaterhabitats.org.uk/projects/million-ponds/). Hopefully the information gathered during the project, and elsewhere, will increase the scientific knowledge about the most successful designs and benefited species.

Selecting suitable conservation measures for wind farm offset/compensation programmes

The selection of a specific conservation measure for a given wind farm requires a baseline study. This study should contain information on the most affected species, but also on the ecological, social and economical scenarios of the directly affected areas and of the bounding areas. Only then it will be possible to adequately identify the most suitable measures for the particular residual effect to be compensated.

In Table 2 we present, for each conservation measure detailed above, the most suitable areas for implementation, the bat species expected to benefit the most, with special emphasis on those showing higher fatality rates at European wind farms, the expected outcomes, an estimate of how long it may take for a visible offset/compensation effect, and a qualitative estimate on the implementation cost.

Bat conservation and wind energy in Europe: opportunities, challenges and constraints

Despite the global financial crisis since 2008, the cumulative installed wind power capacity worldwide had, by May 2013, reached 282 GW, and is still increasing at a rapid pace (WWWEA, 2013). Europe is among the most dynamic markets, with Germany, Spain, Italy, France, UK and Portugal at the top of the installed capacity (WWWEA, 2013). This means that the minimisation and compensation of negative impacts on European biodiversity associated with wind power infrastructures is crucial to reconciling the production of clean energy with nature and biodiversity conservation and management, under the light of sustainable development.

Either directly associated with the offset or compensation of the direct impacts of wind farm facilities or with the mitigation of other indirect impacts of anthropogenic origin, most of the measures suggested in this paper entail management actions undertaken in private land that may not be, and often are not, owned by wind farm developers. This is surely one of the major constraints in the application of many of the proposed measures: the need for partnerships between private managers, where there is little space for the intervention or facilitation by government authorities with responsibility in the evaluation of the process of environmental impact assessment and of follow-up monitoring programmes. Indeed, more than half of European forests are privately owned (Schmithüsen and Hirsch, 2010), and more than 50% of Europe’s land surface is classified as agricultural land (Corine Land Cover, 2013). In this scenario, conflicts of interest may arise between human economic activities and nature and biodiversity conservation in the same land (Breitenmoser, 1998).

The establishment of i) local or regional reserves and/or ii) agreements with landowners or managers may be essential to define regimes of sustainable land-uses. The definition and implementation
<table>
<thead>
<tr>
<th>Offset/compensatory measure</th>
<th>Most suitable area</th>
<th>Target bat species</th>
<th>Expected outcomes</th>
<th>Estimated time for visible effects</th>
<th>Associated costs</th>
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<tbody>
<tr>
<td><strong>Management of Autochthonous Forest</strong></td>
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<tr>
<td>Preservation of older trees with cavities</td>
<td>Patches and forests of autochthonous species Riparian galleries</td>
<td>Especially <em>N. leisleri</em> and <em>N. noctula</em></td>
<td>Preservation of existing roosts Increase in food availability</td>
<td>Short-term</td>
<td>Low</td>
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<tr>
<td>Non-removal of standing or fallen dead trees</td>
<td></td>
<td></td>
<td>Increase in food availability Enhancement of roost formation Creation of flight corridors Enhancement of vertical heterogeneity Healthier tree development</td>
<td>Short-/long-term</td>
<td>Low</td>
</tr>
<tr>
<td>Branch thinning</td>
<td></td>
<td><em>Pipistrellus</em> sp.</td>
<td></td>
<td>Short-term</td>
<td>Medium</td>
</tr>
<tr>
<td>Maintenance of riparian galleries</td>
<td></td>
<td>All bat species</td>
<td>Enhancement of vertical heterogeneity Increase in food availability</td>
<td>Short-/medium-term</td>
<td>Low/medium</td>
</tr>
<tr>
<td><strong>Waterline management</strong></td>
<td>Watercourses</td>
<td>All species but especially <em>P. nathusii</em></td>
<td>Increase in food availability</td>
<td>Short-/medium-term</td>
<td>Medium/high</td>
</tr>
<tr>
<td><strong>Maintenance of the extensive exploitation of traditional agro-forestry European ecosystems</strong></td>
<td>Montados/Dehesas Olive groves Woodland pastures</td>
<td>All bat species</td>
<td>Creation of flight corridors Enhancement of vertical heterogeneity Reduction of the occurrence of large fires Increase in food availability</td>
<td>Short-/medium-term</td>
<td>Low/medium</td>
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<tr>
<td>Creating small clearings or agricultural plots</td>
<td>Scrubland areas</td>
<td>All bat species</td>
<td>Enhancement of spatial heterogeneity Enhancement of foraging areas Increase in food availability</td>
<td>Short-/medium-term</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Diversification of Forest and Agriculture Monocultures</strong></td>
<td>Creation of clearings within the forest, grazing and uneven stands</td>
<td>Production forests</td>
<td>All bat species</td>
<td>Enhancement of spatial heterogeneity Increase in food availability</td>
<td>Short-/medium-term</td>
</tr>
<tr>
<td>Plantation of live fences and native trees and shrubs</td>
<td>Areas of intensive agriculture</td>
<td>All bats species, especially from genus <em>Pipistrellus</em></td>
<td>Enhancement of spatial heterogeneity Enhancement of foraging areas Increase in food availability Increase in roost availability Enhancement of connectivity elements</td>
<td>Long-term</td>
<td>Medium/high</td>
</tr>
<tr>
<td><strong>Preservation of Existing Roosts</strong></td>
<td>Forested areas Caves, buildings, bridges and other artificial structures in the vicinity of the wind farm</td>
<td>Especially <em>N. leisleri</em> and <em>N. noctula</em> All bat species</td>
<td>Maintenance of roost availability</td>
<td>Short-term</td>
<td>Low</td>
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<tr>
<td>Maintaining roost suitability</td>
<td></td>
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<td>Short/long-term</td>
<td>Low/medium</td>
</tr>
<tr>
<td><strong>Provision of New Roosts</strong></td>
<td>Production forests and agriculture areas Areas of water scarcity</td>
<td>All bat species All bat species, especially <em>P. nathusii</em></td>
<td>Increase in roost availability Increase in water availability Increase in food availability Enhancement of foraging areas</td>
<td>Short-/medium-term</td>
<td>Medium</td>
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<tr>
<td>Installing bat-boxes</td>
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<td><strong>Creation of Ponds</strong></td>
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of such regimens must contemplate the effective participation of stakeholders, and should be well sustained by scientific, technical and even traditional knowledge so as to avoid conflicts that may, ultimately, become an additional source of threat for wildlife.

In the European Union, the Birds Directive (79/409/EEC) and the Habitats Directive (92/43/EEC) are the two fundamental pillars of nature conservation legislation. These directives use a twin track approach for habitat and species protection and allowed the creation of an EU-wide network of protected areas, known as Natura 2000, that covers about 20% of the European territory. The Habitats Directive, in Article 6(4), sets out the legal mechanism to protect Natura 2000 sites from damaging plans or projects which, in theory, should only proceed if considered to be of overriding public interest, with no available alternatives, guaranteeing effective compensatory measures, and ensuring that the overall coherence of the Natura 2000 network is maintained (Dodd, 2007). However, the directive has serious implementation problems; presently, as the network-designation process reaches its conclusion, the challenge lies in achieving effective management in each site (Pullin et al., 2009), because there is still a large gap between the designation of the Natura 2000 sites and the effective implementation of conservation measures in these sites (e.g. Apostolopolou and Pantis, 2009).

Additionally, several important areas for wildlife are still lacking any kind of protection policy/mechanism (Araújo et al., 2007; Dimitrakopoulos et al., 2004; Maieronno et al., 2007; Sánchez-Fernández et al., 2008). Because these areas potentially represent good foraging and roosting spots for bats they should be safeguarded, especially during the critical periods of the life-cycle of bats. Despite their importance, due to small size or spatial discontinuity, many of these areas do not fulfill the necessary requirements to be established as formal protected areas by national or European legislation. Nevertheless they could benefit from the creation of local or regional conservation regimes, established by local governments or non-governmental organisations. When managed properly, public access to these areas may be critically important to gaining public support for the classification of such local and regional conservation sites (Bauer et al., 2009). Moreover, public access together with environmental education and eco-tourism schemes, may promote public perception of and support for the conservation of biodiversity (Blangy and Mehta, 2006; Eagles et al., 2002; Kiss, 2004).

Alternatively, or in complement, the establishment of agreements with landowners and/or managers, restricting the timing of potentially disturbing activities may reduce or even completely circumvent bat disturbance during critical periods. Still, some agriculture and forestry activities like cork removal, honey extraction, crop harvest, among others, have temporal specificities, so an agreement between conservation objectives and the requirements of the production system must be pursued.

Therefore, other non-ecological factors determining the practical feasibility of successful offsetting should be analysed under social, cultural, technical, legal and financial headings (BBOP, 2012c). In fact, the proposed offset/compensatory measures should take into account the social dimension and attempt to accomplish benefits for local communities and owners, in order to engage stakeholders in the implementation of the offset/compensation actions. Often, the involvement of different individuals, groups and/or associations may be necessary to ensure biodiversity offset fairness; the success of the offset/compensation programmes may also be dependent on reimbursements to indigenous people, local communities and other directly affected stakeholders (BBOP, 2009b).

Environmental education and raising awareness of communities and local stakeholders is a key issue in wildlife conservation in areas with human occupation. In fact, successful wildlife management is often dependent on the level of engagement of the people living in or nearby conservation areas. Participative sessions should be promoted for these communities, especially involving land managers, hunters, loggers, either individually or in the form of associations and NGOs. Free workshops on themes such as gardening management, organic farming, and waste disposal are desirable, as these activities are directly related to the creation of suitable conditions for native plants and the associated insect fauna (Asociación Columbres, 2009; Guil and Moreno-Opo, 2007).

In the European Union, the potential conflict between human economic activities and biodiversity conservation may also be reduced by the effective implementation of agro-environmental schemes foreseen by the EU rural development policy. These measures are indirect offsets, i.e., agreements with individuals to cede the right to convert land cover for profit (Quintero and Mathur, 2011). More specifically, these schemes foresee payments to farmers who voluntarily subscribe to commitments related to environmental protection (http://ec.europa.eu). Agro-environmental measures are compulsory for the member-states (Council Regulation on Rural Development 1698/2005/EC) but there have been significant cuts in the budget for rural development in many European countries which have to co-fund those agro-environmental schemes — thus creating an additional constraint to the application of many of the proposed measures.

The European landscape entails an additional management problem, as a significant percentage of privately owned rural areas are in the form of small-scale household land parcels and farms (Bowler, 1985; Riddell and Rembold, 2000; van Dijk, 2003, 2007). So, even if a farmer and/or manager comply with some kind of environmental scheme aimed at bat conservation, or other component of biodiversity, this does not necessarily mean that the neighbouring land will follow. In some cases, this may result in a very small area dedicated to the implementation of the compensatory measures, which is frequently ineffective in attaining the conservation objectives proposed.

According to the Business and Biodiversity Offsets Programme (BBOP, 2012b), offsets/compensatory programmes that achieve ‘net gain’ through additional conservation actions could contribute to bat conservation. Additionally, a fraction of the revenues generated by projects with negative impacts may be dedicated to co-fund agro-environmental schemes (Quintero and Mathur, 2011). For example, in Portugal this kind of financing towards conservation is already considered through the creation of offset funds for nature and biodiversity conservation that result not only from the state budget but also from environmental compensation revenues of major private infrastructure projects. Another example comes from the USA where a kind of reclamation fund, paid by the promoters of hydroelectric and oil infrastructures, is in place to be used whenever damages to the environment and biodiversity occur (Cole, 2011).

Another important aspect of offset and compensatory programmes is that they should be based on adaptive management incorporating monitoring and evaluations, with the objective of securing outcomes that last at least as long as the project associated impacts and preferably in perpetuity (Principle 8; BBOP, 2012b). Based on that, mandatory programmes on i) bat mortality monitoring at wind farms, ii) the assessment of the offset/compensatory measure implementation and iii) the monitoring of effectiveness and success of the implemented measures, should be the rule in European countries (Baber, 2012; BBOP, 2012b; Quintero and Mathur, 2011). In fact, even if a continued or periodic evaluation of the effectiveness of the implemented compensatory measures is legally foreseen in some European countries — though often only for specific projects and if included in the infrastructure permit conditions — no country seems to be actually implementing this obligation (personal information obtained through inquiries done to the focal points of the EUROBATS Intersessional Working Group on Bats and Wind Farms). This evaluation of the implementation of the offset/compensatory measures, especially those based on the improvement of the ecological conditions for bats, is essential to effectively assess their benefit to bat conservation.

Concluding remarks

Our review indicates that, in theory, the residual impacts that remain after avoidance and minimisation may potentially be offset or
of compensatory measures in European countries.

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