Chapter 5
The Indirect Impacts of Wind Farms on Terrestrial Mammals: Insights from the Disturbance and Exclusion Effects on Wolves (*Canis lupus*)

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5.1 General Overview

In a growing number of countries, including Portugal, wind power is becoming increasingly important as a power supply. According to the Portuguese Renewable Energy Association (APREN), presently, one quarter of the consumed energy in Portugal comes from wind (APREN 2017). Due to the functional characteristics of wind turbines, most of the impact studies have focused on flying vertebrates, specifically birds and bats, by addressing activity patterns, habitat use and mortality (e.g., Baerwald and Barclay 2009; Drewitt and Langston 2006; Kunz et al. 2007; Pearce-Higgins et al. 2009). Impacts on non-flying vertebrates have been poorly studied, despite several findings that terrestrial animals can be affected by wind power development in various ways (de Lucas et al. 2005; Rabin et al. 2006; Walter et al. 2006; Santos et al. 2010; Álvares et al. 2011; Lovich and Ennen 2013; Agha et al. 2015; Lopucki and Mros 2016).

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M. Mascarenhas et al. (eds.), *Biodiversity and Wind Farms in Portugal*,
https://doi.org/10.1007/978-3-319-60351-3_5

Habitat modifications and behavioural changes are described as impacts that can occur on terrestrial vertebrates, due to several actions inherent to wind farms construction and operation: turbines installation, roads construction, transformers, substations and power lines (Kuvlesky et al. 2007). All these infrastructures may cause direct and permanent habitat loss and fragmentation, even though this might be of minor importance for large terrestrial mammals with extensive home ranges (Helldin et al. 2012). The increased human presence related to wind farm construction and operation can also augment wildlife disturbance, particularly during sensitive periods, such as breeding season, and might also increase the risk of mortality by collisions with vehicles along access roads (Kuvlesky et al. 2007; Northrup and Wittemyer 2013). According to a review by Lovich and Ennen (2013), the construction and operation of wind farms have both potential and known impacts on terrestrial vertebrates, such as: (i) increase in direct mortality due to traffic collisions; (ii) destruction and modification of the habitat, including road development, habitat fragmentation and barriers to gene flow; (iii) noise effects, visual impacts, vibration and shadow flicker effects from turbines; (iv) electromagnetic field generation; (v) macro and microclimate change; (vi) predator attraction; and (vii) increase in fire risks.

Regarding the effect of wind farms on large mammals, Helldin et al. (2012) concluded that these vertebrates are affected by the increase of human activity during construction and operational phases. According to these authors, large animals may temporarily avoid wind farms during the construction phase, but when machinery and human presence decrease, animals seem to acclimatise to wind farms, although these responses may vary with species, sex, age, individual, time of the year or type of disturbance. Helldin et al. (2012) also highlighted that the development of road networks associated with wind farms could promote increased access for traffic related to recreation, forestry, agriculture and hunting. The consequence, particularly on remote places, is the increase in human presence, affecting large mammals via significant disturbance, habitat loss and habitat fragmentation. These negative effects are expected to be particularly relevant for species that are more sensitive to human presence and activities, such as large carnivores.

Large carnivores, such as the wolf, bear, lynx or wolverine, tend to avoid areas that are regularly used by humans and—especially for breeding—show a preference for rugged and undisturbed areas (Theuerkauf et al. 2003; George and Crooks 2006; May et al. 2006; Elfstrom et al. 2008; Sazatornil et al. 2016), which are often chosen for wind power development (Passoni et al. 2017) . However, despite these taxa being the regular focus of research and public interest, currently, there is scant knowledge about wind farms' effects on large carnivores. The only known studies on large carnivores were focused on black bears (Wallin 1998), wolverines (Flagstad and Tovmo 2010), and Portuguese wolves (Álvares et al. 2011, 2017), all reporting some avoidance during the construction phase of wind farms. The lack of robust studies either presenting results of a long term BACI (before-after-control-impact) monitoring programme or enough solid data to rule out the effect of other factors, renders the need for further research focusing on the effects of wind farms on large carnivores, particularly for species with a wide range such as wolves.

Impacts of wind farms on wolves may be inferred from the available knowledge about wind farms effects on other large mammals or, instead, from other human activities on wolves (Helldin et al. 2012). In fact, construction and operation of a wind farm involves a set of actions that is very similar to those associated with other infrastructures or human activities such as road development or forest logging. The effects of extensively logged areas and high density of roads on wolves have been widely studied (Person and Russell 2009; Houle et al. 2010; Taylor 2010; Zimmermann et al. 2014) and can provide us insights on the complexities of behavioural responses of wolves to wind farms.

The density of roads (either gravel or paved roads) and logging can have profound effects on wolf movements, habitat use and den site selection, but may also be associated with ambivalent responses from wolves depending on several factors, such as site characteristics and cumulative effects of other sources of disturbance (Zimmermann et al. 2014). Earlier studies conducted in the USA (Thiel 1985; Mech et al. 1988) suggested low road density thresholds (e.g., $<0.58\ \text{km/km}^2$) may be necessary for wolves to endure, although Fuller et al. (1992) pointed that this threshold could be slighty higher ($0.7\ \text{km/km}^2$) in areas with lower human density. However, recent studies in Europe highlighted the adaptive capabilities of wolves, with the species found to be present in areas with average road densities as high as $1.2\ \text{km/km}^2$ (Theuerkauf et al. 2003; Jedrzejewski et al. 2005; Llaneza et al. 2012), reaching even $1.9\ \text{km/km}^2$ in some areas of the Iberian Peninsula (Dennehy et al. 2013). Wolf responses to road accessibilities are also dependent on several cumulative factors, such as habitat quality, human density and prey availability (Eggermann et al. 2011; Llaneza et al. 2012). Furthermore, the expansion of new traffic accessibilities can cause an increase in human-related mortality on wolves (Zimmermann et al. 2014), presenting a significant negative impact particularly during sensitive periods such as the breeding season. On the other hand, wolves may benefit from the environmental changes induced by wind farms, by preferably using these habitat discontinuities as areas of higher prey availability (Berger 2007). This evidence reinforces the need for local monitoring programmes so that the specific interactions between wolves and wind farms can be fully understood.

In this chapter, based on monitoring plans that have been conducted by the authors, we aimed to summarise the available knowledge about the effects of wind farms on wolves in Portugal, along with insights about methodological approaches, and mitigation and compensation measures.

5.2 Wolves and Wind Farms in Portugal

5.2.1 Setting the Context: Wolf Distribution, Landscape Specificities and Environmental Issues

Until the beginning of the twentieth century, wolves were found across all Portuguese continental territory, but, over a few decades, this species became

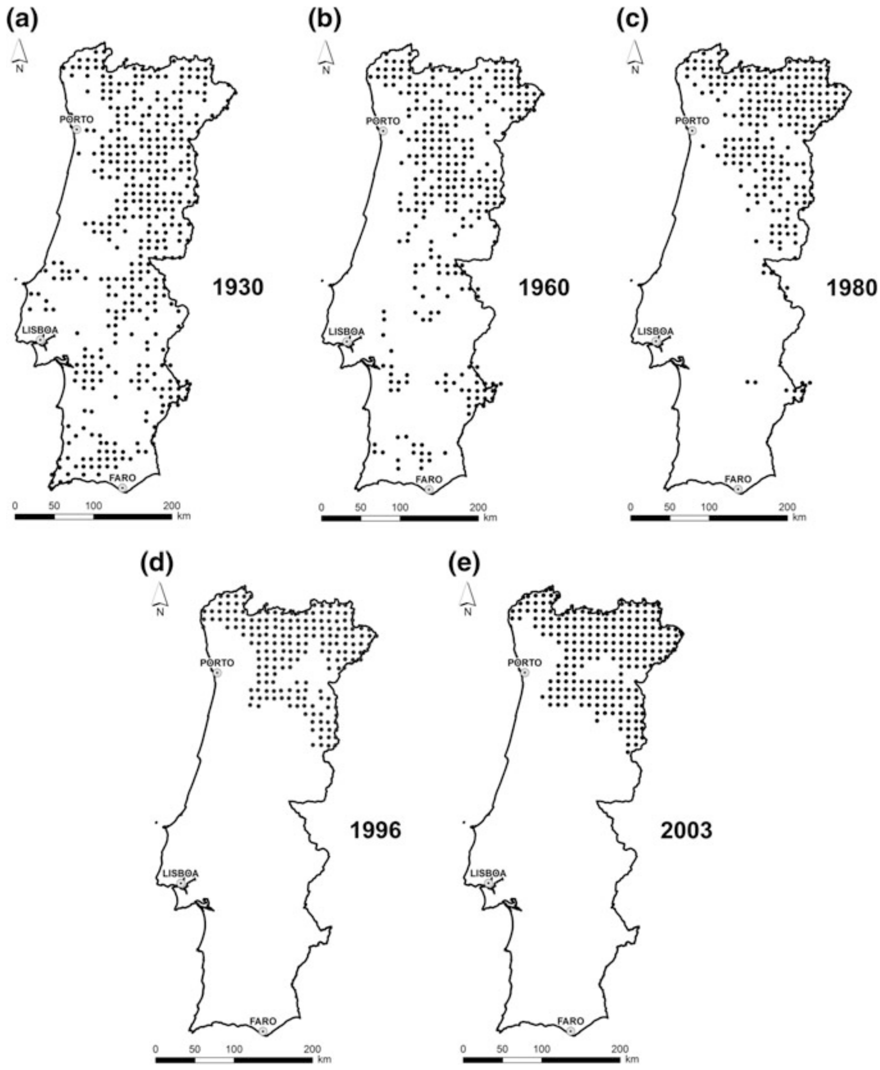

Fig. 5.1 Wolf distribution in Portugal over the last century: **a** 1930, **b** 1960, **c** 1980, **d** 1996, **e** 2003. Adapted from Petrucci-Fonseca (1990) and Pimenta et al. (2005)

extinct from the southern and coastal areas, persisting only in the northern mountainous regions (Petrucci-Fonseca 1990; Fig. 5.1a–e). This sharp decline was probably due to a combination of factors such as a decrease in food availability (both wild and domestic prey), habitat fragmentation from expanding human activities and increasing human persecution as a result of widespread access to firearms and poison (Petrucci-Fonseca 1990).

This population decline induced Portuguese authorities to impose a restrictive legal framework to protect the wolf. Since 1988, this species has been fully protected by national law, which forbids the killing or capturing of individuals or disturbing important areas, such as breeding sites. Additionally, and according to European Community legislation (Habitats Directive 92/43/EEC) the wolf is considered a priority species for conservation, included in the Annexes II and IV, where Sites of Community Importance (SCIs) should be created and managed in accordance with the ecological needs of the species. The wolf is classified as Endangered (EN) by the Portuguese Vertebrate Red Data Book (Cabral et al. 2006) and approximately 30% of its range is covered by National Protected Areas or SCIs.

Since the late 1990s, the wolf range in Portugal has stabilised at approximately 20,000 km^2, corresponding only to 20% of its original distribution area (Petrucci-Fonseca 1990). Currently, and according to the last Portuguese wolf census (Pimenta et al. 2005), the wolf population is estimated at between 200 and 400 individuals (approximately 65 breeding packs), comprising two sub-populations divided by the Douro river (Fig. 5.2). The northern population has between 45 and 54 packs and is continuous with the larger Spanish wolf population, estimated at around 2000 individuals (Álvares et al. 2005) (Fig. 5.2). Nonetheless,

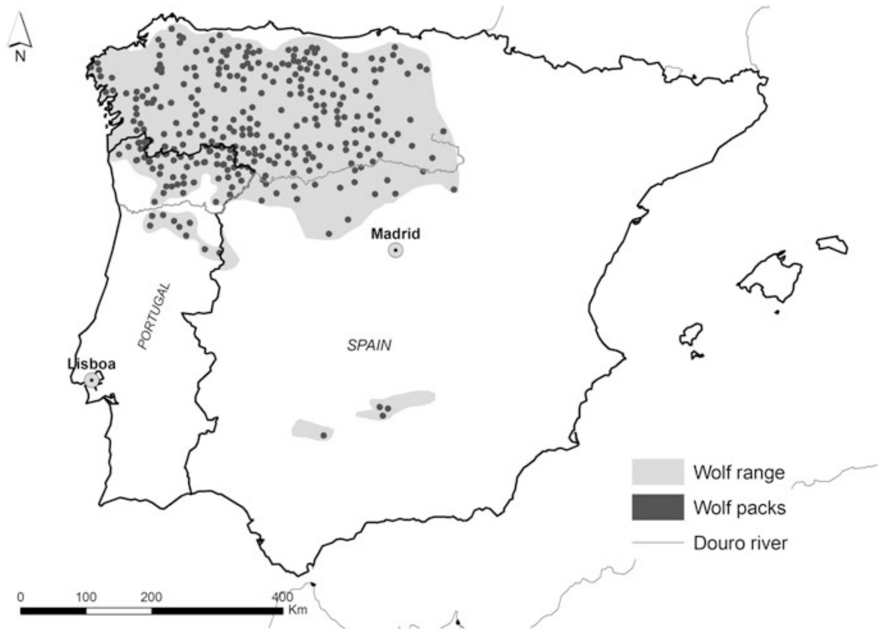

Fig. 5.2 Wolf distribution and location of known packs in the Iberian Peninsula. Adapted from Álvares et al. (2005)

a population decline in some of these northern areas has been predicted if current trends in land use changes, livestock abundance and road density continue to operate (Santos et al. 2007). The portuguese wolf population located just south of Douro river is further reduced, with only six to nine packs, exhibiting a low reproduction rate and a high degree of fragmentation and isolation as suggested by genetic studies (Godinho et al. 2007), which turns it in one of the fewest wolf populations in Europe considered at risk of extinction (Boitani and Ciucci 2009).

Although wolves are often considered a symbol of wilderness and remote places (Mech and Boitani 2003), in the Iberian Peninsula and particularly in Portugal, this carnivore has been living in a very humanised landscape for several centuries, and has adapted to human presence, activities and persecution (Álvares et al. 2011; Eggermann et al. 2011, Llaneza et al. 2012). Wolves can live wherever they have enough food and are not killed by humans (Mech and Boitani 2003), and in Portugal those conditions mostly occur in the mountainous areas of the North and Centre (between 800 m and 1500 m above sea level), which became their stronghold due to lower human density, difficult accessibility and higher prey availability (Grilo et al. 2002; Eggermann et al. 2011). At these domains, the landscape is dominated by rocky scrublands, with scarce forest cover due to livestock grazing and wild fires. The scarcity of forest and woodland results in few available wild prey: roe deer (*Capreolus capreolus*), while expanding, still have low densities (Torres et al. 2015a); red deer (*Cervus elaphus*) are very localised within wolf ranges or occur at low densities (Vingada et al. 2010); while wild boar (*Sus scrofa*) are the only prey with wide occurrence and high densities in recent years (Vingada et al. 2010). This ecological context led wolves to feed mainly on domestic prey, such as cattle, goats, sheep and horses, which comprise up to 80% of the wolf diet in most of Portugal (Vos 2000; Álvares et al. 2015; Torres et al. 2015b). Consequently, there is a big conflict between livestock owners and this predator, resulting in high wolf mortality due to human causes (illegal hunting, poisoning and trapping), despite legal protection and considerable conservation efforts (Álvares et al. 2015).

The recent development of wind farms in these mountainous areas within the wolf range posed a challenge for wolf conservation, mainly due to the increased human accessibility and the consequent disturbance to areas that were previously quite remote.

5.2.2 Methodological Approach

Considering the current endangered and legal status of wolves in Portugal, the national authorities imposed the measure that every new infrastructure (e.g., wind farm, road, dam) projected within the wolf range should be subject to an Environmental Impact Assessment (EIA) study, to evaluate and minimise potential negative effects on this carnivore. If negative impacts are expected, the project's approval is dependent on the promotion of different mitigation and/or compensation measures, which can range from local layout adjustments, restrictions in construction scheduling or promoting regional habitat management actions. Ultimately, if the predicted impacts are too severe, it may lead to the entire project being cancelled.

In order to assess the potential impacts of wind farms on wolves, Portuguese researchers have relied on an array of wolf survey designs and techniques, adapted to the mild climate and absence of snow cover of this southern European country, which we summarise below.

5.2.2.1 Sampling Designs

BACI (before-after-control-impact): survey designs have been the standard for wolf monitoring programmes on wind farms in Portugal. Ideally, these studies are conducted from at least one full year before construction, throughout the whole construction period and for 3–5 years of the wind farm operation. The main goal is to compare several wolf biological parameters between time periods (before, during and after construction) along different distance gradients. This zonation includes control areas (defined as extents far enough from the wind farm to not be affected by the project but located close enough to be used by the same animals or pack) to assess whether any changes are due to the project or related to wolf population hazards. In BACI analysis, the percentage of biological indicators that are significantly different (positive or negative) when tested at a given significance level, is used to determine the direction and magnitude of the impact. Study areas are normally centred on the wind farms and then divided into square cells of 2 $\times$ 2 km or 5 $\times$ 5 km where wolf surveys techniques are systematically conducted (Fig. 5.3).

Impact–gradient approach: has been also used in wolf monitoring programmes on wind farms. This study design is used for impact quantification in relatively small assessment areas on homogeneous environments. The analysis is based on the relationship between the impact indicator (such as the level of wolf presence or abundance) and a gradient of distances from the wind turbines (concentric distances) (Fig. 5.4).

5.2.2.2 Wolf Biological Parameters

Presence/absence: this is the basic parameter for evaluating whether wolves use an area. Within each sampling unit (5 $\times$ 5 km or 2 $\times$ 2 km cell), wolf presence is surveyed throughout the whole monitoring plan (before, during and after construction) and variations in this parameter can be correlated with the wind farm proximity, construction schedule or human disturbance.

Relative abundance and spatial use: the intensity of use of each sampling unit can tell us more than just the presence or absence of the species. Wolf monitoring plans rely on relative abundance indexes to acknowledge changes in the use of space by this carnivore in relation to the wind farm development. The relative abundance indexes most commonly applied are kilometric abundance indexes

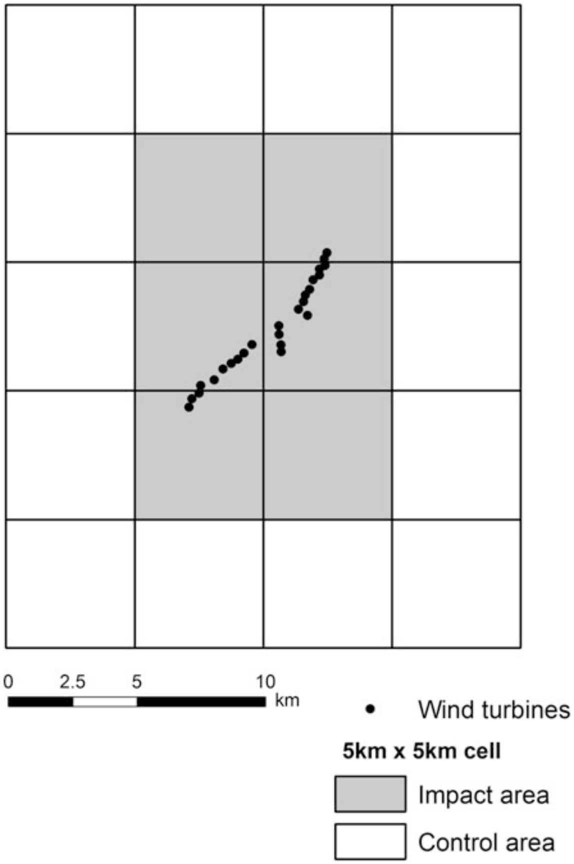

Fig. 5.3 Example of a BACI study area, centred on the wind farm and using 5 × 5 km cells. For posterior analysis, core cells around the wind turbines area considered impact areas while peripheral cells are considered control areas

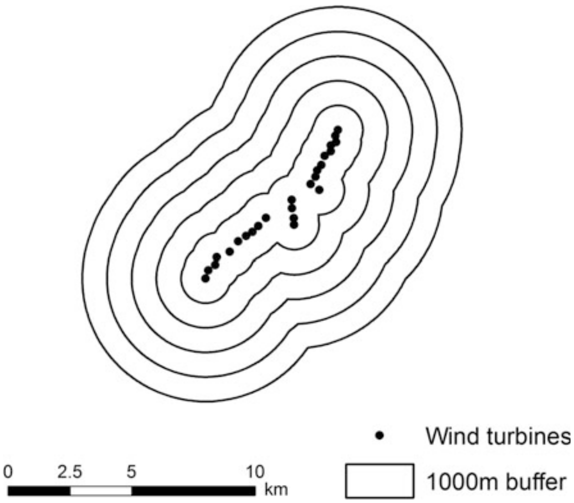

Fig. 5.4 Example of an impact–gradient study area, where concentric buffers of 1000 m width are used for analysis. Inner buffers are considered impact areas while marginal buffers are control zones

(KAI) for scat surveys or records abundance indexes (RAI) for photo trapping. The survey effort must be homogeneous along the whole study area so that results can be compared. Significant statistical differences between different cells or between seasons or years can be correlated with the presence of the wind farm (distance, construction schedule, operational phase).

Breeding location and success rate: wolves breed at specific locations where pups stay for a long period (3–5 months) in the dependency of adults. These sites are often reused over consecutive years and over several decades if no major disturbance event occurs (Mech and Boitani 2003). In this context, breeding sites, comprising both dens and pup-rearing areas, are considered crucial to assure wolf population viability in the short term. Differences in the location and use of these sites, as well as the reproductive success rate of the local pack can be correlated with the wind farm distance and operational phase (before, during and after construction).

5.2.2.3 Wolf Monitoring Techniques

Scats surveys: are the most common method for wolf monitoring in the Iberian Peninsula to assess wolf presence, relative abundance and intensive territorial marking as a predictor of wolf reproduction (e.g., Álvares et al. 2000; Roque et al. 2001; Eggermann et al. 2011; Blanco and Cortés 2012; Llaneza et al 2014). Therefore, this sampling method has been the most used for wolf monitoring programmes on wind farms in Portugal (Fig. 5.5a). Through predefined transects within each sampling unit, wolf scats are used as an indicator of the presence and abundance of this species. The Kilometric Abundance Index (KAI) is calculated monthly, seasonally and annually and then compared between time periods and between sampling units. Currently, most studies use genetic validation of detected scats, since the frequent presence of domestic dogs roaming within wolf range may lead to misidentifications on the field. The use of non-invasive genetic analysis also allows for the identification of individuals and determination of sex ratios, the minimum number of individuals in the study area and the kinship relations between animals, in order to better assess the local wolf population size and social structure.

Camera-trapping: has been used in recent years as a method to assess wolf presence and relative abundance in relation to wind farm projects (e.g., Grupo Lobo 2013). Using the same 2 × 2 km or 5 × 5 km sampling units, one or two cameras are deployed in each cell, and are on the field for 30–45 consecutive days within each survey period (Fig. 5.5b). The data are used to assess wolf presence at each sampling cell, and relative abundance indexes can be calculated using the number of independent events per day. An estimation of site occupancy can also be made using this methodology. Camera-trapping can also be deployed in certain areas to confirm breeding occurrence and determine breeding site location. Despite the advantages and usefulness of this method, there are also some drawbacks—namely the difficulty of using this method in poorly forested landscapes that are frequently used by people, leading to repeated camera thefts. On the other hand, is important to note that wolf photos or videos provided by camera-trapping have a strong

Fig. 5.5 Wolf sampling methods used in wind farm monitoring programmes in Portugal: **a** scats surveys (Photograph © 2008 Gonçalo Ferrão da Costa); **b** camera-trapping (Photograph © 2011 Gonçalo Ferrão da Costa); **c** live-capture for telemetry (Photograph © 2008 Monia Nakamura); **d** howling stations (Photograph © 2006 Gonçalo Ferrão da Costa)

communicational and awareness power close to stakeholders (such as wind farm promoters or Nature Conservation authorities), by providing visual evidences of wolf presence which often are crucial to support decision-making processes for mitigation measures, which other methodologies can hardly achieve (Fig. 5.6).

Telemetry is also being used locally to assess the responses of wolves to wind farms (Rio-Maior et al. 2010; Roque et al. 2011; Nakamura et al. 2013). This approach involves live-capturing wolves and fitting them with a GPS (Global Positioning System) collar in order to obtain fine-scale data on movements, activity and habitat use in relation to wind farm construction schedules (Fig. 5.5c). This method also has an important role to support decision-making processes for

Fig. 5.6 Iberian wolf recorded in camera-trapping during a wind farm monitoring plan, allowing an image with high potential for awareness (Photograph © 2013 Grupo Lobo)

mitigation measures, by showing to stakeholders fine-scale movements and behaviour of individual wolves.

Howling stations: are the most common method used to evaluate pack breeding success and to locate pup-rearing areas. Howling stations are conducted during the late breeding season, corresponding to the pup-rearing period (July–September) and use simulated howls to induce a response by the pack members (Fig. 5.5d). When a response is obtained, acoustic analysis of vocalisations makes it possible to discriminate between pups and adults, and, consequently, to confirm reproduction and breeding site location. Direct observations and camera-trapping can be conducted near known breeding areas, in order to detect pups and count a minimum number of individuals. These methodological approaches are normally applied where sign surveys, howling stations or telemetry reveal evidences of breeding sites. Changes in den locations and reproductive rates related to wind farms construction schedules are some of the most important effects to be studied during monitoring programmes and that theirs negative effects must be mitigated.

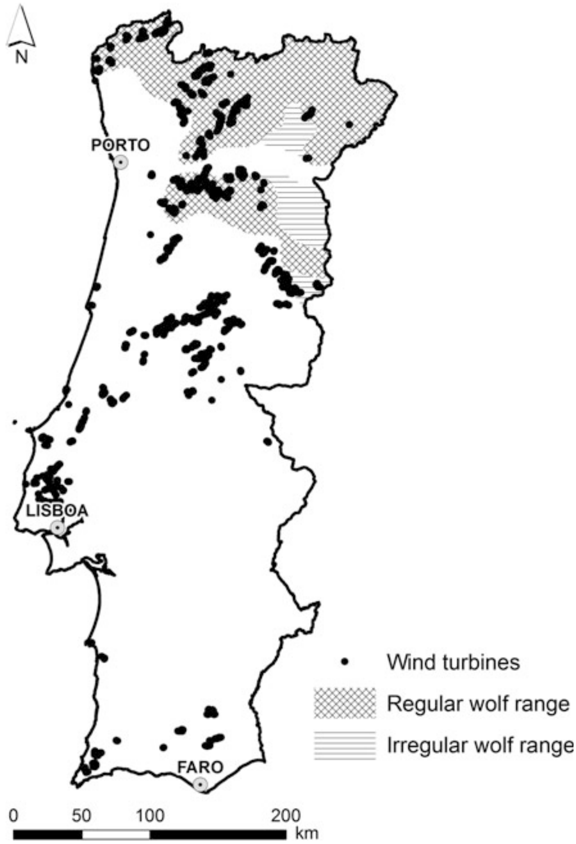

Fig. 5.7 Wolf range and wind turbines distribution in Portugal. Approximately 990 turbines were installed inside the Portuguese wolf range by the end of 2015

5.2.3 Effects of Wind Farms on Wolves in Portugal

Wind farm development in Portugal has an extensive overlap with the wolf distribution area. At the end of 2015, there were 990 wind turbines located inside the Portuguese wolf range (Fig. 5.7), covering the territories of 22 known wolf packs, around one third of the total number of packs estimated to occur in Portugal. These values correspond to an average of 4.8 wind turbines per 100 km^2 inside wolf range and may reach up to 120 wind turbines inside some pack territories located in the South Douro river subpopulation (Álvares et al. 2011) (Fig. 5.8) (for comparison, in Portugal, wolf density ranges from 0.5 to 3.0 wolves/100 km^2 and the average wolf territory size is 170 km^2; Pimenta et al. 2005; Álvares et al. 2015).

Due to the construction of these wind farms, several wolf monitoring programmes have been conducted in Portugal for the last 15 years. Despite the large amount of studies, most of the data collected and analysed is available only in technical reports written in Portuguese rather than in international scientific publications (but see Álvares et al. 2017).

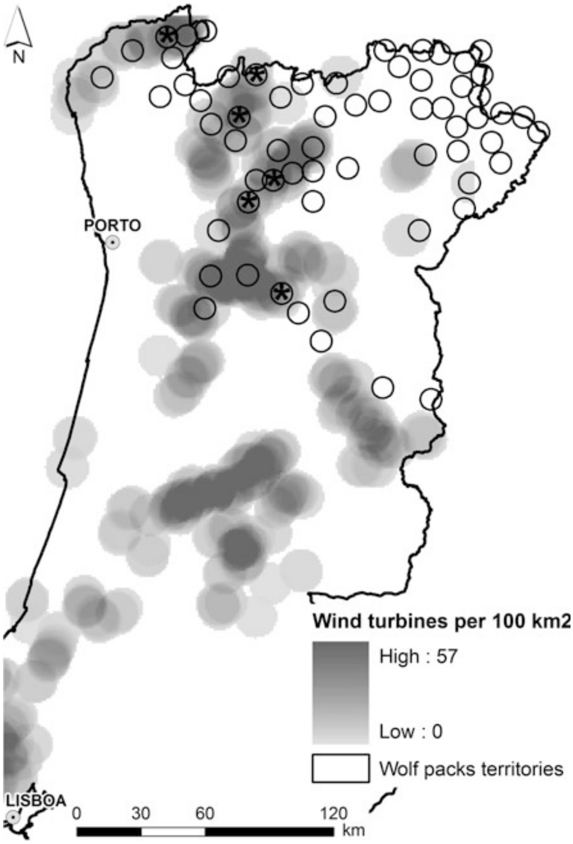

Fig. 5.8 Location of wolf packs in Portugal and wind turbines density per 100 km^2. In total, 22 known wolf territories have wind turbines, reaching 120 turbines inside some territories in the South Douro river subpopulation. Packs marked with * were used below as case studies to assess wolf breeding patterns (e.g., reproductive rates and breeding site location) in relation to wind farms

Based in the results of 11 wolf monitoring programmes conducted by the authors of this book chapter (Table 5.1, see Appendix), the effects of wind farms on wolves can be due to habitat disturbance during construction; acoustic and visual disturbance from wind turbines in operation and increasing circulation of vehicles in the road network built for wind-power development. Regarding disturbance from traffic, results from monitoring plans conducted in Portugal show an evident increase in the number of vehicles using the road network for wind farms. This is very evident during construction and the first years of operation, in contrast with the initial situation when those areas, normally located in remote mountain ridges, were mostly inaccessible to vehicles (Fig. 5.9 and 5.10). The recorded traffic was, on average, 36 times higher during the construction period than in pre-construction (and occasionally reached 200 times higher in some wind farm areas), reducing to 11 times higher in the third year of operation.

The recorded traffic of vehicles during construction and operation of wind farms frequently occurs during night and twilight periods, which largely coincides with the circadian period of highest wolf activity (Mech and Boitani 2003). The traffic inside wind farms is related not only to vehicles from construction and maintenance

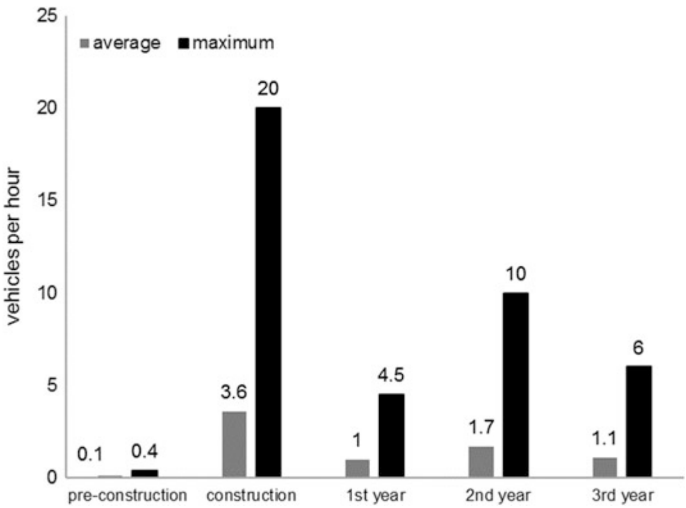

Fig. 5.9 Road traffic (measured as average and maximum number of vehicles per hour) recorded on wind farm areas according to wolf monitoring plans at 11 wind farms within wolf range: pre-construction (1 year), construction and operation (first 3 years)

Fig. 5.10 Examples of wind farm implementation areas within the Portuguese wolf range (Photographs © 2014, 2015, 2008, 2008 Gonçalo Ferrão da Costa)

of these infrastructures but also to vehicles from recreation, hunting, leisure and other outdoor activities. Traffic related to hunting activity is particularly frequent during the operation phase and often includes non-working days, such as weekends (Rio-Maior et al. 2010). Although utility traffic related to wind farm personnel is impossible to prevent, the circulation of leisure traffic is possible to minimise by restricting access for the general public (see Sect. 5.2.4). The augmentation of vehicles circulating in wind farm areas, due to access creation, promotes increased human disturbance, which may induce behavioural changes, particularly in elusive species such as wolves, and increases the risk of mortality due to car collision or poaching (Fig. 5.10a–d).

Regarding wolf presence, monitoring results have shown that this carnivore avoids wind farm areas during construction phase and, on some occasions, throughout the first years of operation. However, the effect seems to be limited as wolves continue to use areas where wind farms have been constructed. In fact, there are packs in Portugal that are still present, although with a very low reproductive rate, in territories where several different wind farms have been implemented (Álvares et al. 2011). The degree of use of wind farms areas by wolves appears to depend on the location and number of wind turbines, habitat suitability and proximity to important core areas in packs territories, such as breeding sites.

Results from wolf breeding patterns showed that packs already breeding more than 3 km away from wind farm areas during pre-construction periods had only minor changes in breeding site location and reproduction success (Fig. 5.11). However, when wind farms were built closer (<3 km) from breeding sites that were regularly used, wolves showed a decrease in breeding success during construction and initial operation phase, as well as shifts in denning sites, which were located progressively further from the wind farm (up to >6 km) to resume regular reproduction (e.g. Álvares et al. 2017) (Figs. 5.11, 5.12 and 5.13). This is particularly evident in the initial stage of wind farm operation, with less than 50% of the wolf packs studied being capable of reproduction in the first year (Fig. 5.13). Results also showed that after 3 years of operation, most of the packs were able of resume reproduction, but with shifts in denning location that involved, on average, a displacement of 2761 m from wind turbines, and could reach up to 6400 m in some packs (Figs. 5.11 and 5.12).

Such responses raise conservation concerns, particularly where availability of suitable breeding sites is a limiting factor and cumulative effects of other threats (e.g., additional infrastructure, human-related wolf mortality) may affect the local wolf population (Passoni et al. 2017). This is particularly relevant in endangered wolf populations occurring in highly humanised and heterogeneous landscapes, such as Portugal.

In conclusion, results from the monitoring studies conducted in Portugal show that wind farms induce important effects on wolves, such as: (i) changes in space use by avoidance during the construction and early operation phase; (ii) decreases in reproductive rates; and (iii) changes in the selection and fidelity of breeding sites used during the birth and pup-rearing period. However, on the other hand, there is evidence that newly formed packs, recently recolonising areas with already built wind farms, have shown a relative tolerance to these infrastructures, selecting breeding sites less than 3 km from wind turbines. Considering these

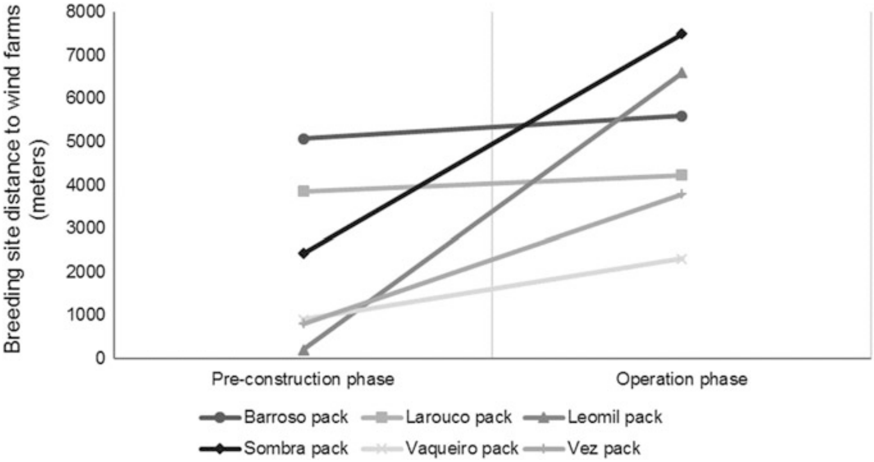

Fig. 5.11 Shifts in individual packs breeding locations, measured as average distance of the last 3 years before wind farm construction (pre-construction phase based in the projected area) and the first 3 years after wind farm construction (operation phase). Results were obtained from long-term monitoring of six wolf packs affected by wind farms comprising a total of 181 wind turbines

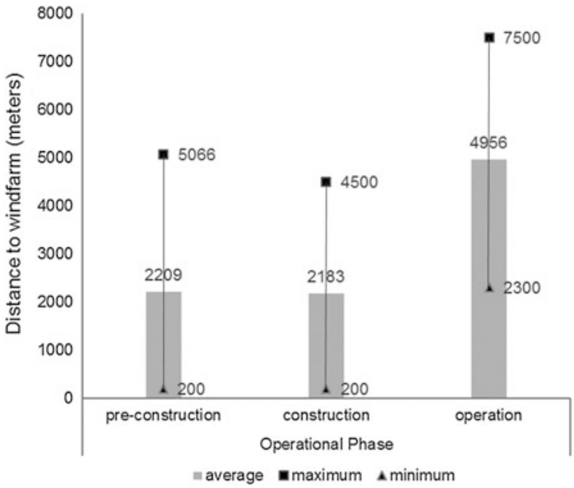

Fig. 5.12 Distances of wolf breeding sites to wind turbines (measured as average, maximum and minimum linear distances in meters) during wind farms schedule, including pre-construction, construction and operation phase, with shifts to breeding sites located further away from wind farms after the construction period. Note that distances reported for pre-construction phase are in relation to projected wind turbines. Results were obtained from long-term monitoring of six wolf packs affected by wind farms comprising a total of 181 wind turbines

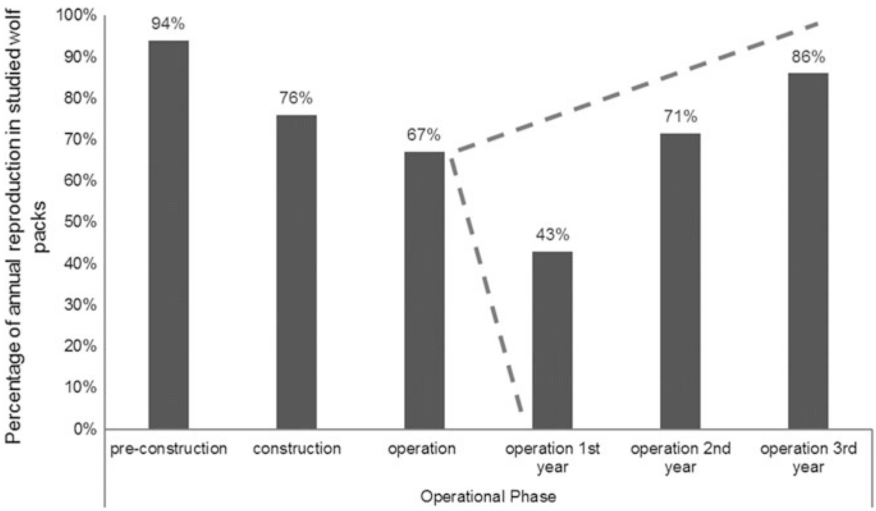

Fig. 5.13 Wolf reproduction success rates (measured as percentage of annual reproduction in studied packs) during wind farms schedule, including pre-construction, construction and operation phase, and in particular, during the first 3 years of operation, with an evident decrease from pre-construction period until early operation phase. Results were obtained from long-term monitoring of six wolf packs affected by wind farms comprising a total of 181 wind turbines

complex responses from wolves to wind farm development, a precautionary approach for protecting known wolf breeding sites should be adopted (see Sect. 5.2.4) in order to minimise the negative effects of wind farms on wolves. Further long-term monitoring studies should also be conducted to evaluate both the degree of tolerance of wolves to existing wind farms and the role of cumulative effects from other human activities on wolf population viability.

5.2.4 Lessons from the Portuguese Experience

The legal protection of wolves in Portugal, which makes them focal species in EIA studies of infrastructures, together with the recent development of wind energy in this country leads to a large number of wind farm monitoring plans targeting this carnivore, probably with no parallel anywhere in the world. Over the last 15 years, survey designs, methodologies or mitigation measures have been fine-tuned so that effective results could be achieved in a way that makes the most sense from a cost–benefit perspective.

In terms of methodological approaches, several considerations can be made:

- Sign surveys, conducted systematically in the study area, are an efficient standard methodology to assess changes on wolf presence and spatial use in relation to wind farms, but require genetic validation of scats, especially in areas with a low wolf density and/or where free-ranging dogs are common;

- Camera-trapping is also a valid methodology to evaluate wolf presence, spatial use and breeding occurrence, but its efficiency is largely dependent on the risk of being stolen. For example, at mountain ridges where most of the wind farms are built in Portugal, the habitat is dominated by open areas and low scrublands, where cameras cannot be hidden or secured from human robbery. The high number of thefts led to data loss and high financial costs.
- Telemetry is the most reliable method to assess fine-scale changes in wolf movements and spatial use. However, the duration and number of individuals that are tagged should be considered in order to cover the whole wind farm schedule (pre-construction, construction and operation phases) and evaluate possible individual differences related to age and social status.

Results have shown that the main impact of wind farms on wolves is the induced reduction on breeding site fidelity and reproductive rates. These effects, particularly when breeding sites shift to more unsuitable areas, may imply decreasing survival and pack viability in the short term. Thus, the primary focus of a monitoring plan should be the detection of breeding sites and breeding success rates before, during and after the construction of a wind farm.

Based on these findings, several mitigation and compensation measures have been applied to attenuate wind farm impacts on wolves in Portugal, such as:

- Protection of known breeding sites by considering a buffer at least 2 km from breeding locations as a 'no-construction' area for wind farm elements, including wind turbines, cables, road network and powerlines.
- Closing the road network built for wind power development in order to reduce traffic and direct human disturbance. However, in Portugal, the use of gates in the main access to wind farms has been difficult to implement due to public use of those areas and the claim for free access to mountain ridges by local populations.
- Besides other mitigation measures to reduce significantly the impacts of a wind farm (by layout adjustments or work restrictions during wolf breeding season or circadian periods with higher wolf activity), compensation measures have been also implemented to positively promote wolf presence at the local or even regional scale. These measures are mostly related to habitat management in order to promote suitable conditions for wolf breeding sites and to recover wild prey populations, such as roe deer (Brotas et al. 2015).
- Other compensatory measures aim to decrease the level of conflict from humans towards wolves, which is mainly related to livestock depredations, and includes actions such as promoting damage prevention measures by using livestock guarding dogs or electric fences (e.g., Ribeiro and Petrucci-Fonseca 2016).

Wolves are an adaptable species, and their ability to coexist with humans for centuries in a landscape as human-dominated as Portugal has been the key factor allowing their persistence despite intense human persecution. However, wolves can cope with human activities and disturbance only to a certain level and in the context of an increasing anthropogenic interference on worldwide habitats, the recent wind farm development can become a major concern when other cumulative factors also occur. Further research on the effect of wind farms in wolves is still needed but the results from monitoring programmes conducted in Portugal already provide valuable insights on the concerns and recommendations that should be taken into account when developing wind farm projects within the wolf range.

Acknowledgements We would like to thanks to everyone whose work contributed to the reviewed data, namely Sara Roque, Helena Rio-Maior, Monia Nakamura, Pablo Sierra, Julia Eggermann, Ana Guerra, Mónica Almeida, Diana Barreto and Barbara Marti-Domken. For financial support, we would like to thanks to EDP Renováveis, ENEOP2, Vento Minho SA and ACHLI.

Appendix

Table 5.1 Wolf monitoring projects used to assess wind farm effects in Portugal, namely for quantification of road traffic and evaluation of breeding patterns

Wind farm	Wind turbines	Wolf pack affected	Reference
Alto do Marco	5	Sombra	Bio3 & Grupo Lobo (2014). Monitorização do lobo-ibérico nos Parques Eólicos do Alto do Marco e Meroicinha II [Iberian wolf monitoring at Alto do Marco and Meroicinha II wind farms]. Relatório 5, Fase 3. 69 pp. (In Portuguese)
Alto Minho I	49	Vez	Álvares, F., H. Rio-Maior, S. Roque, M. Nakamura & F. Petrucci-Fonseca (2017). Ecological response of breeding wolves to wind farms: insights from two case studies in Portugal. In M.R. Perrow (Ed.), Wildlife and Wind Farms: Conflicts and Solutions. Volume 1: Onshore. -Volume 1: Onshore: 432 (pp. 225–227). Pelagic Publishing
Cabeço Alto	9	Larouco	Álvares, F. (2011). Ecologia e Conservação do lobo, *Canis lupus* L., no Noroeste de Portugal [Ecology and Conservation of *Canis lupus*, L. in Northwestern Portugal]. PhD Dissertation. Faculty of Sciences, University of Lisbon. 193 pp. (In Portuguese)
Falperra	20	Falperra/Sombra	Grupo Lobo (2016). Plano de Monitorização do Lobo no Parque Eólico de Falperra-Rechãnzinha, Ano 2 da fase de exploração [Wolf monitoring plan at Falperra/Rechãnzinha wind farm, 2nd year of operation phase], 56 pp (In Portuguese)
Meroicinha II	6	Sombra	Bio3 & Grupo Lobo (2014). Monitorização do lobo-ibérico nos Parques Eólicos do Alto

(continued)

Table 5.1 (continued)

Wind farm	Wind turbines	Wolf pack affected	Reference
			do Marco e Meroicinha II [Iberian wolf monitoring at Alto do Marco and Meroicinha II wind farms]. Relatório 5, Fase 3. 69 pp. (In Portuguese)
Negrelo-Guilhado	11	Falperra/Sombra	Ferrão da Costa & Petrucci-Fonseca (2011). Plano de Monitorização do Lobo – Parque Eólico de Negrelo e Guilhado [Wolf monitoring plan at Negrelo/Guilhado wind farm]. Relatório Técnico Anual 2010, abril de 2011. 36 pp. (In Portuguese)
Outeiro	13	Vaqueiro	Ferrão da Costa, G. & Álvares, F. (2008). Plano de Monitorização do lobo-ibérico no âmbito da Ampliação do Parque Eólico de Pena Suar – Ano 2007. (3º Ano da Fase II) [Iberian wolf monitoring plan at Pena Suar wind farm enlargement]. Relatório Técnico Final e Análise Global dos Resultados. ENERNOVA-EDP/CIBIO-UP. 46 pp. (In Portuguese)
Serra da Nave	19	Leomil	Álvares, F., H. Rio-Maior, S. Roque, M. Nakamura & F. Petrucci-Fonseca (2017). Ecological response of breeding wolves to wind farms: insights from two case studies in Portugal. In M.R. Perrow (Ed.), Wildlife and Wind Farms: Conflicts and Solutions. Volume 1: Onshore. -Volume 1: Onshore: 432 (pp. 225–227). Pelagic Publishing.
Serra do Alvão	21	Sombra	Saraiva, T., Petrucci-Fonseca, F., Ferrão da Costa, G., Barreto, D.& Marques, L. (2011). Monitorização do Parque Eólico da Serra do Alvão e Linha de Transporte de Energia [Wolf Monitoring anual report at Serra do Alvão wind farm]. Relatório Anual de Monitorização do Lobo-ibérico. Ecosativa, Lda. São Teotónio, January 2011. 32 pp.[In Portuguese]
Serra do Barroso III	11	Barroso	Ferrão da Costa (2013). Plano de Monitorização do Lobo – Parque Eólico da Serra do Barroso III [Wolf monitoring plan – Serra do Barroso III wind farm]. Relatório Final de Projeto. março 2013. 60 pp. (In Portuguese) Ferrão da Costa (2016). Plano de Monitorização do Lobo – Parque Eólico da Serra do Barroso III – Reforço de Potência [Wolf monitoring plan – Serra do Barroso III

(continued)

Table 5.1 (continued)

Wind farm	Wind turbines	Wolf pack affected	Reference
			wind farm - Repowering]. Relatório Anual, Ano2. julho 2016. 70 pp. [In Portuguese]
Vila Cova	17	Vaqueiro	Grupo Lobo (2016). Plano de Monitorização do Lobo no Parque Eólico de Vila Cova [Wolf monitoring plan at Vila Cova wind farm]. Ano 4, outubro 2016, 49 pp (In Portuguese]

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