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Universidade de Aveiro Departamento de Biologia
Ano 2014

Maria João de Sousa Soares

AN AVIAN RELATIVE FATALITY RISK INDEX FOR IBERIAN SPECIES ON WIND FARMS BASED ON ZERO INFLATED COUNT MODELS

ÍNDICE DE RISCO RELATIVO DE MORTALIDADE DE AVES IBÉRICAS EM PARQUES EÓLICOS BASEADO EM MODELOS INFLACIONADOS EM ZERO

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Biologia Aplicada, realizada sob a orientação científica da Doutora Regina Bispo, Professora Auxiliar do Instituto Superior de Psicologia Aplicada – Instituto Universitário, coorientação da Mestre Joana Bernardino, Responsável de Projetos da Bio3 – Estudos e Projetos em Biologia e Valorização de Recursos Naturais, Lda. e do Doutor António Nogueira, Professor Associado c/ Agregação do Departamento de Biologia da Universidade de Aveiro.

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O júri

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Agradecimentos

Ao terminar este etapa, começa a ser difícil controlar a ansiedade e adrenalina. Agradecer a quem contribuiu para a conclusão deste trabalho passa não só a ser um direito mas como um dever imposto pelo coração. Agradeço à Prof.ª Regina Bispo, ao Prof. António Nogueira e à Joana Bernardino por todo o apoio e também por terem tornado este trabalho possível.

Agradeço também à minha família e a todos aqueles que, cientes do meu talento em protagonizar épicos homicídios à escrita, se prontificaram a serem testemunhas de tais linguísticos delitos. De todos, devo destacar a verdadeira criminalista da formatação, pelos contributos e por tantas outras coisas para as quais um mero agradecimento parece não ser suficiente. Devo também um sincero agradecimento à brigada de salvamento de pipocas, computadores, saltas, isolamentos sociais e de pés frios.

Mas o fim tem um início bem antes dele mesmo. Há que abrir a comporta para deixar a água inundar a Salina e para que se inicie mais uma temporada da safra do Sal. Enquanto as águas repousam e o Sol atua, afinam-se os instrumentos a as doces vozes das nossas belas varinas. Essas noites perfumadas de luar têm festas, romarias, Paródias que ficam para toda a vida. Mas nem sempre o vento vem de feição. Vivas são as marés da vida académica na prática, que nos fazem provar que estamos vivos. Assim, em cada ideia, atrevimento, cabo de tormentas ou porto de convicções tornamo-nos melhores navegadores. Nos canais vogam barcos, moliceiros e nas ruas desfilam os momentos derradeiros. É nessas derradeiras horas que clamamos aos nossos “Deuses”, para nos tornarmos, cada vez mais, verdadeiros Homens. E no fim do culto, às vezes percebemos que alguém nos quebrou a fechadura do coração, “nele cabe até o meu amor” e esse, “bem se diz sem se falar”. Enquanto se forma a flor de sal, as correntes trazem outras sabedorias e pessoas para a vida. Até cangurus e crocodilos podem dar às suas margens. E vejam lá que sorte a minha, que a Ria, fez da pessoa que mais se admira uma das nossas melhores amigas. Sem esquecer que somos todos NEB-AAUAv, agora que Biologia já está em Cena, há que dar um pé de dança, chegar à plataforma e dar o salto para outros palcos. Nas Marinhas, está tudo pronto para a Cura e Feitura do Sal. Após concluídos os trabalhos, procede-se ao alagar da salina para reiniciar outra safra.

No adro da igreja de S. Gonçalinho já se ouve o sino e é hora de atirar a minha cavaca: “Obrigado por tudo, vocês sabem quem são”. Dois, três ou quatro anos depois sabe bem ouvir: “Obrigado por me teres recebido nesta grande Academia”. E agora é a minha vez: Um sincero Obrigado Academia por quem sou hoje e por quem poderei ser amanhã.

Keywords

Avifauna; Birds' Sensitivity; Environmental Impacts; Excessive zero counts; Fatality Risk Index; Vulnerability; Wind farms; Zero inflated models.

Abstract

Climate change is one of the greatest threats towards humankind and wildlife. This consciousness motivated the search for alternatives that could contribute to mitigate climate change. Betting on renewable energies seems to be a winning strategy adopted worldwide in order to reduce greenhouse gas emissions responsible for global climate alterations and to improve nations’ energy independency. However, nowadays, these energy usages still have negative impacts, mostly on wildlife. Wind energy is even considered the greatest unintended human impact on avifauna. In this context, the aim of this thesis was to increase the knowledge about wind farms impacts on avifauna, which variables influence birds’ fatalities by collision with wind turbines and birds’ vulnerability. Models based on excessive zero counts were tested to understand which variables influence birds’ fatalities assessed on 25 Portuguese wind farms. This allowed to estimate the probability of mortality observation per species. The information obtained was used to build the fatality risk index that also considered the vulnerability factors, which give information of species conservation concern and resilience. Those indexes allow to prioritise the existing and limited conservation efforts on more vulnerable species. Models and indexes are also important for improving knowledge about wind energy impacts on wildlife and what can lead to reduce them, in order to achieve a sustainable and greener future.

Palavras-chave

Avifauna; Excesso de zeros; Impactes; Índice de Risco de Mortalidade; Modelos Inflacionados em zero; Parques eólicos; Sensibilidade; Vulnerabilidade.

Resumo

As alterações climáticas são uma das maiores ameaças para a Humanidade e para a vida selvagem. A consciência sobre a importância destas questões motivou a procura de alternativas, com intuito de mitigar estas alterações globais, causadas nomeadamente pelos gases de efeitos de estufa. Assim, as energias renováveis apresentam-se como uma possível estratégia vencedora a adotar, de forma a reduzir as emissões destes gases e levar à independência energética. No entanto, o uso destas energias renováveis ainda apresenta impactes negativos, especialmente para os ecossistemas. A energia eólica é inclusivamente considerada uma das maiores causas não intencionais de origem antropogénica para a mortalidade adicional de aves. Neste contexto, esta dissertação tem como os principais objetivos o desenvolvimento do conhecimento relativo aos impactes da energia eólica, quais as variáveis que influenciam a mortalidade de aves respeitante à colisão com as turbinas eólicas assim como as variáveis que afetam a vulnerabilidade das espécies. Foram testados modelos de contagem com excesso de zeros para compreender a influência das variáveis nas observações de mortalidade em 25 parques eólicos portugueses. A partir destes modelos foi possível estimar a probabilidade de observação de mortalidade para cada uma das espécies estudadas, provocada por colisão com eólicas. Esta informação foi ainda utilizada de forma a desenvolver um índice de risco de fatalidade com base nestas estimativas, assim como em fatores elucidativos da vulnerabilidade das espécies, nomeadamente o seu estatuto de conservação e resiliência. Desta forma é então possível direcionar esforços e recursos para a preservação das espécies com maior vulnerabilidade e prioridade de conservação. Este tipo de modelos e índices é ainda fundamental para incrementar o conhecimento sobre os impactes da energia eólica na vida selvagem e para compreender quais as medidas que podem ser tomadas para os reduzir e, assim, garantir um futuro mais verde e sustentável para todas as formas de vida.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

THESIS OUTLINE

The anthropogenic impacts on the environment led to serious climate changes. The nations are progressively aware of the risks and threats that this issue entailed to Humanity and wildlife. Climate change mitigation measures are being defined as well as strategies are being tested and implemented, in order to achieve those goals.

Renewable energies, such as wind energy, are unavoidable strategies on mitigation plans proposed by the nations. However, the adoption of this “clean energy” may also present negative impact outcomes on the environment, especially on avifauna.

Hence, the fundamental motivations for this thesis are: 1) the awareness about the importance of wind energy in climate change mitigation; 2) the negative impacts of wind farms on avifauna; and 3) the development of methods that help to reduce them.

This study is divided in three chapters. Chapter 1 is the general background about these topics. In this chapter a brief introduction about climate change and consequent commitment to renewable energies is given as well as a brief overview about wind energy. A general overview about wind energy, impacts on avifauna and a brief presentation on the key concepts inherent to the statistical analysis used on Chapter 2 are also presented.

Chapter 2 presents an article in development about the creation of an Iberian Birds’ Fatality Risk Index. The aim of this chapter is to increase the understanding of which ecological factors influence birds’ proneness to collide with wind turbines. To achieve this goal, a statistical model based on excessive zero counts was used. The Index was then established to understand which species are more vulnerable to this impact and which justify a higher conservation effort.

Chapter 3 presents the final remarks about the general impacts of wind farms on birds, presenting some possible mitigation measures and some future development prospects.

CHAPTER 1. GENERAL BACKGROUND

1.1 Climate Change and Mitigation Targets

Since the industrial revolution, economic growth has implied a great consumption of natural resources, which has led to environmental alterations and shortage of resources. Global warming is one of the consequences of the fast process of industrialization (DGEG 2014).

Nowadays, global climate change represents a great challenge to humankind and a great environmental, social and economic threat (APA 2014). Climate change is a serious concern not only to humanity but also to wildlife. These changes can significantly aggravate other global problems, for example world hunger or lack of resources and extreme weather phenomena could become more frequent and intense (Bright *et al*. 2009).

Greenhouse Gas Emissions (GGE) are the main and most recognized anthropogenic cause for climate change (Huntley *et al*. 2006; Drewitt & Langston 2006). Thanks to international protocols such as the United Nations Framework Convention on Climate Change, signed in 1992, and the Kyoto Protocol, adopted in 1997, worldwide governments are implementing measures to reduce the increase of global temperature and GGE emissions (Amaral 2009; APA 2014).

Adaptation and mitigation are the key strategic guidelines to deal with climate change. For example, GGE emissions reduction are defined as mitigation measures and approaches that ambition to reduce the negative impacts already evident are defined as adaptive measures (APA 2014).

As an alternative to decrease the use of fossil fuels stocks and as a measure to reduce GGE emissions of the energy sector, the adoption of renewable energy sources is growing (Amaral 2009; GWEC 2014). This strategy is essential to achieve the International Community goals of GGE reduction and the increase in global mean temperature remains below 2°C. The failure to meet these targets may result in serious problems to mankind which may not be able to cope with them (GWEC 2014).

Aware of these issues, the European Union (EU) established a goal of 20% reduction in GGE by 2020 compared to 1990 (APA 2014; EWEA 2014). For 2030, EU member states established a target of 40% of GGE reduction compared to 1990, aligned with a growing representation of renewable energy penetration (GWEC 2014).

Political alignment, both local and international, is essential to put into practice effective solutions to cope with this issue (APA 2014). The governments concerned with climate changes also contributed to growing investment on renewable technologies (Langston & Pullan 2003; Chamberlain *et al*. 2005). Wind energy is not an exception and is an unavoidable topic in climate change mitigation policies (Wiser *et al*. 2011; EWEA 2014; GWEC 2014). This source of energy is already close to 4% of the global electricity demand (WWEA 2014). As mentioned by the European Wind Energy Association, an average of 696 g CO_2/kWh is created by the traditional energy sector and it could be significantly avoided by wind energy production (EWEA 2014).

1.2 Wind Energy

Nowadays, the kinetic energy of air masses movements (wind) is used to produce mechanical energy that can be transformed in electricity (ENEOP 2014).

Humankind has been using wind energy in a wide variety of applications since 5000 B.C. By that time, sailing vessels in Egypt were pioneers in the application of this technology. By 200 B.C windmills were used in China to pump water and, in Persia and Middle East, to grind grain. Technological advances allowed the evolution of these applications as well as the finding and improvement of new usages (Wiser *et al*. 2011; WEF 2014).

Only in the 1970's, at a marketable scale, the generation of electricity produced through wind power was possible due to governmental support, technological advances and motivated by oil shortages (Wiser *et al*. 2011; WEF 2014). Currently, this source of energy has been showing a fast worldwide development (Figure 1) (Wiser *et al*. 2011; Saidur *et al*. 2011).

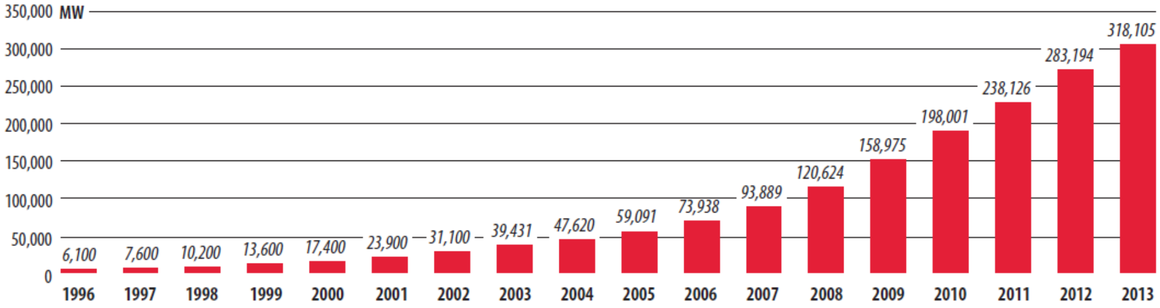

Figure 1. Cumulative wind capacity installed in the world between 1996 and 2013. Source: GWEC 2014

Since it depends on wind availability and speed, the location of the wind farms is very important. Turbine technological development is also important to guarantee an efficient energy production on a wide range of wind speeds (Wiser *et al*. 2011). Currently, wind turbines have 2 or 3 MW of production capacity rates, which that can fulfil the electricity needs of approximately 2000 to 3000 homes. The height of these wind turbines can reach 50 m to 120 m and the rotor blades may have 25 m to 45 m of wide (ENEOP 2014). To minimize wind energy cost and maximize energy capture, the design of the wind turbine has been upgraded and its size is significantly growing. This allows a greater energy capture by lowing necessary wind speeds to produce power (Wiser *et al*. 2011).

Wind energy projects present a high initial cost in infrastructures installation, however in a long term scenario, winds farms present low maintenance and other associated costs. Besides, wind power is considered a cheap energy source compared to fossil fuels and it also present a great potential to reduce investments costs in the future (Wiser *et al*. 2011; ENEOP 2014). This alternative energy also presents other social and economic advantages. This type of energy exploitation generates employments in rural areas, promoting economy decentralization.

Compared to other sources, this generates the highest number of jobs per MW (ENEOP 2014). Wind power entails the lowest levels of greenhouse gas emissions of all the energy sources. Compared to the traditional sources, wind energy present other advantages, such as reduced environmental pollution, by not producing toxic emissions, and does not entail water consumption (Saidur *et al*. 2011; ENEOP 2014). That is why wind power is considered the energy with lowest direct impacts on the environment (ENEOP 2014).

In 2013, it was reported by the World Wind Energy Association (WWEA) that wind energy capacity reached 318 529 MW worldwide, after reaching 282 275 MW in 2012. In 2013, the growth of installed capacity of this wind source has slightly decreased, since 2008, representing a rate of only 12.8% (Figure 2) (WWEA 2014). However, this energy source still is the global fastest growing source of electricity production (WEF 2014). The WWEA predicts that more than 700 000MW of wind energy capacity will be reached in 2020.

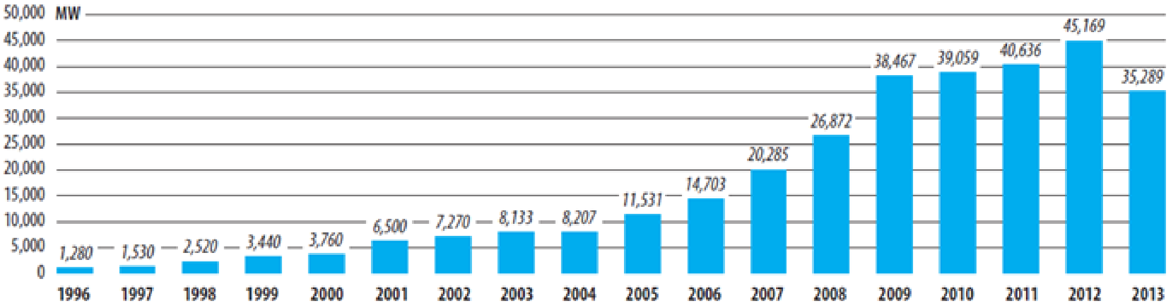

Figure 2. Annual wind capacity installed in the world since 1996 until 2013. Source: GWEC 2014

Currently, the five nations with higher cumulative installed wind capacity are China (91 412 MW), the United States of America (61 091 MW), Germany (34 250 MW), Spain (22 959 MW) and India (20 150 MW) (GWEC 2014). Portugal presents more than 4 000 MW of installed wind energy capacity (4% of all installed capacity on the European Union). This percentage places Portugal on the top 10 countries of EU with more cumulative installed capacity (Figure 3) (EWEA 2014).

In 2010, 14% of the energy production in Spain came from renewable energy sources. The commitment of this country to achieve energetic European goals is clear and that is reflected on the increasing number of wind farms across the country in the last few years (de Lucas *et al*. 2012). In 2013, Spain reached 22 900 MW of cumulative capacity generated by wind energy. In these terms, this Iberian country is the second largest market in the European Union (GWEC 2014).

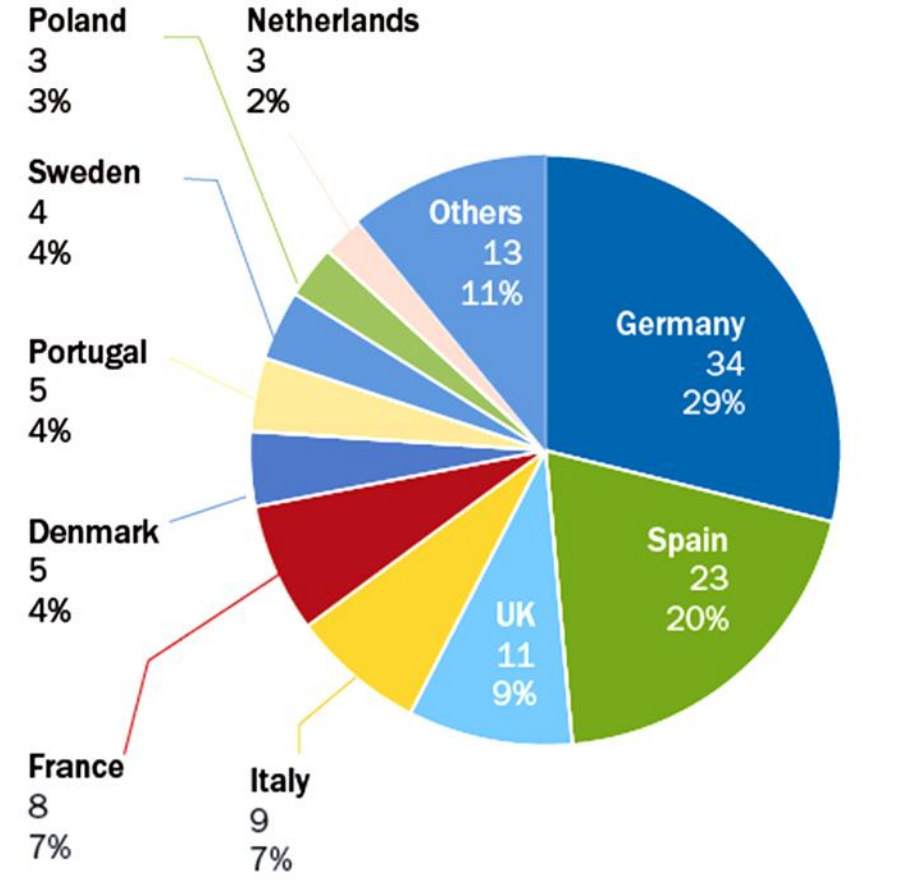

Figure 3. Installed wind capacity in EU members in 2013 (GW). Source: EWEA 2014

In the 1990's, Portugal was extremely dependent on fossil fuels to produce energy and the energetic efficiency was lower than 50%. A strategic redefinition in consonance with the European Union was mandatory to promote endogenous renewable energy sources and the improvement of energetic independency of the country (ENEOP 2014). In the last decade, the growing tendency of wind energy on Portugal was also clear (Amaral 2009; Bernardino *et al*. 2012). Nowadays, 20% of electricity consumed in Portugal is produced by wind energy (APREN 2014). In 2013, the use of renewable energy sources (excluding hydric power) allowed this country to save 806 million of Euros on imported fossil fuels and a significant reduction of CO_2 emissions (estimated 20%) (Quercus 2014). In Portugal, only mountainous areas have enough wind regularity for energy exploitation. These areas with optimal conditions are found to the north of Tagus River, along the south coast and in the southern end of the country. The wind farms location in the country reflects this (ENEOP 2014; DGEG 2014).

The growth of renewable energies, including wind energy, was only possible due to political and economic incentives and support. However this development also depends on other factors such as operational issues, grid expansion, resource availability, technological progress, among others issues (Wiser *et al*. 2011; GWEC 2014; WEF 2014). The European Wind Energy Association states that the significant progress that could lead to representative evolution of wind energy in European electricity demand in the future are the existing technology upgrade and the improvements in grid infrastructures. This energy could represent 30% of this demand in 2030 and 50% in 2050 (EWEA 2011).

Renewable energy generation is predicted to represent more than 25% of the world's electricity by 2035. By that time, it is likely that wind energy has become the second largest renewable energy source, after hydro power. In 2050, wind power capacity could represent more than 20% of worldwide electricity demand (Wiser *et al*. 2011). This will be crucial not only for the reduction of GGE, but also for the economy by creating more job opportunities in a decentralized manner. Other economic and political positive and significant impacts are the reduction of fossil fuels importation and the promotion of energetic independency of nations in the future (GWEC 2014).

1.3 Wind and Biodiversity: Impacts on Avifauna

Wind farms are located on windy areas that are usually unsuitable for the majority of human activities. Thus, these areas may be rich in natural heritage and/or with considered conservation status (DGEG 2014). Despite their advantages, wind farms could bring some negative impacts on these habitats and their wildlife, mainly on flying vertebrates susceptible to collision with wind turbines (WEF 2014).

The understanding of wind farm impacts on wildlife is not growing so rapidly as the development of the technology (Drewitt & Langston 2006). Many studies performed on wind farms have shown low rates of birds mortality (e.g.: Langston & Pullan 2003; Percival 2005; de Lucas *et al*. 2008). Although these events may be considered relatively rare, the number of studies compared to the number of infrastructures is still low and these impacts should not be ignored (Langston & Pullan 2003; Percival 2005; de Lucas *et al*. 2008; Noguera *et al*. 2010; Marques *et al*. 2014).

The most deadly onshore wind farms recognised in the world are Altamont Pass in California, USA, mainly for Golden eagles (*Aquila chrysaetos*), Tarifa and Navarre in Spain, especially for griffon vulture (*Gyps fulvus*) and Smøla in Norway for White-tailed eagles (*Haliaatus albicilla*) (Thelander *et al*. 2003; Barrios & Rodríguez 2004; Drewitt & Langston 2006; Smallwood & Thelander 2008; de Lucas, Ferrer, Bechard, *et al*. 2012; Dahl *et al*. 2013; WEF 2014). The study of de Lucas *et al*. (2008,2012) presents variable mortality rates between turbines, with these rates depending on different factors, not all associated with the species. De Lucas *et al.* (2008) is one of the few long-term studies available, that compiled data of birds' fatality sampling collected during 10 years (de Lucas *et al*. 2008; de Lucas, Ferrer, Bechard, *et al*. 2012).

Some species show more sensitivity to these impacts and high mortality rates compared to others (Drewitt & Langston 2008). The numbers may vary not only between species but also between locations (Langston & Pullan 2003; Percival 2005; de Lucas *et al*. 2008). In some species even small fatality rates could result in significant impact for its population or even to the species itself, especially if species presents a high conservation concern (e.g.: Chamberlain *et al*. 2005; Drewitt & Langston 2006; de Lucas *et al*. 2012; Furness *et al*. 2013; Marques *et al*. 2014).

Wind farms present many other negative impacts on birds such as habitat fragmentation and loss, disturbance, displacement and barrier effect (Orloff & Flannery 1992; Barrios & Rodríguez 2004; Garthe & Huppop 2004; Percival 2005; Drewitt & Langston 2008; Bright *et al*. 2009; Paula *et al*. 2011). Habitat loss per turbine is small and the total impact on habitat depends on the size of the wind farm project, but major impacts at this level could occur if the construction interferes with hydrological patterns or with geomorphological processes. Alteration of land-use can also lead to habitat changes (Drewitt & Langston 2006). Wind turbines are obstacles that could cause death not only due to direct collision but also due to barotrauma caused by extreme and abrupt pressure changes (Drewitt & Langston 2006; Barclay *et al*. 2007; Noguera *et al*. 2010). Other wind farm associated infrastructures, for example the power lines, could also be a threat for birds (Drewitt & Langston 2006).

There are many possible factors that influence bird fatality by collision with wind turbines. Collision risk may depend on a wide range of factors that can be related to: species characteristics and behaviour; the wind farm features and specific local conditions (Drewitt & Langston 2006; Marques *et al*. 2014). Species sensitivity and proneness to collide can be associated to their flight manoeuvrability and behaviour, birds' activity, phenology, relative abundance among other possible influence factors. Population and species vulnerability can be evaluated by their conservation status and breeding capacity, for example (Barrios & Rodríguez 2004; Garthe & Huppop 2004; Noguera *et al*. 2010; Furness *et al*. 2013; Marques *et al*. 2014).

Avoidance and displacement behaviour are also determinant on birds' fatalities rates. Species that exhibit avoidance behaviours to wind farms possibly will present lower risk to collide (Dahl *et al*. 2013; Marques *et al*. 2014). Thus, these are important factors when mortality rates on wind farms are calculated or predicted (Chamberlain *et al*. 2005). Disturbance on birds' populations is an indirect impact that can be caused by noise, vibration impacts or visual presence of these obstacles. The real effects of this disturbance are not entirely understood due the lack of studies about this topic (Drewitt & Langston 2006; Desholm 2009). The consequent avoidance and displacement behaviours are also variable between species and locations and can also implicate negative impacts to birds' populations survival and productivity (Drewitt & Langston 2006; Bright *et al*. 2009; Desholm 2009).These impacts can also vary between small fly paths deviations to alterations on flight behaviour that leads to a significant reduction of the number of birds in the surrounding areas (Drewitt & Langston 2006).

Species flight features have great influence on mortality rates due to collision with wind turbines. Flight height can vary due to species characteristics but also with topography, weather conditions, seasonality and other factors (Drewitt & Langston 2008). The risk is higher if species fly at greater altitudes and at the height of the rotor blades. Manoeuvrability is related to the aerial agility of species and consequently to their ability of swift reactions and avoiding obstacles, like wind turbines (Garthe & Huppop 2004; Furness *et al*. 2013). Manoeuvrability is associated with wing parameters: wind loading and aspect ratio. Species with low manoeuvrability are characterized by rapid flight (high wing loading) and heavy body mass and small wings (low aspect ratio) (Noguera *et al*. 2010).

Flight behaviour also seems to have a great influence on birds' fatalities (Marques *et al*. 2014). Some birds use hovering. This type of flight is associated with strong and unpredictable winds that could affect birds' position. Additionally, birds present this flying type when hunting what could distract them of the danger of collision (Smallwood & Thelander 2008; Krijgsveld *et al*. 2009; Marques *et al*. 2014). Soaring birds are usually large and use updrafts to gain altitude. These species may present low manoeuvrability and consequently higher collision risk (Garthe & Huppop 2004; de Lucas *et al*. 2008; Furness *et al*. 2013; Marques *et al*. 2014). Morphological birds' features, like size, weight and wings length, have been associated with species proneness to collide with the wind turbines. These features could influence birds' flight manoeuvrability and behaviour and determine species susceptibility to collide (Bevanger 1994; Barrios & Rodríguez 2004; de Lucas *et al*. 2008; de Lucas, Ferrer & Janss 2012; Herrera-Alsina *et al*. 2013; Marques *et al*. 2014).

Another factor related to birds flight is the percentage of time flying. Species that spend more time flying are more exposed to the danger and consequently are considered in higher risk of collision. Since this parameter is dependent of flight activity it will probably present a seasonal variation. Likewise, nocturnal flight activity is also considered a risk factor for birds, but further information about this is still needed (Garthe & Huppop 2004; Furness *et al*. 2013).

The influence of relative abundance and phenology on mortality rates has presented controversial results on literature (de Lucas *et al*. 2008; Noguera *et al*. 2010; Marques *et al*. 2014;). Some authors suggest that higher bird density is associated with higher probabilities of collision with the turbines due to a higher exposure to the danger (Langston & Pullan 2003; Smallwood & Karas 2009; Carrete *et al*. 2012;). However, this is not verified in other studies that suggest this relation may not be so simplistic and could be highly related with differential birds' behaviours instead (Madders & Whitfield 2006; de Lucas *et al*. 2008; Ferrer *et al*. 2012; Dahl *et al*. 2013; Marques *et al*. 2014). Barrios & Rodríguez (2004) propose that high mortality rates may be determined by the density of birds passing close the rotor blades of a turbine. Thus, it is essential to reach a better understanding on this question to reinforce the prediction of these impacts on birds (de Lucas *et al*. 2008; Carrete *et al*. 2012).

Likewise, phenology is associated to birds' mortality due to the density of birds exposed to the risk. In the study of Krijgsveld *et al*. (2009) the risk seems higher for resident raptors that may use wind farm areas regularly. Resident species due to their longer exposure may present higher risk (Barrios & Rodríguez 2004; Percival 2005; Drewitt & Langston 2006). However, Drewitt & Langston (2008) suggested that resident species are less sensible to collision due to habituation and familiarity with this danger. Is also suggested that this influence can be associated with the flight behaviour or with possible avoidance behaviours (Barrios & Rodríguez 2004). Relative position of migratory pathways with respect to wind farms may also constrain the phenology influence on birds' mortality (Dahl *et al*. 2013; Marques *et al*. 2014). Habitat specialisation is also a factor that may influence wind farm impacts on birds, which is also related to the probability of area usage by birds (Furness *et al*. 2013).

Visual perception of dangerous situations may be another factor that influences birds' fatality due to collision with wind turbines. Some species, described as potential vulnerable, for example vultures, present very slender frontal binocular fields, which may difficult the perception of this danger (Martin & Katzir 1999; de Lucas, Ferrer, Bechard, *et al*. 2012; Martin *et al*. 2012; Marques *et al*. 2014).

Intraspecific features, like sex and age, may influence birds' behaviours and fatalities rates (Morinha *et al*. 2014; Langston & Pullan 2003; Stienen *et al*. 2008; Drewitt & Langston 2008). For example, Morinha *et al*. (2014) addresses the factors that influence differential mortality due to collision with wind turbines on Slylark (*Alauda arvensis*) in Northern Portugal. This species presents decreasing population trends, despite having low conservation status. This study highlights the intraspecific influence of sex and age in mortality rates, which may be related with breeding behaviour (Morinha *et al*. 2014).

There are other factors that may influence birds' mortality. Some features associated to the wind farm features like turbine characteristics, blades visibility, signal lights and infrastructures arrangement could also affect birds' fatalities (Marques *et al*. 2014). Birds mortality is also associated to the location features, mainly if the wind farm area is in flight path or if it has high food availability (Hoover & Morrison 2005; Drewitt & Langston 2006; Marques *et al*. 2014).

Weather conditions also play an important role in this issue by affecting birds' behaviour and flight (Drewitt & Langston 2008). Strong winds that affect flying control and other adverse conditions may disturb visibility or increase attraction to artificial light (Langston & Pullan 2003; Marques *et al*. 2014). Weather conditions like fog or rain may affect visibility, which might increase species risk. In severe weather conditions the number of flying birds could be low, but for migration species this could be an unavoidable problem (Drewitt & Langston 2008).

To recognize species priority on the effort for impacts reduction, some factors like conservation status, survival rates and breeding capacity could give a better understanding of species real vulnerability as well as of the impacts effect at birds' population level (Desholm 2009; Noguera *et al*. 2010; Furness *et al*. 2013;). Conservation status could be used as an external measure of conservation priority (Desholm 2009). Species that present a higher breeding capacity and with bigger clutch sizes could more easily replace the losses in their populations (Noguera *et al*. 2010). On the other hand, in species with high adult survival rates and with low breeding capacity rates, these losses could represent an higher impact on the population restoration (Desholm 2009; Furness *et al*. 2013). Population dynamics define the ability of losses compensation what is essential to understand the level of the impact (Drewitt & Langston 2008).

Long-lived species like raptors and waterbirds are the more vulnerable expected species to these impacts (Desholm 2009). Birds of prey present seem high proneness to collision and low productivity, which may difficult the population renewal in higher rates of mortality. Even small increases in mortality could lead to population decline. The information about passerines remains limited, due to lower detections rates, rapid scavengers' removal and possible lower collision rates. This justify the fewer numbers of studies about these species (Drewitt & Langston 2008).

Among the variability of species and its behaviours, in conservation is vital to prioritise higher risk species, identifying which ones are most vulnerable to impacts (Gardali *et al*. 2012; Furness *et al*. 2013). To achieve this, different authors have proposed sensitivity and vulnerability to impact indexes with specific adaptations (Garthe & Huppop 2004; Bright *et al*. 2009; Desholm 2009; Noguera *et al*. 2010; Furness *et al*. 2013). These indexes not only permit to concentrate conservation efforts on more vulnerable species but also permit to establish death estimations, identify more vulnerable areas and predict impacts of a wind farm project at earlier stage (Noguera *et al*. 2010).

Wind farms negative impacts on birds vary widely across species and even within the species. The knowledge about the impacts of wind farms on biodiversity is increasing but further research should be performed to reach a better understanding of these impacts, how they influence birds and their populations and how they could be significantly minimized (Bright *et al*. 2009; Furness *et al*. 2013; Marques *et al*. 2014)

1.4 Excessive zero counts in statistical models

Mixed effects models provide heterogeneous response variables, containing both fixed and random effects. These type of models are commonly used to describe biological and ecological data (Zuur *et al*. 2009). The models are choose based on maximum likelihood methods and frequently used in many different study areas, like ecology, medicine or economy (Baayen *et al*. 2008).

Poisson distributions are defined by a mean value as a result of the action of the co-variables. When the observed variance is higher than the one presented by the model, overdispersion is present (Turkman & Silva 2000). Ecological research data usually present a large quantity of zero values (Clarke & Green 1988). That may cause extra overdispersion which could not be fitted with the standard distributions, like Poisson distributions or Negative Binomial distributions (Cameron & Trivedi 1989; Martin *et al*. 2005; Zeileis *et al*. 2007). In those cases zero inflated models or hurdle models can be a solution (Zuur *et al*. 2009).

To deal with excessive zero counts two main types of models could be applied. For each model two different distributions could also be used. These models are: Zero-inflated Poisson (ZIP), zero inflated Negative Binomial (ZINB); hurdle or zero-altered Poisson (HP) and hurdle or zero-altered Negative Binomial (HNB). The main difference between zero-inflated models and hurdle models is linked to the source of the zero counts. The Negative Binomial model allows dealing with extra overdispersion in the positive part of data comparing to the Poisson model (Zuur *et al*. 2009).

There are two main types of zeros: the true zeros and the false zeros. False zeros included the ones counted due to design error, which could be caused by poor experimental sampling practises or planning, observer error, or even due to “bird error”, which means that although the habitat is suitable, the species is not there. The true zeros are the ones caused by structural error, in which the absence is explained because the habitat is unsuitable for the species. Zeros obtained due to sampling outside the species habitat range should be excluded (Zuur *et al*. 2009).

Zero altered or hurdle models were originally proposed by Mullahy (1986) in econometrics and present two parts. In a first step a binomial model is used to assess the probability to observe a zero, regardless of the source. In the second part of the model, the non-zero observations are assessed with zero truncated models (the response variable cannot produce zero counts) using Poisson or Negative Binomial distributions. Covariates could be used in both parts. This type of models is also considered hurdle models because positive observations have to cross a hurdle to get non-zero count. Thus, the source of zeros is not discriminated (Zuur *et al*. 2009).

Zero inflated models (Mullahy 1986; Lambert 1992) also result from the combination of a binomial process to model the probability to obtain a false zero and a count process where a Poisson or Negative Binomial could be applied. Unlike the hurdle models, in the count process, true zeros could be produced beyond the non-zero observations (Zuur *et al*. 2009). In these cases, true zeros may represent real ecological effects with study interest (Zeileis *et al*. 2007).

Distinguishing the zero types is indispensable for ecological interpretation and the choice of the best suitable model to use (Zuur *et al*. 2009). Zeileis *et al*. (2007) show how the erroneous choice of the model might lead to considerable different parameters and precision estimations, which could also lead to biased results. Thus, not taking excessive number of zeros into account could compromise the model’s conclusions and the interpretation of results (Zuur *et al*. 2009).

Hence, the cause of an excessive zero count and the knowledge on data allow a better choice between the two types of models. Statistical tests and information criteria could also be used to support the model choice (Zuur *et al*. 2009).

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CHAPTER 2. AN AVIAN RELATIVE FATALITY RISK INDEX FOR IBERIAN SPECIES ON WIND FARMS BASED ON ZERO INFLATED COUNT MODELS

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Resumo

As alterações climáticas e o esgotamento dos recursos fósseis são atualmente um grande desafio para a Humanidade. A energia eólica apresenta-se como uma possível solução para estes problemas. No entanto a produção de energia eólica acarreta impactes negativos, nomeadamente para as aves. Com o objetivo de estudar os fatores que determinam o risco de mortalidade por colisão com as turbinas eólicas, foram compilados registos de censos de aves e prospeção de cadáveres de 25 parques eólicos Portugueses. Foi também recolhida informação adicional sobre as características das espécies ibéricas presentes nestes registos. Apesar de apresentar larga escala, verifica-se uma elevada variabilidade de comportamentos entre espécies havendo algumas para as quais este fenómeno pode considerar-se relativamente raro, tendo como consequência a observação de mortalidade nula. Assim, o uso de modelos aumentados em zero pode apresentar-se como uma solução para lidar com o excesso de zeros. Este estudo teve como objetivo avaliar a importância de fatores etológicos e morfológicos na mortalidade de aves por colisão em dois grupos de espécies. As variáveis explicativas e significativas que foram obtidas para estes modelos foram as características morfológicas, manobrabilidade, tipo de voo, fenologia, comportamento gregário e abundância relativa, variando a sua significância consoante o grupo de aves em estudo. Os modelos implementados permitiram inferir acerca da sensibilidade das espécies à colisão e à sua vulnerabilidade a este impacte. Para espécies ameaçadas de extinção e com maior propensão à colisão, a mortalidade adicional pode trazer impactos irreversíveis para a sobrevivência de uma população e até da espécie. Perceber a vulnerabilidade de aves e a realização deste tipo de estudos são uma mais-valia para minimizar os impactes de um parque eólico em qualquer fase do seu projeto e permitir que esta seja uma energia verdadeiramente verde.

Palavras-chave

Excesso de zeros; Índice de Risco de Mortalidade; Modelos Inflacionados em zero; Parques eólicos; Ranking de Vulnerabilidade; Sensibilidade de Aves.

Abstract

Climate change and fossil resources depletion are the greatest global challenges of nowadays. Wind energy could be a solution to climate change mitigation but it presents impacts on biodiversity, in particular for avifauna. There are many records of birds' mortality from collisions with these structures. To establish a fatality risk index, records from birdlife census and carcass searches at 25 Portuguese onshore wind farms were compiled. Data of different Iberian birds' species present on those records as well as their characteristics were also collected. Birds' species present a high variety of characteristics and behaviours and, for some of them, fatality due to collision could be considered a rare event, hence null mortality counts could be observed. In this context, to deal with the data, characterized by an excessive zero counts, zero inflated models and hurdle models were used. Zero inflated models are the most suitable for this data, once some species could actually present no mortality due to collision. Two groups of birds were evaluated and a model was choose to explain which morphological and ethological factors leads to birds' fatalities for each group. Morphological characteristics', manoeuvrability, flying type, phenology, gregarious behaviour and relative abundance were the significant variables on the chosen models, whose significance varied according to each group on study. These models permitted the evaluation of species' sensitivity to collision and understanding of their real vulnerability to this impact. If species with greater risk of extinction and high protection concern present high sensitivity to fatalities, additional mortality caused by collision with wind turbines could have a great impact on their population viability. This type of studies are essential to predict and understand impacts of wind farms on birds and turn wind into a truly green energy with minimal effects on wildlife.

Keywords

Birds' sensitivity; Excessive zero's counts; Fatality Risk Index; Vulnerability Ranking; Wind farms; Zero inflated models.

2.1 Introduction

Climate change is a great global threat and a major environmental concern (APA 2014). Greenhouse gas emissions have an anthropogenic origin and are a recognized cause for the global climate change (Huntley *et al*. 2006). The adoption of renewable energy sources is an effective measure to reduce gas emissions in the energy sector and an alternative to the decrease of fossil fuels stocks (Amaral 2009; GWEC 2014). Therefore, wind energy is an unavoidable topic when we discuss emissions reduction strategies and climate change mitigation (Wiser *et al*. 2011).

The exploitation of wind energy to produce electricity is currently growing rapidly and in a large scale, especially in Europe (Drewitt & Langston 2006; Noguera *et al*. 2010; GWEC 2014; EWEA 2014; WWEA 2014). We are witnessing to a remarkable increase on production of wind energy and its progresses. In the last decade, Portugal is not an exception to this trend (APA 2014; EWEA 2014; DGEG 2014). However, the knowledge and understanding of the environmental impacts of this development are lagging behind (Drewitt & Langston 2006).

Wind farms represent impacts on wildlife, especially in flying vertebrates (e.g.: Percival 2005; Drewitt & Langston 2006; de Lucas *et al*. 2008; Wiser *et al*. 2011; Bernardino *et al*. 2012; Furness *et al*. 2013; Marques *et al*. 2014; WEF 2014). Avifauna direct fatalities or lethal injuries can be caused by collision with turbines, cables or other associated structures of the wind farm (Drewitt & Langston 2006). The collision risk depends on many different factors, for example, environmental conditions, wind farms features and birds' characteristics (Drewitt & Langston 2006; Noguera *et al*. 2010; Furness *et al*. 2013; Marques *et al*. 2014).

Numerous pre and post construction monitoring studies have been conducted to understand and assess the impacts of wind farms on biodiversity (de Lucas *et al*. 2008; Bernardino *et al*. 2012). Although many studies present low levels of bird mortality, this issue requires attention and should not be underestimated (Langston & Pullan 2003; Percival 2005; Madders & Whitfield 2006; Drewitt & Langston 2006; Marques *et al*. 2014). For more vulnerable species this additional mortality could be significant and affect the capability of population renewal and survival (Drewitt & Langston 2006; Noguera *et al*. 2010; Furness *et al*. 2013).

Some authors tried to develop different vulnerability indexes for different categories of birds to reach a better acquaintance of bird collision risk and their conservation concern (e.g.: Garthe & Huppop 2004; Noguera *et al*. 2010; Furness *et al* 2013). Garthe & Huppop (2004) developed a wind farm sensivity index for seabirds, using 9 factors scored on a point scale based on fields assessements and existing knowlegde or subbjective considerations. Based on this, they created vulnerability maps to identify areas of major conservation concern. Furness *et al*. 2013 followed a similar aproach incorporating new data and modifying the allocated scores based on more recent research. Noguera et. al (2010) adapted the indexes developed by Garthe and Hüppop (2004) to raptors in onshore areas.

In this study, 6 factors were statistically modeled to understand their significance as explanotary variables of collision risk and then, vulnerability scores were applied. Since, in some cases, these fatalities could be considered rare events (Langston & Pullan 2003; Percival 2005), statistical models based on excessive zero's count were used to model this proneness.

Knowledge about this topic is essential for a better understanding of species sensitivity and vulnerability to wind energy impacts. Thus, it is possible to improve the impacts' prediction of wind farm projects and more efficient measures can be implemented to reduce them (Chamberlain *et al*. 2005; Drewitt & Langston 2006; Marques *et al*. 2014).

The main aim of this study is to understand which morphological and ethological factors better explain birds' proneness to collide with wind farms structures using models based on zero counts. Additionally, a Fatality Risk Index was established scoring three vulnerability factors and the fatality proneness obtained from mortality data on 25 Portuguese wind farms.

2.2 Materials and Methods

2.2.1 Study design

Based on previous studies, in this approach two types of factors were defined: sensitivity and vulnerability factors. Sensitivity factors may directly affect the birds' fatalities proneness by collision with wind farms, and vulnerability factors relate to species survival and conservation status (Garthe & Huppop 2004; Bright *et al*. 2008; Noguera *et al*. 2010; Furness *et al*. 2013).

To achieve this study's goals, records from birdlife census and carcass searches at 25 onshore wind farms were compiled. Data on different Iberian birds' species present in those records as well as their characteristics were collected from the literature. After this, a statistical model based on excessive numbers of zeros was applied to study which factors influence the proneness of birds' fatality by collision. A Fatality Risk Index was established by scoring the collision sensitivity and vulnerability factors. The detailed procedures are described in the following sections.

2.2.2. Species relative abundance and mortality data

Data of birds' census and carcass searches from 25 Portuguese onshore wind farms were analysed. The studied wind facilities are mainly located in Northern (n = 6) and Central (n = 16) Portugal, three of them are located in the country's south. The total amount of regularly searched wind turbines was 494. Data was collected in different periods from each wind farm between April 2005 and January 2014.

Concerning species abundance, data collected was divided in two groups due to the different census methods used in the field and consequently as a result of its different survey effort. The two groups were defined concerning the different methodology used: Group 1 (G1) and Group 2 (G2). The G2 (n = 31) represents to the species of diurnal raptors and other soaring birds whose relative abundance was assessed by vantage points with duration of 30 minutes, 1 hour or 2 hours depending of the wind facility. The G1 (n = 99) represents the other diurnal birds species found assessed by 5 minute point counts. In each method all the visual or auditory contacts were counted in limited and predefined intervals.

The fatality data are from surveys performed on these wind farms at the same periods. In the wind farm searches, all traces of bird fatalities were recorded and collected for identification. Survey took 20 minutes for each search plot and covered an area up to 50 m around each wind turbine.

The values of observed mortality obtained in each wind farm were summed for each species included in this study. All the contacts concerning species relative abundance were also summed for each species detected. The census effort for G1 corresponds to multiplying the number of survey points by the total number of surveys performed. For G2, the census effort is the result of the multiplication of the number of vantage points by the number of searches and by the number of hours spent per point. For carcass searches, the survey effort matches the product of the number of surveys performed and number of turbines searched in each survey, for both groups. Respective survey effort of each wind farm was also summed for each species. The summed survey effort for each species of G1 was 4106 for bird census and 30194 for carcass searches. For G2 the sum value for abundance and carcass searches effort is 1750 and 32498, respectively. In this way, the results are considered independently of the wind farm and the survey efforts uniformed for each species of each group.

In order to ease statistical analysis due to the wide range of data, the values of abundance were categorized based on quartile values.

It is important to apply correction factors to the observations on the field, as Langston & Pullan (2003) refer. Hence, the values of observed mortality were corrected with a mean detection probability for each carcass size (small: 0.351; medium: 0.462; large: 0.606), assessed through the conduction of searcher efficiency trials at wind farms.

2.2.3 Species sensitivity and vulnerability factors

To determine which variables can influence species sensitivity to collision with wind turbines, different variables were tested to include in the models. These variables included morphological characteristics, flight type, phenology, gregarious behaviour, manoeuvrability and relative abundance. The information for each species was collected from literature research. Annex 2 summarizes the literature used for each variable. Bibliography also indicates other likely factors that may be associated with species sensitivity to wind farms (e.g.: Noguera *et al.* 2010) but they were not considered in this study due to incomplete or inexistent information for all the species evaluated.

The morphological characteristics taken into consideration were average weight (kg), length (m), wingspan (m) and wing area (m^2). The flight type is considered an important sensitivity factor (Drewitt & Langston 2008). Garthe & Huppop (2004) and Noguera *et al*. (2010) analysed the behaviour and percentage of time flight based on direct observation data. Complete data for this kind of evaluation was not found in the literature for all species. Therefore, it was indicated which flying behaviours could be presented for each species. Based on the species descriptions of Cramp & Simmons (2004), four different flying types were considered: fluttering, soaring, gliding and hovering. Regular flapping was not considered because all species can exhibit this flying behaviour (Cramp & Simmons 2004).

Phenology, the study of biological activity linked with climate and life cycle events such as birds' movements (Ricklefs 2003), identified whether birds are resident or non-resident in continental Portugal.

The gregarious behaviour of the species was also assessed due to high amounts of bird movements and lower attention to imminent threats when in flock (Drewitt & Langston 2006). It was indicated for each species if they show gregarious behaviour.

As mentioned by Noguera *et al*. (2010), manoeuvrability elucidates for the swift ability, especially in reaction to unexpected obstacles. This parameter is associated with two calculated parameters for each species: wing loading and aspect ratio. Wing loading is calculated by dividing the weight of the bird by its wing area and elucidates about flight speed. Aspect ratio is obtained by dividing the square of the wingspan by wing area and is related to the shape of the wing (Tennekes 2009).

To establish the Fatality Risk Index the resulting information of the sensitivity model and three vulnerability factors were scored: population trend, conservation status and breeding capacity. This index was based following Garthe & Huppop (2004), Noguera *et al*. (2010) and Furness *et al*. (2013) methodologies. Scores of 1 to 4 were associated with each parameter, wherein 1 represents "low vulnerability" and 4 represents "high vulnerability".

Information for Portuguese bird population's trends was obtained on *Equipa Atlas* (2008) and Catry *et al*. (2010). In this study, populations with possible and certain increase were scored with 1. Populations without apparent alterations were scored with 2. Undetermined population trend was scored with 3 and populations with certain or possible decline were scored with 4. Noguera *et al* (2010) considered population size instead of population trend as a vulnerability factor. We defined that population size as the relative abundance assessed in the field, which was included as an explanatory variable of species sensitivity and fatality. Therefore, population size was here replaced for population trend, which gave a comparable evaluation of the state of the species' population (IUCN 2012).

The conservation status used was the one assigned to birds that occur on the Portuguese territory according to Cabral *et al*. (2005). The score of 1 was assigned to considered low concern species, 2 for near threatened, 3 for vulnerable species and 4 for endangered and critical in risk birds' species.

For breeding capacity the score of Noguera *et al*. (2010) was applied based on clutch sizes. According to Noguera *et al*. (2010), 1 was endorsed for clutch sizes with an average of more than four eggs, 2 for clutch with three or four eggs, score of 3 for those with two eggs and 4 for the ones with only one egg. This parameter reflects the capability of population regeneration and consequently naturally diminishes the impact of additional mortality caused by wind turbines (Noguera *et al*. 2010).

Annex 1 presents a table that summarizes the bibliography used to collect the information for each factors.

2.2.4 Statistical methods

Count models are usually adjusted with simple Poisson or Negative Binomial distributions, but an excessive number of zeros can cause overdispersion and bias the results if the mean of the distribution is small. In ecological research, data usually present more zeros than expected. In these cases, zero inflated (ZI) or hurdle (H) models may be a solution to get a more adequate and reliable fit to the observed data (Zuur *et al*. 2009).

The main differences between zero inflated and hurdle models rely on the source of the zero counts. Depending on the source, it is possible to discriminate different types of zeros. All zeros obtained on samplings outside the species habitat range should be removed from the analyses. The other zeros could be divided into categories: true and false zeros. True zeros are related to structural errors reflecting the specie's absence due to the non-suitability of the environment for that particular specie. False zeros are associated with the observers, experimental design, sampling practises and survey errors (Zuur *et al*. 2009).

Hurdle models, which do not differentiate the source of the zeros, are divided in two steps. First, the data is divided in zeros and non-zeros and the probability of observing a zero is given by a Binomial model. Then, the non-zeros are modelled based on zero truncated distributions (count process). Zero inflated or mixture models differentiate from the hurdle models because true zeros could be produced on the count process. A Binomial process to model the false zeros is also included on zero inflated models (Zuur *et al*. 2009).

In zero inflated or hurdle models, the count process can be modelled by a Poisson (P) distribution or a Negative Binomial (NB) distribution. To summarize, the cause of an excessive zero observations and the knowledge on data allow a better choice between the two types of models (Zuur *et al*. 2009).

2.2.5 Fatality Risk Index

The Fatality Risk Index was determined in two stages. First, the sensitivity of birds' mortality by collision was model and, second, a species ranking was built by assigning scores to the results of sensitivity model and to the vulnerability factors previously mentioned. The data analysis was performed using R version 3.1.0 (R Core Team, 2014).

In the sensitivity model, the corrected mortality number for each species (estimated mortality) was the response variable. This implies that a count model was needed to adjust bird's sensitivity to fatalities by collision with wind turbines. The wrong choice of the model used may lead to erroneous conclusions (Turkman & Silva 2000). Thus, for this data the mixture-effects zero inflated and hurdle models were tested to try to deal with these difficulties (Zuur *et al*. 2009).

Four different types of models were built for each group: zero inflated model with Poisson distribution (ZIP), zero inflated model with Negative Binomial distribution (ZINB), hurdle model with Poisson distribution (HP) and hurdle model with Negative Binomial distribution (HNB).

The R functions `zeroinfl()` and `hurdle()` were used from the package `pscl` to adjust data to the different models, specifying the arguments `dist` and `link`, respectively as `poisson/negbin` and `logit` (Zeileis *et al*. 2007; Jackman 2014).

Before running the models one extreme outlier was removed.

On a first step, only the morphological and manoeuvrability factors were included to build the different models. The variance inflation factor (`vif()` function) was used to exclude the collinear variables from the model. After this selection, all the remaining variables related to species sensitivity were taken into consideration, but it was not possible to include them all to each type of model tested in a first approach due to their unbalanced sample sizes (Zuur *et al*. 2009).

After trying different combinations and building the models for each group with all the variables that could be included on them, model selection was performed using the Akaike information criterion (AIC), via the `step()` function in R (Zeileis & Hothorn 2002; Fox & Weisberg 2011; R Core Team 2014). This function was used to examine which variables could be dropped from the initial models and to select the significant ones to reach the best adjustment to this data (Zuur *et al*. 2009).

Furthermore, to infer the best fitted model, methods of selection criteria based on maximum likelihood (Borgatto 2004) and other statistical information were used. For model selection, the criteria calculated were the Pearson correlation coefficient (r), Spearman rank correlation (r_s), intercept and slope of the linear regression relating observed versus fitted values and RMSE (Root-mean-square deviation), MAE (mean absolute error), AIC, log likelihood and degrees of freedom (Zuur *et al*. 2009). These statistics were calculated using R packages: `pcsl`, `stats`, `qpcR` and `Metrics` (Zeileis *et al*. 2007; Hamner 2012; Jackman 2014; R Core Team 2014; Spiess 2014).

After model selection for each species' group, both models were analysed to understand the influence of each variable and to establish a sensitivity score. This sensitivity score matched with the characterization of the fitted values quartiles that was then used to build the Fatality Risk Index. Species in the 25 percentile were scored with 1 (lower sensitivity). Species with a probability between 25% and 50% of presenting fatalities were scored with 2, and the species between 50% and 75% of probability were scored with 3. The species that are present on the fourth quartile of fitted mortality were scored with 4 (higher sensitivity).

By adapting the models presented in the literature (Garthe & Huppop 2004; Bright *et al*. 2008; Noguera *et al*. 2010; Furness *et al*. 2013), the global species ranking was achieved by applying the following formula per each species, where SS represent the Sensitivity Score and PT, CT and BC the scores assigned to Population Trend, Conservation Status and Breeding Capacity, respectively.

$$Fatality\ Risk\ Index\ = SS * \frac{PT + CT + BC}{3}$$

2.3 Results

In total, 31 different species were assessed in G2 and 99 species in G1 on the field surveys. All this 130 different birds constitute the initial species pool in this study. Due to the lack of complete available information and after the removing of the outlier, the species pool was reduced to 97 (G1: 72 species; G2: 25 species) from 13 different taxonomic orders in total (Accipitriformes; Anseriformes; Apodiformes; Charadriiformes; Ciconiformes; Columbiformes; Coraciiformes; Cuculiformes; Falconiformes; Galliformes; Passeriformes; Pelecaniformes; Piciformes).

The observed distribution of the corrected mortality counts for the G1 and G2 species group respectively are presented in Figure 4. Both distributions show high number of zeros. These zero counts represent 75% of the estimated mortality observations for the G2 species and 69.4% for G1 group. The estimated mortality for birds of G1 group presents median equal to 0, which is clearly lower than the mean (mean = 2.12). The variance of this count is approximately 40.56. Seventy five percent of G1 species present estimated mortalities lower than approximately 1.250, which is even lower than the mean. For G2 species the median of estimated mortality is equal to 0. The mean and variance of this count is 2.12 and 47.36, respectively.

For G1 the species with larger estimated mortality were *Alauda arvensis*, *Lullula arborea* and *Apus apus*. For G2 the highest values were observed on *Falco tinnuculus*, *Circus pygargus* and *Buteo buteo.* Table 1 resumes the estimated mortality for all the species of this study. These mortality observations may be influenced by different factors. Table 2 presents a summary of all the factors tested on the sensitivity model for each group.

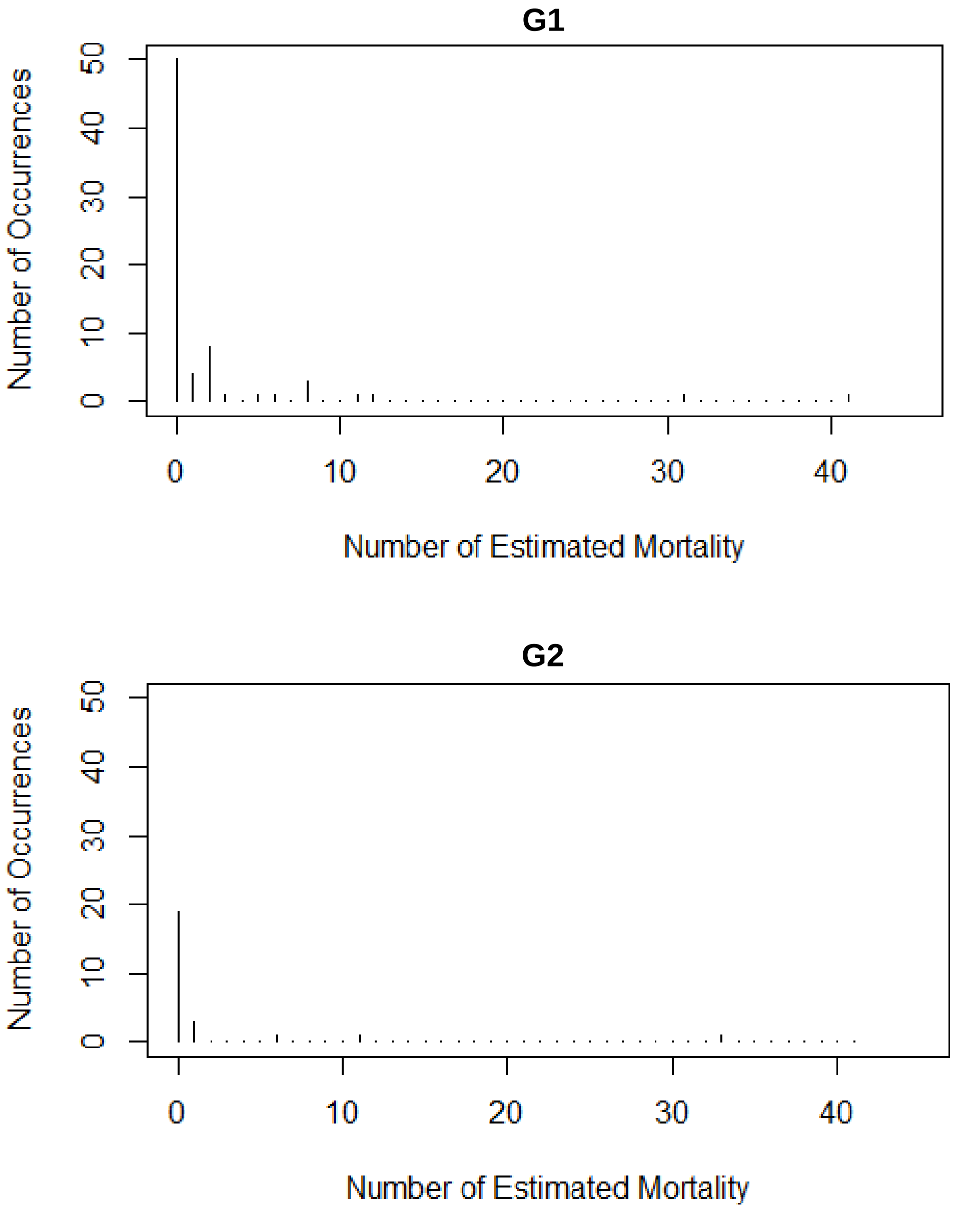

Figure 4. Empirical distribution of estimated mortality for G1 and G2 groups.

Table 1. Estimated mortality counts for each species of G1 and G2.

G1		
Estimated Mortality	**Number of Occurrences**	**Species**
0	50	*Aegithalos caudatus; Anas platyrhynchos; Anthus campestres; Anthus pratensis; Anthus spinoletta; Anthus trivialis; Carduelis carduelis; Carduelis chloris; Carduelis spinus; Certhia brachydactyla; Columba palumbus; Coturnix coturnix; Cuculus canorus; Dendrocopos major; Fringilla coelebs; Gallinago gallinago; Hirundo daurica; Hirundo rustica; Loxia curvirrostra; Motacilla cinérea; Motacilla flava; Oenanthe oenanthe; Parus ater; Parus caeruleus; Parus cristatus; Parus major; Passer domesticus; Phoenicurus phoenicurus; Phylloscopus trochilus; Pica pica; Prunella modulars; Pyrrhula pyrrhula; Regulus regulus; Riparia riparia; Saxicola rubetra; Serinus serinus;Sitta europaea; Streptopelia decaocto; Sturnus unicolor; Sturnus vulgaris; Sylvia atricapila; Sylvia communis; Sylvia hortensis; Sylvia melanocéfala; Troglodytes troglodytes;Turdus merula; Turdus philomelos; Turdus torquatus; Turdus viscivorus; Upupa epops*
1	4	*Merops apiaster; Garrulus glandarius; Picus viridis; Streptopelia turtur*
2	8	*Galerida cristata; Luscinia megarhynchos; Phoenicurus ochruros; Muscicapa striata; Ptyonoprogne rupestres; Motacilla alba; Emberiza hortulana; Jynx torquilla*
3	1	*Columba livia*
5	1	*Hippolais polyglotta*
6	1	*Galerida theklae*
8	3	*Apus pallidus; Carduelis canabina; Ficedula hypoleuca*
11	1	*Erithacus rubecula*
12	1	*Apus apus*
31	1	*Lullula arborea*
41	1	*Alauda arvenses*

G2		
Estimated Mortality	**Number of Occurrences**	**Species**
0	19	*Accipiter gentilis; Aquila chrysaetos; Ardea cinérea; Ciconia ciconia; Ciconia nigra; Circus cyaneus; Corvus corax; Corvus corone; Egretta garzetta; Elanus caeruleus; Falco peregrinus; Falco subbuteo; Larus cachinnans; Larus fuscus; Milvus migrans; Milvus milvus; Neophron percnopterus; Pernis apivorus; Phalacrocorax carbo*
1	3	*Accipiter nisus; Gyps fulvus; Hieraaetus pennatus*
6	1	*Buteo buteo*
11	1	*Circus pygargus*
33	1	*Falco tinnunculus*

For the G2 model, fluttering was excluded due to the characteristics of the species and its consequent absence. Soaring and gliding were not considered once the majority of species presented this behaviour, unbalancing these variables. For the G1 model, all the variables related to flying were included on the first model formula.

Variables present in the model formula were selected by its significance as explanatory variables for this data. Then, four different models were obtained for each group, one for each model type and applied distribution, to ascertain which fits better with the empirical data.

Table 3 shows the results of the statistical criteria calculated for the selected models for G1 and G2. These results formally validate the proposed models.

Table 2. Summary of each variable tested on the statistical models. Min: minimum value; max: maximum value; $\bar{x}$: the mean value.

Variable	G1			G2		
	min	**max**	**$\bar{x}$**	**min**	**max**	**$\bar{x}$**
Average Weight (Kg)	0.006	1.175	0.084	0.204	47.525	5.008
Average Length (m)	0.090	0.640	0.192	0.330	1.075	0.610
Average Wingspan (m)	0.145	0.895	0.316	0.625	2.600	1.394
Average Wing Area (m^2)	0.003	0.105	0.020	0.065	1.000	0.276
Wing Loading (Kg/m^2)	1.085	12.998	2.813	2.063	79.606	10.938
Aspect Ratio	3.500	13.500	5.872	3.934	19.857	8.413
Relative Abundance	0.000	1706.000	214.250	1.000	1068.000	131.500

	Present	**Absent**	**Present**	**Absent**
Fluttering	20	52	0	25
Gliding	27	45	21	4
Soaring	2	70	22	3
Hovering	25	45	7	18

	Yes	**No**	**Yes**	**No**
Gregarious Behaviour	38	34	6	19

	Resident	**Non-resident**	**Resident**	**Non-resident**
Phenology	37	35	14	11

Table 3. Model comparison based on the described adjustment statistics (see text for details).

	Model	r	r_s	Intercept	Slope	RMSE	MAE	AIC	Log lik	df
G1	ZIP	0.40	0.20	0.20	0.93	1.08	2.57	217.20	-90.60	18
	ZINB	0.46	0.33	0.07	0.87	0.79	2.65	202.56	-82.28	19
	HP	0.41	0.18	0.07	0.96	1.06	2.69	218.36	-91.18	18
	HNB	0.39	0.21	0.33	0.84	1.00	2.64	204.22	-89.11	13
G2	ZIP	-0.09	0.26	2.30	0.00	0.61	96318.20	52.91	-16.46	10
	ZINB	-0.09	0.26	2.30	0.00	0.61	77825.09	54.91	-16.46	11
	HP	-0.08	0.25	2.25	0.00	0.91	645.68	56.06	-20.03	8
	HNB	0.26	0.22	1.23	0.36	0.97	3.44	66.37	-24.19	9

The best fitted model for G1 was a zero-inflated Negative Binomial model that includes the following variables: average weight; aspect ratio; gliding; hovering; gregarious behaviour; relative abundance. Average length, wingspan, wing loading and average wing area were dropped from the model due to their collinearly. Fluttering and phenology were dropped through `step()` function once they were not statistically significant explanatory variables for this case study. For the final G1 model, average weight (p = 0.025) and high abundance (p = 0.003) were determinant for the model count process, explaining the true zeros and positive counts observations. Aspect ratio (p = 0.016), presence of gliding (p = 0.033) and gregarious behaviour (p = 0.004) were the significant variables for the Binomial model part, that is related to false zeros generation.

For G2 the model that give the best fit was the zero-inflated Poisson model that includes average weight, hovering, gregarious behaviour and phenology. Average length, wingspan, wing loading and average wing area were also dropped due to their collinearly. Then, aspect ratio was also dropped from the model but due to non-significance. For the G2 model, none of the variables were significant on the binomial part of the model (p > 0.05). For the count part, all the final variables were statistical significant (average weight: p < 0.001; presence of hovering: p < 0.001; presence of gregarious behaviour: p < 0.001; phenology – non-resident species: p < 0.001).

Probabilities of observing mortality due to collision with wind turbines were assessed through the selected models, which allowed scoring each species according to the quartile it belonged. For species with higher probabilities to present fatality observations, a higher score was given. The Fatality Risk Index for all the species studied was built also taking all the vulnerability variables into consideration.

Table 4 presents the Fatality Risk Index obtained for all species.

Table 4. Fatality Risk Index (FRI) calculated for all the species through scores.

Group	Species	FRI	Group	Species	FRI	Group	Species	FRI	Group	Species	FRI
G2	*Milvus milvus*	13.33	G1	*Parus cristatus*	5.33	G1	*Phylloscopus trochilus*	3.33	G1	*Motacilla alba*	2.00
G1	*Apus apus*	10.67	G1	*Parus major*	5.33	G1	*Ptyonoprogne rupestris*	3.33	G1	*Pyrrhula pyrrhula*	2.00
G2	*Circus pygargus*	9.00	G1	*Prunella modularis*	5.33	G1	*Streptopelia decaocto*	3.33	G1	*Riparia riparia*	2.00
G1	*Alauda arvensis*	8.00	G1	*Sturnus unicolor*	5.33	G1	*Turdus merula*	3.33	G1	*Saxicola rubetra*	2.00
G2	*Circus cyaneus*	8.00	G1	*Troglodytes troglodytes*	5.33	G2	*Accipiter nisus*	3.00	G1	*Sylvia atricapilla*	2.00
G1	*Columba livia*	8.00	G1	*Anthus Pratensis*	5.00	G1	*Anthus campestris*	3.00	G1	*Turdus viscivorus*	2.00
G2	*Larus fuscus*	8.00	G1	*Anthus trivialis*	5.00	G1	*Garrulus glandarius*	3.00	G1	*Carduelis spinus*	1.67
G1	*Merops apiaster*	8.00	G2	*Buteo buteo*	5.00	G1	*Hirundo daurica*	3.00	G1	*Columba palumbus*	1.67
G2	*Neophron percnopterus*	7.33	G1	*Ficedula hypoleuca*	5.00	G1	*Picus viridis*	3.00	G2	*Larus cachinnans*	1.67
G2	*Gyps fulvus*	7.00	G1	*Luscinia megarhynchos*	5.00	G1	*Certhia brachydactyla*	2.67	G1	*Turdus torquatus*	1.67
G2	*Pernis apivorus*	7.00	G1	*Sturnus vulgaris*	5.00	G2	*Corvus corone*	2.67	G1	*Aegithalos caudatus*	1.33
G1	*Apus pallidus*	6.67	G1	*Sylvia communis*	5.00	G1	*Hirundo rustica*	2.67	G1	*Anas platyrhynchos*	1.33
G2	*Elanus caeruleus*	6.67	G1	*Dendrocopos major*	4.00	G1	*Motacilla cinerea*	2.67	G2	*Ardea cinerea*	1.33
G1	*Lullula arborea*	6.67	G1	*Erithacus rubecula*	4.00	G1	*Muscicapa striata*	2.67	G1	*Carduelis carduelis*	1.33
G2	*Milvus migrans*	6.67	G1	*Loxia curvirostra*	4.00	G1	*Oenanthe oenanthe*	2.67	G2	*Ciconia ciconia*	1.33
G1	*Serinus serinus*	6.67	G1	*Parus caeruleus*	4.00	G1	*Pica pica*	2.67	G1	*Cuculus canorus*	1.33
G2	*Falco peregrinus*	6.00	G2	*Phalacrocorax carbo*	4.00	G1	*Sylvia hortensis*	2.67	G1	*Emberiza hortulana*	1.33
G1	*Galerida cristata*	6.00	G1	*Phoenicurus ochruros*	4.00	G2	*Aquila chrysaetos*	2.33	G1	*Motacilla flava*	1.33
G2	*Hieraaetus pennatus*	6.00	G1	*Sitta europaea*	4.00	G2	*Falco subbuteo*	2.33	G1	*Passer domesticus*	1.33
G1	*Carduelis cannabina*	5.33	G1	*Streptopelia turtur*	4.00	G1	*Gallinago gallinago*	2.33	G1	*Phoenicurus phoenicurus*	1.33
G1	*Carduelis chloris*	5.33	G1	*Sylvia melanocephala*	4.00	G2	*Accipiter gentilis*	2.00	G1	*Regulus regulus*	1.33
G2	*Falco tinnunculus*	5.33	G1	*Turdus philomelos*	4.00	G1	*Anthus spinoletta*	2.00	G1	*Jynx torquilla*	1.00
G1	*Fringilla coelebs*	5.33	G1	*Upupa epops*	4.00	G2	*Ciconia nigra*	2.00			
G1	*Galerida theklae*	5.33	G2	*Corvus corax*	3.33	G1	*Coturnix coturnix*	2.00			
G1	*Parus ater*	5.33	G1	*Hippolais polyglotta*	3.33	G2	*Egretta garzetta*	2.00			

2.4 Discussion

The observed mortality numbers varied between the two groups analysed. As shown in Figure 4, both present an excessive number of species for which mortality was not observed. This means that the mortality distribution clearly shows an excessive number of zero counts, thus justifying the choice in using zero-inflated or hurdle models. Additionally, the high values of variance indicate the presence of overdispersion (Zuur *et al*. 2009).

Both zero-inflated models and hurdle models could be a wise solution to represent the studied data. If the excessive number of zeros were ignored and a Poisson and Negative Binomial distributions were applied, standard errors and estimated parameters might have been biased and extra overdispersion could be caused (Zuur *et al*. 2009). The main differences between the two types of models are related to how the zeros are modelled, as explained above. Considering our data, zeros could be produced on the count process, which means some species could effectively present zero mortality counts. Therefore, for this ecological data the existences of the two main types of zeros: true zeros and false zeros, makes sense. Taken this into account, the zero inflated models were more suitable th4n hurdle models for this study (Zuur *et al*. 2009).

After setting aside hurdle models, statistical selection criteria were used to choose the model distribution that better fits the data (Table 3). These statistical and information criteria allowed us to assess the suitability for each model and to perform models validation (Akaike 1974; Turkman & Silva 2000; Borgatto 2004).

The calculated parameters did not show high correlation between observed and fitted values. For G2, as presented on Table 3, the coefficient correlation values are close to 0, indicating a very weak relation between the observed and estimated values. Also intercept (2.302) and slope (0) present values far from 0 and 1, respectively, what also indicates a wicked adjustment between fitted and observed values. Therefore, fitted values might not represent reliable estimations. The chosen model presents the lower AIC. Thus, for G2 a ZIP model was chosen, instead of a ZINB model which presents worst selection criteria. This indicates that, after dealing with excessive zeros, a Poisson distribution could easily represent the suited data and deal with possible over dispersion. The results also show that the analyses could be biased and data adjustment could be improved. This could happen since it was not possible to include all the studied variables on the model due to unbalanced samples of those variables. A bigger sample with more balanced values could allow the analyses of all the variables. More factors and more detailed analyses of each one could help to explain what truly affects birds' mortality due to collision with wind turbines.

For G1 data, a ZINB model shows the best fit compared to the other models under evaluation. In this case dealing with the overdispersion caused by zeros was not enough to get a better adjustment and a model with Negative Binomial distribution on the count process was chosen. This choice was also based on evaluated information criteria (Table 3). As shown in Table 3, the Pearson correlation coefficient is also not close to 1, indicating that there was not a good adjustment between observed and fitted values. However, slope and intercept indicates a better fit, once they are close to 0 and 1, respectively. The ZINB model was chosen not only due to its already presented results but also because for G1 it presented the lowest AIC from the tested models.

Results for G1 and G2 models were significantly different. The G1 model presents better parameters results indicating a more reliable model. The main differences of the models were in the variables that defined each model, which could be related to the samples sizes. G1 has a larger sample size with less unbalanced variables. With a larger and/or balanced sample, data adjustment could be improved and more factors could be tested. Once the G1 model includes more variables, it could give a better understanding about birds' sensitivity to wind turbines collision and may represent a less biased analyses. Both models gave an estimated probability to observe mortality for each species, but for G2 models the information is not as reliable as explained before.

To improve these models other variables should be considered and a higher and more balanced sample could allow a more reliable assessment without dividing the species groups. Significant factors to explain mortality sensitivity could be related not only to species behaviour and characteristics but also to intra-specific factors (e.g.: Henderson *et al*. 1996; Drewitt & Langston 2006), environmental conditions (e.g.: Erickson *et al*. 2001; Drewitt & Langston 2006) and alterations on birds population and communities ecological niches (e.g.: Thelander *et al*. 2003; Drewitt & Langston 2006; Kuvlesky *et al*. 2007)

According to the literature, the relation of relative abundance and birds mortality presents contradictory results (Carrete *et al*. 2012). Relative abundance was not included in the model for G2, whereas for G1 it is a significant variable to positively adjust data, especially on the count process when species present higher rates of relative abundance. Langston & Pullan (2003) and Smallwood & Thelander (2008) considered that higher birds abundance should present higher mortality levels because of a probable higher exposure to the risk, but Fernley *et al*. (2006), Whitfield & Madders (2006) and de Lucas *et al*. (2008) do not support this idea.

Barrios & Rodríguez (2004) propose that the risk of fatalities for soaring birds may be connected to the density of birds' movements close to the rotting blades and suggested that this could be linked to the species behaviour, especially the flight behaviour. Other authors considered that this behaviour is associated with birds mortality (Orloff & Flannery 1993; Thelander *et al*. 2003; Barrios & Rodríguez 2004; Drewitt & Langston 2006).

Our results indicate that the presence of certain flying behaviours presented higher risk for birds (the ones significant on the count part of the model – hovering on G2 model) or higher probabilities of generate zero observations (the ones significant on the binomial part of the model – presence of gliding on the G1 model). Hovering birds present higher collision risk since this flight type is associated with strong and unpredictable winds that could unexpectedly change the birds' position, when they are focused on preys (Smallwood & Thelander 2008; Krijgsveld *et al*. 2009; Marques *et al*. 2014). Soaring was considered not significant in the G1 once this behaviour is almost absent for this group. On the other hand, it characterizes the G2 species, recognised as a high vulnerability risk group (Madders & Whitfield 2006). The influence of each flying type could also be associated with the flying altitude that each type entails. Birds that fly in higher altitudes could present a higher collision risk due to the proximity to the rotor blades (Furness *et al*. 2013). However, different birds may present different flying types in different proportions, which could explain the influence of each flying behaviour (Garthe & Huppop 2004). Analysing this aspect in a different perspective and adopting a methodology similar to Bright *et al.* (2008), Noguera *et al.* (2010) and Furness *et al.* (2013) could improve this study. In their studies they examined the percentage of flying time and the behaviour presented as well as mean heights of flights for each specie.

Furthermore, the risk of these flying types could be influenced by other risk factors, like manoeuvrability (Pennycuick 1998). This parameter expresses the aerial agility of species to avoid imminent obstacles and is considered a consequence of birds' morphology rather than behaviour (Furness *et al*. 2013). For example, birds with small wings and high weight, despite having high flying speed, present lower manoeuvrability. This means that they present high wing loadings and low aspect ratios which results in a greater difficulty to avoid turbine collision (Bevanger 1998; Drewitt & Langston 2006; Noguera *et al*. 2010). This way, birds with lower manoeuvrability, which matches to high wing loading and low aspect ratio, present a higher risk of collision with wind farm structures (Brown *et al*. 1992; Bevanger 1998; Garthe & Huppop 2004; Drewitt & Langston 2006; Noguera *et al*. 2010). Both models present manoeuvrability and morphological variables significant to model the estimated data. These variables present high collinearity among them and their effects are connected. Subsequently, only the representative variables of the group were applied to avoid erroneous outcomes in the models. In the G1 the significant variables were average weight and aspect ratio. In the G2 only average weight is present, but it also confirms the significance of manoeuvrability to understand birds' collision with wind turbines due to its collinearity relation to wing loading and the other morphological variables.

Both groups present gregarious behaviour as an explanatory variable but with contradictory results. For G2 it was a significant variable in the count model, which could also be associated with the concentration of bird movements close to higher risk zones and lower levels of attention by birds when in flock (Alonso & Alonso 1999; Pettersson 2005; Drewitt & Langston 2008). However, for G1 it is a significant variable on the Binomial part, influencing zero counts observations. This variable and birds fatalities could be influenced also by the combination of other factors, such as seasonal factors, avoidance behaviours, wind farm location, habitat specialization and probability of area usage by birds. The combination and interaction of these factors may be the explanation for the contradictory results presented (Barrios & Rodríguez 2004; Furness *et al*. 2013).

Although resident species may present a higher risk due to longer exposure to the risk of collision (Barrios & Rodríguez 2004; Percival 2005), this study indicates that non-resident species might show higher sensitivity, as also proposed by Noguera *et al*. (2010). Resident species might be more familiarized with these infrastructures or present avoidance behaviours, which could explain lower collision rates (Barrios & Rodríguez 2004; Drewitt & Langston 2008;). Phenology is a significant variable only for G2. For G1, a longer time of exposure may not be a cause of birds' mortality, as migrants may be more exposed to this effect, especially if wind farms are on their routes (Dahl *et al*. 2013; Marques *et al*. 2014).

The combination of all the variables of each model allowed inferring the probability of birds showing mortality due to collision with wind turbines. These probability analyses also permit the comparison of all the species, independently of the group. Nonetheless, as also suggested in Table 3 and in Annex 2, fitted values may be biased once the final model present a low correlation with observed count and inadequacy to model data.

Among the studied species, the most sensitive to wind turbines collision are *Milvus milvus, Larus fuscus* and *Phalacrocorax carbo* for the G2 and *Apus apus, Lullula arborea* and *Sylvia communis* for G1. This reflects the high probability of collision with wind turbines by these species due to their morphological and ethological characteristics as described by the respective sensitivity models. However, these species are not necessarily the most vulnerable species to this impact and consequent to additional mortality on their population. To understand which species are more vulnerable, the Fatality Risk Index was established taking into consideration the conservation status of the species and their resilience parameters.

The results show that the species with a highest fatality risk are *Milvus milvuss, Apus apus, Circus pygargus, Alauda arvensis* and *Circus cyanus.* These species present high sensitivity to collision with wind turbines and high vulnerability index. For these species the number of fatalities could compromise the renewal capacity of their population. In these cases, impacts of wind farms can compromise these species survival, if mitigation measures are not taken into account (Noguera *et al*. 2010). Species like *Carduelis chloris, Sylvia melanocephala* and *Phalacrocorax carbo*, had high probability for observed mortality but do not present a high Fatality Risk Index. For these species, the renewable ability of the population is high and/or the conservation concern is low. Additional mortality may not represent a major impact for species survival (Noguera *et al*. 2010). However the impacts on these species should not be completely overlooked. Although this study gives some indications about which species should be the target of future impact assessment and monitoring studies, more detailed studies should be performed to account the specificities of the sites and surrounding bird populations as well as reaching stronger and reliable predictive models (Madders & Whitfield 2006; Chamberlain *et al*. 2005; Noguera *et al*. 2010; de Lucas *et al*. 2012; Furness *et al*. 2013; Marques *et al*. 2014).

These results support the studies that highlight raptors as a highy sensible group to wind farms, not only due to their sensitivity to collision but also due to possible barriers effects, disturbance, habitat loss and conservation concern (Orloff & Flannery 1992; Barrios & Rodríguez 2004; Garthe & Huppop 2004; Drewitt & Langston 2006; Madders & Whitfield 2006; Noguera *et al*. 2010; de Lucas *et al*. 2012). However some passerines also present high Fatality Risk Indexes that should not be overlooked (Morinha *et al*. 2014).

This type of energy source presents clear advantages and a high potential, as an answer for the electricity needs as well as a possibility for climate change mitigation (Amaral 2009). Nevertheless reducing or neutralizing its impacts on biodiversity, through better planning and more efficient mitigation measures, is also essential, to make this a reliable and truly clean and green solution (Ek 2005; Fielding *et al*. 2006; Gamboa & Munda 2007; de Lucas *et al*. 2008; Amaral 2009).

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CHAPTER 3. FINAL REMARKS

With this study, it was possible to conclude that different variables influence different groups of species. According to the models, the morphological characteristics, manoeuvrability, flying type, behaviour and relative abundance are the most significant factors tested. These zero-inflated models permitted the calculation of the fatality risk index where sensitivity to impact and conservation vulnerability were combined. Ranking species with more potential risk is a way to prioritise the investment of limited resources in the conservation of species with higher impact risk (Desholm 2009).

The levels of the correlation coefficients between estimated and fitted values obtained were extremely low, the selected models should be used with wariness, due to the high probability of biased and unreliable results in relation to the impacts on nature. This way, it is essential to improve these models and reliability of their results.

In general, the literature indicates that calculation of indexes should be significantly improved. Incorporating a wide variety of factors on models and indexes has been criticized because the variables tested may present different scales which could be incomparable and incompatible. Multi-collinearity among factors could also occur and bias the models (Desholm 2009; Furness *et al*. 2013).

Other problems about building this kind of models and with their results reliability are the inconsistency in sampling and the limited number of long-term studies (de Lucas *et al*. 2008; Drewitt & Langston 2008). The development and application of precise and standardized search methods are fundamental to obtain more reliable estimations (Paula *et al*. 2011). This can also enable studies comparison (Drewitt & Langston 2008). The field observations should be corrected by detection probabilities and rates of scavengers' removal (Langston & Pullan 2003). In the future, more studies about avoidance rates should be performed and taken into consideration in collision risk models as a determinant factor influencing estimated mortality values (Chamberlain *et al*. 2005; Furness *et al*. 2013). Better assessments tools can also allow the development of more objective, complete and reliable models and indexes (Madders & Whitfield 2006).

During the last few years the knowledge about these impacts and how birds are influenced by wind farms is increasing, but complete information is still low (Marques *et al*. 2014). This way, more studies should be performed to fill existing information gaps and strengthen the reliability of the available data (Noguera *et al*. 2010).

This kind of models and indexes are fundamental to reach a better understanding of the factors that influence birds' mortality by turbine collision. This is why models and indexes should be continuously re-evaluated and upgraded (Chamberlain *et al*. 2005; Madders & Whitfield 2006; Desholm 2009; Furness *et al*. 2013). This knowledge is fundamental to improve future studies, development of more suitable methodologies and impacts predictions (Drewitt & Langston 2006; de Lucas *et al*. 2008).

In the future, the models created and the fatality risk index calculated in this research could be used to build vulnerability maps (e.g.: Garthe & Huppop 2004; Bright *et al*. 2008; Bright *et al*. 2009; Noguera *et al*. 2010; Furness *et al*. 2013;). Vulnerability maps could represent great tools in wind farm location selection (Noguera *et al*. 2010; Furness *et al*. 2013). The development of these spatial models and indexes allow the prediction of the impacts of one wind farm as well as the cumulative effects of infrastructures groups across extensive areas. These spatial models are additional tools to improve impacts assessments (Furness *et al*. 2013; Marques *et al*. 2014).

Although most studies present low mortality rates, even these low values could bring great impacts on species and respective population (Langston & Pullan 2003; Madders & Whitfield 2006; Drewitt & Langston 2008; de Lucas *et al*. 2012). At any stage of a wind farm project impact minimization measures should be considered. A good project planning of wind farms is vital to achieve minimal impacts on avifauna (Fielding *et al*. 2006; de Lucas *et al*. 2008; Marques *et al*. 2014).

The right location of wind turbines is the most effective measure to reduce negative impacts on wildlife (de Lucas *et al*. 2012; Marques *et al*. 2014). At a planning stage, identification of potential sensitive locations by spatial fatality models or the avoidance of areas with high densities of threatened species or prone to collisions could be a strategy to minimize impacts as well as the avoidance of conservation key areas (Drewitt & Langston 2006; Fielding *et al*. 2006; Madders & Whitfield 2006; de Lucas *et al*. 2008; de Lucas *et al*. 2012; Northrup & Wittemyer 2013; Marques *et al*. 2014).

After wind farms construction, different impacts mitigation measures could be applied. Replacing wind turbines that present higher effects on flying vertebrates for less problematic sites could be an example of an impact reduction measure (Northrup & Wittemyer 2013; Marques *et al*. 2014). Stopping turbines on demand in potentially hazardous situations may also be an alternative measure that could be used with minimal effects on energy production (de Lucas *et al*. 2012). Other alternative is the restriction of turbines operation during expected potential periods, like high birds' activity periods and adverse climate weather episodes. However, this may implicate higher effects on the energetic production then the measures mentioned above (Smallwood & Karas 2009; Marques *et al*. 2014).

Technical and scientific developments are also powerful tools in negative impacts mitigation. Advances on turbines design and technology could improve turbine visibility for birds (Marques *et al*. 2014). Radars, cameras, telemetry and other systems are other technologies in development that could give important contributions in different topics, such as identification of risky situations and assessments of behavioural information (Drewitt & Langston 2006; de Lucas *et al*. 2012; Marques *et al*. 2014). Deterrents devices, like laser or bioacoustics stimulus, could also be used but habituation to the stimuli could occur. However, this could have other unpredictable effects on birds (Marques *et al*. 2014).

Habitat modification techniques are another possible minimization method examined by Marques *et al*. (2014). With these techniques the wind farms areas usage by birds could be decreased as well as alternative usage areas could be created and incremented (Marques *et al*. 2014).

After construction, monitoring programs are essential to evaluate the effectiveness of the implemented measures and potentiate their improvement and increasing knowledge about this issue. In extreme situations, compensatory measures by enhancing target populations or minimizing other human impacts on birds might be considered (Amaral 2009; Marques *et al*. 2014).

Monitoring and environmental impacts studies are relevant at all stages of a wind farm project (Amaral 2009). Before-after control impact approaches are also crucial to reach a better understanding of factors that influence these impacts, getting reliable results and assess mitigation measures effectiveness (Marques *et al*. 2014).

Wind energy still depends on technological advances to solve some constrains, such as wind intermittency and its integration on electric grid, to turn this into a real alternative to fossil fuels. However, new technologies could bring new conservation questions. But, at the same time, this developments could at the same time bring new knowledge in how wind farms impacts could be reduced (Wiser *et al*. 2011; Marques *et al*. 2014).

Compared to other human interferences, such as illegal shooting, windows, power lines, poisoning, cars and pets, wind farms present the lowest mortality rates, not exceeding 40 deaths per turbine per year (Drewitt & Langston 2008; Sovacool 2009). These differences between impacts rates of different activities are especially relevant when it is compared with the considerable impacts caused by fossil fuels exploration. Climate change could also present devastating impacts on wildlife and may be the cause of the extinction of 15% to 37% of global species by 2050 (Bright *et al*. 2009).

In conclusion, climate change is an enormous threat not only to humans but also to wildlife. Sustainable expansion of renewable energy is an essential tool in climate change mitigation (Bright *et al*. 2009) and to accomplish climate and energetic international commitments. Both wind energy enlargement and environmental associated topics need further research and depend on close collaboration between industry, governments and researchers (Drewitt & Langston 2008; Wiser *et al*. 2011). A better understanding of this issue is vital to minimize impacts and improve alternative energies exploration for a greener future (Panwar *et al*. 2011).

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ANNEX 1

Bibliography source of the data used for each variable.

Variable	References
Morphological Variables (weight; length; wingspan)	Cramp & Simmons 2004
Wing Area	BOS 2014 and some data provided by Sander Gussekloo, Experimental Zoology Group, Wageningen University, The Netherlands
Flight type	Cramp & Simmons 2004
Gregarious Behaviour	Cramp & Simmons 2004
Phenology	Equipa Atlas, 2008; Catry *et al*. 2010
Conservation Status	Cabral *et al*. 2005
Breeding Capacity	Cramp & Simmons 2004
Population Trend	Equipa Atlas, 2008; Catry *et al*. 2010

ANNEX 2

Fitted Values for Mortaliy (FM) calculated with the selected models.

G1		G1		G1		G2	
Species	**FM**	**Species**	**FM**	**Species**	**FM**	**Species**	**FM**
Aegithalos caudatus	0.43	*Galerida theklae*	2.75	*Pica pica*	0.57	*Accipiter gentilis*	0.03
Alauda arvensis	7.92	*Fringilla coelebs*	9.20	*Picus viridis*	1.17	*Accipiter nisus*	0.35
Anas platyrhynchos	0.06	*Galerida cristata*	1.55	*Prunella modularis*	8.64	*Aquila chrysaetos*	0.00
Anthus campestris	1.35	*Galerida theklae*	2.75	*Ptyonoprogne rupestris*	0.93	*Ardea cinerea*	0.00
Anthus pratensis	1.89	*Gallinago gallinago*	0.08	*Pyrrhula pyrrhula*	0.56	*Buteo buteo*	3.53
Anthus spinoletta	0.01	*Garrulus glandarius*	1.21	*Regulus regulus*	0.36	*Ciconia ciconia*	0.00
Anthus trivialis	2.26	*Hippolais polyglotta*	0.91	*Riparia riparia*	1.00	*Ciconia nigra*	0.02
Apus apus	15.93	*Hirundo daurica*	1.16	*Saxicola rubetra*	0.35	*Circus cyaneus*	3.58
Apus pallidus	3.62	*Hirundo rustica*	0.89	*Serinus serinus*	6.19	*Circus pygargus*	4.40
Carduelis cannabina	5.66	*Jynx torquilla*	0.27	*Sitta europaea*	1.36	*Corvus corax*	0.18
Carduelis carduelis	0.49	*Loxia curvirostra*	0.89	*Streptopelia decaocto*	0.68	*Corvus corone*	0.18
Carduelis chloris	2.52	*Lullula arborea*	10.23	*Streptopelia turtur*	0.90	*Egretta garzetta*	0.21
Carduelis spinus	0.10	*Luscinia megarhynchos*	1.72	*Sturnus unicolor*	14.51	*Elanus caeruleus*	13.18
Certhia brachydactyla	1.07	*Merops apiaster*	2.31	*Sturnus vulgaris*	1.53	*Falco peregrinus*	3.43
Columba livia	1.68	*Motacilla alba*	0.79	*Sylvia atricapilla*	0.84	*Falco subbuteo*	0.03
Columba palumbus	0.07	*Motacilla cinerea*	0.58	*Sylvia communis*	1.14	*Falco tinnunculus*	13.88
Coturnix coturnix	0.13	*Motacilla flava*	0.08	*Sylvia hortensis*	0.85	*Gyps fulvus*	1.00
Aegithalos caudatus	0.43	*Muscicapa striata*	0.62	*Sylvia melanocephala*	9.84	*Hieraaetus pennatus*	0.32
Alauda arvensis	7.92	*Oenanthe oenanthe*	0.68	*Troglodytes troglodytes*	7.68	*Larus cachinnans*	0.06
Anas platyrhynchos	0.06	*Parus ater*	3.25	*Turdus merula*	1.09	*Larus fuscus*	665235.60
Cuculus canorus	0.35	*Parus caeruleus*	1.62	*Turdus philomelos*	1.95	*Milvus migrans*	2334.32
Dendrocopos major	1.39	*Parus cristatus*	2.94	*Turdus torquatus*	0.03	*Milvus milvus*	1213125.52
Emberiza hortulana	0.40	*Parus major*	2.52	*Turdus viscivorus*	0.29	*Neophron percnopterus*	0.21
Erithacus rubecula	8.32	*Passer domesticus*	0.41	*Upupa epops*	1.51	*Pernis apivorus*	2.23
Ficedula hypoleuca	1.35	*Phoenicurus ochruros*	1.45			*Phalacrocorax carbo*	64878.90
Fringilla coelebs	9.20	*Phoenicurus phoenicurus*	0.24			*Accipiter gentilis*	0.03
Galerida cristata	1.55	*Phylloscopus trochilus*	0.85				