Birds and power lines
From conflict to solution

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This book is the result of work on two of his lifelong passions, the study of population dynamics in the Spanish imperial eagle in Doñana, and his highly successful study and correction of the impact of power lines, which has given the best possible outcome, the coexistence of birds and power lines.
**Endesa** is the largest electric power company in Spain. At Endesa, we look to the future, seeking intelligent solutions, to develop realistic proposals that address present and future energy challenges. Our corporation is also strongly committed to preserving the environment, because we firmly believe that service provision can and must be compatible with the protection of the environment. Thus, we have been pioneers both in studying the impacts that may cause the power lines crossing our landscape and in finding solutions to these impacts.
**Migres Foundation** is a private non-profit organization founded in 2003 to promote scientific research on bird migration and to boost sustainable development activities. We are convinced that these policies offer the best tools for biodiversity conservation.

Moreover, Migres Foundation has turned into a necessary association which reconciles sustainable development and biodiversity conservation, providing solutions for environmental challenges which, if conveniently tackled, become true opportunities of economic and social sustainable growth.
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1. Origins

The story begins

If George Perkins Marsh had written his book *Physical geography as modified by human action* (1864) 100 years later, he would have undoubtedly included a long chapter on power lines as one of the most obvious of all human impacts on the landscape. Today, if we were to look for a simple indicator of the degree of development of modern societies, a good candidate would be the number of kilometres of power lines per inhabitant. The Industrial Revolution, the development of factory-based production systems, the demand for energy in large conurbations and the mechanization and irrigation of agricultural production, along with the growth of the planet’s human population, have all contributed to a previously unparalleled need for an immense grid of energy transmission and distribution. Energy is the origin of life and has fuelled growth in living standards and economic development. The industrial era has multiplied exponentially human demand for energy and the ability to transport energy from its source to the consumer has become one of the clearest indicators of how our societies have progressed. Power lines have become essential features of our modern landscapes and are today vital for transporting energy from producers to consumers. The recent move in many countries towards the use of renewable energy sources as a significant part of their energy production has greatly increased the need for power lines, above all for transmission lines, and in the foreseeable future this situation is unlikely to change.

The network of power lines that transmit energy from production centres to substations and the lines that then distribute energy to customers reach out in vast spider’s-web-like grids across the landscape and, logically, into areas that to some extent or other enjoy a degree of legal protection. This unavoidable state of affairs generates a series of environmental costs and all efforts to minimize their impact bring out into the open the classic conflict between the efficient running of electrical infrastructures (substations and power lines) and the conservation of biodiversity.

Electricity is generally distributed along bare overhead cables known as conductors, which normally transmit voltages – or electric tensions – that range between 1 and 400 kV (kilovolts). Voltages of less than 1 kV are known as low-tension and are, amongst other uses, used in domestic circuits and have no impact on birds. In Spain, the familiar mid-tension conductors carry voltages in the range 14–45 kV. Typically, medium- and high-tension lines can be separated into transmission lines (66–400 kV) and distribution lines (14–45 kV), although this distinction varies from country to country and even between one electric company and another.
Transmission lines transport energy from large production centres (thermal, hydroelectric and nuclear power stations, or from renewable sources) to the main centres of consumption (e.g. cities and heavy industry) and to substations, which feed the energy into the distribution lines and thence onto the smaller centres of demand. Even to the most uninitiated in the subject, the differences in the different types of lines are apparent. Transmission lines loop between large towers or pylons, over 25-m high, that, aside from the conductors, often have another cable on top – known as groundwires – that protect conductors by earthing pylons in the event of being hit by lightning. Pylons on transmission lines in Spain are usually made out of a lattice of metal struts, although concrete is commonly used in other countries. Due to the voltages they carry, these types of lines have long chains of insulators and normally three conductors per circuit, although it is not unusual for lines to carry more than one circuit (double or even triple circuits).

The pylons on distribution lines are much smaller than those used on transmission lines and are normally only 8–12-m high. In Spain, they are also usually made of metal struts that, as conductors, do not require groundwires to prevent overloads on the line from occurring. In other countries such as the United States, Norway and Sweden, these smaller pylons are usually made out of wood, which is cheap and plentiful. Reinforced concrete is frequently used but mainly as the central mast with – at least in Spain – metal crossarms.

The impact of power lines

Power lines have at least four potential impacts on their surroundings: their visual impact on the landscape, acoustic and electromagnetic contamination, alterations of in habitats and their interaction with fauna. Overhead power lines are long lineal structures that are obvious at great distance. In forests, they run through deforested swathes like a scar on the landscape that only serves to emphasize their presence. Unlike naturally occurring lines, power lines break up homogenous textures, which only goes to accentuate their artificiality even further. In agricultural areas and in low Mediterranean woodland, these evident deforested avenues are unnecessary and so the impact is limited to the infrastructure itself. Yet, even without taking into account either their design or the cables they carry, the very presence of a row of pylons has a severe visual impact on the landscape, whose overall structure is determined by the presence of contrasting elements that stand out one from one another and modify our perception of the whole. A symmetrical, geometrically designed pylon provides a great contrast to a landscape characterized by natural, asymmetrical forms and shapes. Pylons and power lines also act as points of visual disturbance, altering the perception of a panoramic view by distracting the observer’s gaze.
Nevertheless, given the cultural dimension of any landscape – at least in my opinion, which may differ from the views of other authors who see the landscape as a biological phenomenon – in the final instance the image an observer derives will depend on the cultural connotations and associations that are present in the objects in the observed landscape. Surprisingly – or perhaps not – power lines and, above all, distribution lines (voltage of less than 45 kV) tend not to be noticed by most people. You can test this assertion by asking any friend (who doesn’t work for an electricity company or live in a city) if they see power lines on their way to work: the majority will be unable to respond because they simply do not see the power lines even though they are there. I believe that, despite everything, distribution lines have positive cultural connotations related with the ideas of both progress and growth, and linked to their association with modern society in which ingenuity and human capacity are able to overcome the unrelenting harshness of the natural world. Power lines represent security and comfort and as necessary ‘evils’ their presence goes without comment. Perhaps it is this kind of reasoning that means that transmission lines (voltages over 220 kV) receive far more criticism from an aesthetic point of view – we do not perceive them as being directly linked to our own personal security or comfort, regardless of the logic that this has in terms of the electricity supply system in general.

Another impact of power lines is the generation of electromagnetic fields, which emanate from the conductors and potentially affect people, animals and objects alike. Currents induced in conducting materials such as cars or wire fences cause unpleasant but harmless electric shocks if we touch them. The possible repercussions on personal health of prolonged exposure to electromagnetic fields have been a subject of public concern. Epidemiological data from the 1970s indicate that the continued exposure to powerful electromagnetic fields had measurably damaged the health of workers in Russian electricity companies (Witwer et al. 1978). On the other hand, in a wide-ranging review of the subject Bridges and Preache (1981) concluded that there is no solid evidence that electromagnetic fields have any indisputable effects on human health. The World Health Organization published a document in 1984 on the effects of low-frequency electromagnetic fields that stated that medical studies conducted on workers exposed to electromagnetic fields had found no evidence of any adverse effect on human health. Thus, they argued, there was no reason to restrict the existence of areas subject to electromagnetic fields under 10 kV/m, although the same document did also emphasize the need to continue with further epidemiological studies. In other animals, though, electromagnetic fields have been shown to disorientate species such as pigeons and bees that navigate using the Earth’s magnetic field (Walcott 1974). Nevertheless, like all such fields the intensity of electromagnetic fields is inversely proportional to the square of the distance: thus, the electromagnetic field we experience when we use an electric razor is much greater than the field generated by 400 kV power lines at the distance at which we normally approach them.

Another effect of power lines is known as the ‘crown effect’, which is caused by the ionization of the air around the conductors, whose magnitude can increase noticeably in the event of rain, fog and snow. Atmospheric pollution is caused by the forma-
Interaction with fauna

Although each and every one of the above-mentioned impacts merits its own detailed study, the focus of this book is centred on how living creatures interact with and are affected by power lines. Animals learn to live with power lines as soon as they appear: cables and their anchorages (pylons or posts) are present in many kinds of landscapes and are used by numerous species of bird as perches (elevated points from which they can watch over a large area of land) and as places to rest and even nest. In some places the gradual transformation of the environment has led to a drop in the number of natural ‘constructions’ – trees, essentially – in which birds can carry out their life cycles, and pylons and other types of supports for power lines represent excellent substitutes. The habitual presence of birds on power lines can cause problems that are not always fully taken into consideration. Other faunal groups also frequent pylons: spiders proliferate in the metal struts and certain species of micro-mammal and reptiles often take refuge in and around pylon bases. Red (Cervus elaphus) and roe (Capreolus capreolus) deer use electrical posts to help cast their horns, while red foxes (Vulpes vulpes) and other carnivores leave their excre-
ments at pylon bases to mark their territories. Many reptiles, insects and even mammals use infrastructures such as substations for shelter and to keep warm, not infrequently interrupting the supply of electricity.

Nonetheless, the human disturbance of the landscape can often have surprising and dramatic consequences for the conservation of wild species and, of all animals, birds probably interact with power lines more often and more intensely than any other group. Countless species of bird use pylons as perches, while species as diverse as crows, kestrels, storks and even imperial eagles use them as nesting sites. Yet, the best-known case of a relationship between animals and electrical infrastructures is probably that of bird mortality resulting from collisions with power lines and electrocution on pylons. Birds are flagships of public awareness of nature conservation, but are also directly affected by the power lines that criss-cross natural areas. The number of incidents between birds and power infrastructures has provoked concern in both the electricity supply industry and in conservation circles, public and private alike, as well as amongst scientists. Over the years, numerous scientific studies have shown that accidents with power lines (collisions and electrocution) in certain sites are one of the most important causes of human-induced mortality in certain bird species and a determinant factor in certain cases of population decline.

The relationship between birds and power lines has been documented since the moment this type of infrastructure came into existence (Hallinan 1922, Michener 1928). The first studies on their interaction were conducted from the angle of how birds might interfere with the delivery of energy supplies (Turcek 1960). In general, any intensive use by birds of electrical infrastructures represents a danger and thus – from the point of view of the electricity companies and their clients – an unwelcome disturbance, which varies in accordance with birds’ behaviour. For example, nesting birds frequently disrupt energy supplies when part of their nest touches and earths one of the conductors. Electrocutions can also generate maintenance problems when overloads cause safety devices to trip and can even provoke forest fires.

As is well known, birds suffer two main types of accident on power infrastructures: electrocution on pylons and collision with cables. Electrocut can occur in two ways: by contact between two conductors or, more frequently, contact between a conductor and an earthed metallic structure, which leaves characteristic burn marks on the bird (Haas 1980, Oledorff et al. 1981, Ferrer et al. 1991). Given the distance between pylons and the size of the gap between conductors and the length of the insulators, electrocutions are only frequent on power lines with voltages below 45 kV. Death is usually caused directly by the electric discharge, although in some cases in which the shock is not mortal, birds die as a result of falling from the top of a pylon (Haas 1980). Electrocut occurs above all in medium-to-large birds that habitually perch on top of pylons. Unfortunately, this description corresponds perfectly with birds of prey, which, moreover, are generally scarce and in many cases at risk of extinction. As a rule, more birds are involved in collisions than in electrocutions (Negro 1987). Birds’ gregarious habits, their dusk flights and flight in flocks when threatened, for example, ensure that
many duck, wader, bustard and crane species are seriously affected by power lines. In the case of high tension lines, most birds collide with the ground-wires; it seems that when visibility is poor birds in flight detect the conductors relatively late and attempt to fly over them, at which point they collide with the ground-wire, noticeably thinner and as such less visible than the conductors. Data from certain studies (Heijnis 1980, Beaulaurier 1981) indicate that up to 80% of collisions occur with the ground-wire.

In many cases birds do not die immediately, but rather fall at varying distances from the power lines. Sometimes birds only suffer a fracture and are able continue flying; wounded birds equipped with radio transmitters have been found at distances of over 2 km from the point of collision (Heijnis 1980). Nevertheless, it is important to note that collisions can occur equally with transmission and distribution lines, and even occasionally with telephone lines (although much less frequently, as they are usually much more visible).

Curiously, most people believe that the only potential problem between birds and power lines is the possibility of collision in flight. I imagine that this belief is due to the everyday occurrence of seeing birds perched on conductors, often in great number and apparently without risk. Nevertheless, people tend to forget that electrocution only occurs when there is a difference in voltage or tension, that is, when a bird perched on one cable comes into contact with another earthed cable or with another conductor at the same time. As we shall see, this occurs much more frequently than many suppose and in fact electrocution is a much greater threat to bird conservation than collision.

This book has been written for those who wish to understand not only the specific problem of power lines and possible solutions, but also the more general question of whether or not it would be possible to modify our infrastructures – which are regularly regarded as having a negative impact on our biodiversity – to make them more compatible with a healthy, diverse and rich environment. And if indeed this is possible, how might we go about it in the real world? In summer 1996, when I had just been appointed its Director, the equally recently appointed Minister of the Environment, Isabel Tocino, came to the Doñana Biological Station on a visit. Whilst we watched a spectacular sunset overlooking the reserve’s wonderful heronries, she took me to task for comments I had made to the press a few days earlier. I had stated that I was opposed to the construction of the Melonares reservoir if the problems that were bound to arise with the Spanish imperial eagles that frequented the area to be flooded were not resolved beforehand. ‘Miguel’, she asked, ‘if we have to choose between water and eagles, what should we do?’ ‘Well’, I replied, ‘if I had to choose one or the other I too would pick water. But, I believe that what people want from you and me is both water and eagles. It’s our job to find a way to make that possible’. I feel the same way about overhead power lines.

For years, I have had to face up to extreme positions such as ‘we don’t want the eagles to die, but we need more energy’. Or, ‘we’ve got to take down all the power lines crossing areas with birds; we’ve got to save the eagles even if we have to make do
without cheap energy supplies’. I, nevertheless, see no reason why this conundrum, in theory, shouldn’t be solvable. What’s wrong with thinking that we can have power lines and eagles? This is the position that I have tried to follow throughout my professional life, in part because I don’t believe in an apartheid-like ‘one-or-the-other’ approach to the politics of biodiversity. Using the example of power lines, this book attempts to show that there are solutions to these kinds of problems.

In the following chapters we examine how this conflict led to collaboration and then, finally, to success both at world level and in Spain. Given our tendency in Spain to regard ourselves as less capable than the world’s other developed countries, some may find it hard to believe that in this particular field Spain has become a world leader; indeed, Spanish research, scientific advances and legislation in this field have been followed by all the countries in our European sphere of influence and by electricity companies and researchers throughout the world.
2. The United States, Germany, the Netherlands and other countries in the period 1950-1980

The American story

The unexpected effects on birdlife of the development of power lines – both transmission and distribution lines – was probably first noticed in the United States of America. A number of publications in the period 1950–1970 began to warn of what was to become one of the most serious conservation problems resulting from human activity for many threatened species of birds.

The origins of this awareness date back to publications from before the 1970s (Hallinan 1922, Marshall 1940), in which for the first time the electrocution of birds of prey on power lines was reported. A. H. Benton published an article in 1954 in the journal Kingbird entitled Relationship of birds to power and communication lines, which highlighted the finding of dead birds under power lines. This initial report was subsequently developed by the same author and others (Benton and Dickinson 1966, Edwards 1969, Coon et al. 1970) in what were possibly the first data on bird electrocution on electric infrastructures ever published in the USA.

In 1972, Richard R. Olendorff published a study entitled Eagles, sheep and power lines that was one of the first descriptions of how distribution lines were threatening the survival of large raptors, in this case, golden eagles (Aquila chrysaetos) in Colorado (USA). This study describes the finding of 17 electrocuted golden eagles under just 5.6 km of power line in north-east Colorado. A few years later, these first findings were authenticated by P. C. Benson (1977, 1980, 1981, 1982) who further drew attention to the great impact of electrocution on golden eagle survival in light of finding 37 electrocuted adult eagles during a study in Utah. Along a total of 192 km of power line running through six different states, Benson recovered 416 electrocuted raptors. In Utah, members of the U.S. Fish and Wildlife Service found 495 dead raptors beneath 402 km of power lines. Similar discoveries were beginning to be made throughout the whole country.

In 1975 the publication of the first edition of Suggested Practices for Raptor Protection on Power Lines (Miller et al. 1975) made one of the first notable contributions to the question by suggesting new designs for pylons that were safer for birds. Unfortunately, many of the recommendations made in this first edition were found to be inadequate and
so a second edition was published with more up-to-date information and a revision of the suggestions made in the first edition.

Nevertheless, without any doubt it was the publication by Olendorff, Miller and Lehman (1981) that marked a before and after in the identification of the problem and a search for solutions. Their book, *Suggested Practices for Raptor Protection on Power Lines — The State of the Art in 1981*, soon became the most referenced work on the subject of the interaction between birds and power lines in the USA and probably also in the whole world. This magnificent summary of the situation in North America in 1981 was accompanied by a series of proposals for correcting pylons that were hazardous for birds and, above all, large raptors. This work not only provided a large amount of reliable information, but also indicated how this problem should be tackled in the rest of the world. This first phase, consisting of public pronouncements by biologists, naturalists and conservation managers, soon led to work – whose seriousness can be gauged by the funding it received from the Edison Electric Institute and by the participation of engineers from 10 electrical companies – aimed at finding technically viable solutions to the problem.

After the publication of this review, further studies and reports of new findings of dead raptors continued to appear in the USA, along with a number of criticisms of some of the proposals published in the original work. Thus, in 1996 a new version of *Suggested Practices for Raptor Protection on Power Lines — The State of the Art in 1996* appeared, funded on this occasion by the Edison Electric Institute and the Raptor Research Foundation. This most recent version collates all existing information on the subject from both the USA and other countries and updates possible ways of resolving the problem of dangerous pylons.

This most recent edition was as influential as its predecessors and has helped increase awareness of the problem and its possible solutions throughout the world. Nonetheless, its very success has unwittingly generated a number of additional problems wherever its recommendations have been applied in environments and infrastructures that are completely different from those studied by the original work. This was the case when measures designed to avoid contact between two phases on wooden posts were applied to metal-strut pylons that are excellent conductors and on which electrocution occurred largely through contact between a single phase and an earthed cable (Negro and Ferrer 1995). As has been reported in a number of publications and as we discuss at greater length below, the widespread use of wooden posts in the USA, as well as in European countries such as Norway and Finland, ensures that it is much less likely that birds can earth themselves. The accidents on this type of pylon occur most commonly when birds touch two phases at the same time, which means that only the largest birds are at risk. Essentially, the majority of birds that die on metal-strut pylons are medium-sized raptors, whilst on wooden posts most deaths are of large birds such as some of the larger eagle species. Thus, care must be taken when the solutions proposed for specific types of pylon and bird species are applied directly to other types of support and for other bird species; such practices may in the end turn out to be no kind of solution at all (Ferrer et al. 1991).

Despite the publication of the successive editions of *Suggested Practices for Raptor Protection on Power Lines* and the efforts by sectors of the electricity supply industry to
correct many of their power lines, reports of bird deaths by electrocution continued to appear in North American journals. The National Board of Animal Health in the USA (1985) reported that 130 (9.1%) of the 1429 dead bald eagles (*Haliaeetus leucocephalus*) examined between 1963 and 1984 had died through electrocution. In all, 50% of these eagles had died in the final six years of the sampling period (1978–1984), the majority in the eastern United States. A more recent review revealed that 12% of bald eagle deaths whose causes were known were due to electrocution (Franson et al. 1995).

Since 1981 deaths through electrocution in other threatened and endangered species such as the peregrine falcon (*Falco peregrinus*) and the Californian condor (*Gymnogyps californianus*) have also been documented. Moreover, in this period at least 11 other species of North American raptor that had previously never been recorded as victims of electrocution were added to the list of species known to be vulnerable. Likewise, the number of owl species known to be at risk to electrocution has increased threefold since 1981. During the 1980s and 1990s the electrocution of species known to be vulnerable continued at an often alarming rate. A seemingly surprising number of Harris Hawks (*Parabuteo unicinctus*) were being electrocuted in some areas of the south-west USA and in a study of an urban population of this hawk around Tucson (Arizona), Dawson and Mannan (1994) found that 112 (63%) of the 177 deaths with known causes in the period 1990–1993 were due to electrocution. Deaths occurred typically on pylons and transformers near houses. In the basin of the Klamath river between Oregon and California, 66 golden eagles were found to have been electrocuted in the period 1986–1992, while in Montana 32 dead golden eagles were found in 1980–1985 (O’Neil 1988). In Nebraska around 500 raptors, the majority eagles, were estimated to have died through electrocution every year during a six-year survey (U.S. Fish and Wildlife Service 1988).

Although the electrocution of raptors continues to be a problem, it is important to recognize the efforts that have been made in the USA to reduce the number of birds that die in this way. For example, many electricity companies now participate in raptor conservation programmes (Blue 1996) and today measures for protecting birds of prey are a mandatory part of the requirements demanded by the majority of federal agencies in the USA when authorizing and licensing new power lines. For example, the Federal Energy Regulatory Commission (FERC) includes in all its projects for tender specific obligations that all electrical infrastructures be equipped with systems that will protect birds of prey from electrocution.

The story of the problem of bird collisions with power lines in the USA has followed a similar road to that of electrocutions. In 1904, Emerson reported that numerous waders (small birds that frequent mudbanks and shorelines) were colliding with a power line crossing a salt-marsh in San Francisco Bay. Despite this and other references to the problem of collisions from before the first published data on electrocutions, it was not until 1977 with the publication of a study by Lee and Meyer, funded by Bonneville Power Administration, that the first rigorous description of this problem saw the light of day in the USA. This and other studies not only quantified the deaths of birds by collision, but also proposed for the first time that power lines should be signalled to decrease the number of accidents; in addition, cutting-edge technology such as the use of thermal-imaging cameras to study the nocturnal movements of birds around the power line was proposed.
In 1978 a national congress on the problem was organized (Avery 1978) in which subjects such as how collisions with power lines affect bird populations, how transmission networks affect flight patterns and migratory behaviour, how to lessen the impact of power lines through improved design and how to tackle habitat management were discussed. A few years later one of the essential works of reference on the problem of bird collisions was published (Beaulaurier 1981).

After a series of national meetings, in 1989 the Avian Power Line Interaction Committee (APLIC) with participants including companies from the energy sector and entities such as the National Audubon Society was created with the express aim of coordinating and financing the necessary studies for solving the problem of avian collisions (Brown and Drewien 1995). In 1992, in collaboration with EPRI (Electric Power Research Institute), APLIC held a further congress in Miami (APLIC and EPRI 1993).

In 1994, a revision of current knowledge of the subject, *Mitigating Bird Collisions with Power Lines: The State of the Art in 1994*, was published by Brown, Gauthreaux and Miller for APLIC and remains today the most-used reference on the subject of bird collisions in the USA.

### The African story

The only detailed study of bird collisions with power lines in Africa from before the 1990s (Longridge 1986) reported high mortality rates in two species of flamingo (13% of all birds found dead), geese and ducks in a wetland known as Blesbokspruit. Collisions with power lines were identified as the most important non-natural cause of death in the wattled crane (*Bugeranus carunculatus*) in South Africa (McCann and Wilkins 1995). Even the South African national bird, the blue crane (*Grus paradiseus*), was badly affected by this new hazard (Allan 1997), and 31 of these cranes were found dead along a 10-km stretch of power line in just five months. Significant percentages of birds such as the grey crowned-crane (*Balearica regulorum*) (5%) and Ludwig’s (*Neotis ludwigii*) and kori (*Ardeotis kori*) bustards (21%) were also found amongst birds killed through collisions with power lines (Allan 1997).

In South Africa the first data on bird electrocutions date back to around 1970. Markus (1972) recovered 148 electrocuted Cape vultures (*Gyps coprotheres*) from under a single-circuit 88-kV line in eastern Cape Province over a period of two years. Five years later, a further 300 vultures had been killed on the same power line (Ledger and Annegarn 1981). More Cape vultures have probably been killed through electrocution in South
Africa than any other raptor. Today this species is classified as threatened in South Africa and electrocution is regarded as the principal – although not only – cause of its decline (Ledger 1980). Besides this vulture, other large raptors such as the magnificent martial eagle (*Polemaetus bellicosus*) and the no less spectacular Verreaux’s Eagle (*Aquila verreauxii*) also suffered important numbers of casualties on power lines in the 1980s. These two species are particularly susceptible to electrocution in rural areas where distribution lines carry current to small irrigation pumps and other farm infrastructures. Such distribution lines were also suggested as being the main cause of the decline in populations of Egyptian vulture (*Neophron percnopterus*) in this area (Nikolaus 1984). Unfortunately, given the deep-rooted economic, political and social crises experienced by the African continent, little progress has been made in solving these problems and it seems that the conservation of the local avian fauna is not going to be very high on the agenda of those in charge of African power lines in – at least – the near future (Ledger et al. 1993).

The European story

The relevance to bird conservation of bird deaths on power lines began to be studied in various European countries at the end of the 1970s. Scott et al. (1972) in Great Britain, Renssen (1975) in the Netherlands, Haas (1970) in Germany and Bijjleveld and Goeldin (1976) in France were the first authors to document the death of birds through electrocution or collision.

Subsequently, numerous studies were to leave no doubt as to the alarming scale under certain circumstances of the problem of bird deaths on power lines. The numbers speak for themselves: 700 dead birds per kilometre per year found in a wetland in the Netherlands (Heijnis 1980), over one million birds killed per year in France (Faure 1988), a further million birds per year colliding with power lines in the Netherlands (Renssen 1975), and 586 white storks (*Ciconia ciconia*) killed in West Germany over a period of 40 years (Fiedler and Wissner 1980), the most important cause of death in this species during this period. During this same time, Haas reported the existence of the problem in Germany, Switzerland and Spain (Haas 1980), while Bevanger warned of the danger of western capercaillies (*Tetrao urogallus*) colliding with power lines in Norway (1988).

Since then, the number of publications on the interaction between birds and power lines has increased rapidly (Ferrer and Janss 1999). Haas’ work has continued, culminating for the time being with the publication in 2005 of the manual *Protecting Birds from powerlines* by the Council of Europe, which represents a quick guide to solutions for hazardous pylons. In Italy, Penteriani (1998) with support from the WWF
published a review of the problem of collisions and electrocution and provided suggestions for correcting pylons and lines, as far as we know the first such attempt to find a solution for this problem in Italy. Bevanger continued to publish studies from Norway, Finland and Denmark with important insights into the problem and was one of the few researchers in Europe who regularly published findings in internationally recognized scientific journals, thereby ensuring widespread diffusion of up-to-date knowledge on the subject (Bevanger 1994, 1995).

Despite the existence of a few basic recommendations from the Council of Europe, today in Europe regulations differ enormously from one country to another, being highly advanced in countries such as Spain but almost inexistent in others, typically in Eastern Europe. As we shall see below, one of the most pressing challenges we have is to attempt to unify basic legislation on this question.
3. The Spanish story

Doñana and the Spanish imperial eagle

Up to 1977, only a few isolated records of cinereous vultures (*Aegypius monachus*) dying on power lines in Extremadura and of great bustards (*Otis tarda*) colliding with lines in Castille had been published in general works on these species. Nevertheless, the first true review from Spain of birds dying on power infrastructures was without any doubt carried out by Jesús Garzón in his paper to the 1977 International Council for Bird Protection (ICBP) Congress in Vienna on raptor conservation. Garzón reported that electrocution could be a very important factor in the mortality rates of large birds such as the black vulture, Eurasian eagle-owl (*Bubo bubo*) and even the Spanish imperial eagle (*Aquila adalberti*), and as such, represented a serious conservation problem.

Even so, the true history of the question in Spain did not begin until summer 1982 in Doñana, when the author of these lines had just turned 20. At this age, my lifelong passion for birds had already led me to study biology at the University of Seville and to confront life head-on full of energy and determination. By then, my friend Manuel de la Riva and I had already been working for two years as volunteers with the Doñana Biological Station and in our spare time from school had begun to hunt down raptors that – for whatever reason (nest robbery, chance encounter, purchase and so on) – had fallen into private hands. We would try to convince people that the illegal possession of protected species was a practice that should be eradicated and would offer bird owners the opportunity and privilege of having ‘their raptor’ taken to a rehabilitation centre in Doñana, where they would be liberated in due course. We must have been very convincing in our arguments – or perhaps just very annoying – as we managed to rescue a notable number of birds, which were taken to the Doñana Biological Station and then, once restored to full health, liberated in the National Park.

In those days, the Biological Station was housed in a detached house in the Heliópolis quarter of the city of Seville. This area of the city was built for the Ibero-American Exhibition in 1929 and lies on the road out of Seville towards Cadiz, near the stadium of Betis football club. Yet, despite being so near this symbol of the city, this area seemed not to be part of the city at all. The small and chaotic research centre, filled with frenetic activity, was dominated by Dr. Javier Castroviejo, an intense and disconcerting person if ever there was one, but one with an undoubted ability to transmit the enthusiasm for wildlife that coursed through his veins to all those he came in contact with. Our dedication to rescuing birds of prey came to the attention of the Station’s
Director, Dr. Castroviejo, who we pestered at every opportunity with new doubts and proposals, as well as with, naturally, more raptors to be liberated.

Two years previously in 1980 (although we had no idea of this), Javier Castroviejo had been visited by two German researchers, Essrich and Huttenlauch, who had worked with Haas in his efforts to document the problem of birds and power lines at a European scale. They had asked the Director for permission to investigate a number of areas of the National Park chosen at random. Dr. Castroviejo gave his consent and these two scientists provided the Biological Station with a large amount of documentation regarding the electrocution of birds that they had been gathering during their visits to various other European countries. Naturally, the information was in German, a language in which Dr. Castroviejo was fluent, and what he read came as a shock. The alarming data in these documents represented the first data from Europe – some of which was from Spain – of what was undoubtedly one of the most serious conservation problems for certain species of birds. In a partial survey in the area around the Doñana National Park, these scientists had found 87 dead birds underneath 342 pylons.

In spring 1982, my life took on a new and fundamental direction: my family agreed to buy me a motor scooter and in doing so afforded me the priceless ability – not without a certain degree of danger – to go anywhere, anytime it was necessary. With this newfound means at my disposal, I plucked up courage to ask for a meeting with the Director of the Biological Station. My intention was to tell him that I wanted to do more than just bring caged birds into the Biological Station. I wanted to help with one of the Spanish National Research Council’s (CSIC) projects because my dream was to become a scientist some day; and now my scooter would enable me to get wherever I wanted to go. Dr. Castroviejo didn’t think twice and suggested that Manuel and I should begin to study the mortality of birds on the power lines in Doñana. He wouldn’t pay us anything – not even petrol or any other expenses such as the plastic bags that we would eventually need by the thousand – but he would provide us with the necessary permits and we would be working for the Biological Station. It seemed that our dream might be beginning to come true.

In those days, there was no Google Earth, digitals maps or GPS and so we began by drawing by hand on the Spanish military maps of the area all the power lines around and inside Doñana in order to best decide which stretches and spans we were going to study. Up until then, as I suppose is the case with the majority of people, I had never noticed quite how dense the spider’s-web of power lines in the area was. In developed countries such as Spain it is practically impossible to enjoy the landscape without seeing pylons, posts and cables. Curiously, like in some of those well-known optical illusions in which a single drawing hides two hidden silhouettes, of which you only see one or the other, we don’t notice pylons and lines until for one reason or another we stop to look at them. And then, from that moment on, like a curse, you can never not notice their presence again! This was thus the new vision of Doñana that appeared before our eyes when the two of us, maps in rucksacks, entered the National Park on my scooter. The inconceivable fact that Doñana was plagued by power lines hurt like an open wound: the natural area in Europe par excellence, a magical place full of life and inhabited by a series of wonderful creatures such as
the Iberian lynx (*Lynx pardinus*) and the Spanish imperial eagle, the latter by definition the flagship of nature conservation in Spain, was in fact criss-crossed by cables and full of pylons and posts – and nobody seemed to particularly care!

We walked over 130 km in a week as we mapped the power lines and plotted the number of pylons and their type. As chance would have it, when we began walking from pylon to pylon we started with a line in the fields near Isla Mayor, around 10 km outside the Park’s boundaries, whose design was of no danger to birds. After a couple days, I had begun to think that our investigation had little future given the fortuitous lack of victims at the foot of the pylons. On day three, however, after spending a night sleeping under an enormous mastic tree, we entered into an area known as Matasgordas inside the National Park. This estate lies in the contact zone between the dunes and the salt-marshes – what we ecologists refer to as an ‘ecotone’ – in an area with exceedingly high levels of biological productivity and as such great densities of everything, including raptors. I remember at dawn how the very ground seem to move as unbelievable torrents of rabbits cascaded back to their warrens to take cover before the eagles woke up. The seven kilometres of power line that ran through this ecotone were suspended on pylons with rigid, pin-type insulators. We began to walk under the line but soon had to stop to take in the terrible spectacle that was unfolding before us: at the base of every pylon lay grotesque piles of bones and feathers, gently caressed by the wind, of what had once been magnificent, majestic flying birds of prey. The heaps of corpses resembled the trophies lying at the feet of some cruel but dumb hunter. Under some pylons we found only a couple of dead birds, whilst under others ten or more were piled up: there were corpses of common buzzards (*Buteo buteo*), black kites (*Milvus migrans*), Eurasian griffon vultures (*Gyps fulvus*) and short-toed (*Circaetus gallicus*), booted (*Hieraaetus pennatus*), Bonelli’s (*Hieraaetus fasciatus*) and, most dramatically of all, Spanish imperial eagles, all scattered obscenely over Doñana’s surface. It was at that precise moment that we began to realize the sheer enormity of the task that we had just undertaken.

Completely determined to do whatever we could to put an end to this unacceptable state of affairs, in the following weeks we selected the power lines for which we were to monitor mortality rates for a full year. With care, we chose power lines that represented five of the most typical of Doñana’s landscapes (roads/tracks, rice-fields, salt-marshes, non-irrigated farmland and oak/pine wood pasture) and the greatest possible variety in pylon and insulator designs. We classified each pylon as one of six types – three with staggered crossarms and suspended, strain or pin-type insulators, two with triangular configurations and pin-type or strain insulators and transformer pylons with circuit-breakers (see Fig. 1) – in an attempt to cover all types of pylons in all types of habitat. In the end, we selected 1127 pylons and posts distributed along 100 km of 16–22 kV power line in the area around and inside the National Park. Our area of study was to the north of the main Guadalquivir salt-marshes, between Isla Mayor and the village of El Rocio. The lines had a single circuit and were suspended from 8–12-m high metal-strut pylons. Only 41% of the pylons were actually within the National Park, in the areas known as Coto del Rey, Lucio de Mari Lope and the FAO dike, the rest being located to the north of this dike (Fig. 2).
Figure 1. The commonest types of pylons used on distribution lines (13–25 kV) in Spain.

**Pylons with aligned (pin-type or suspended) insulators**

- Staggered crossarms with suspended insulator
- Staggered crossarms with pin-type insulators
- Vaulted configuration with suspended insulators
- Triangular configuration with pin-type insulators on two crossarms and a projecting central mast
- Horizontal configuration with pin-type insulators

**Pylons with strain insulators**

- Staggered configuration with jumpers below crossarm
- Triangular configuration with two crossarms and jumper wire above projecting central mast

**Transformer**

- Circuit-breaker on pylon mast
Our work had only just begun. For a whole year we visited our study area once a month in an attempt to detect inter-seasonal differences in bird mortality and to obtain a large bank of data that would enable us to identify the most dangerous power lines and thus be able to propose possible modifications. Our first task was to clear away the old remains of birds from under the pylons. We carried out our study on foot, walking each stretch either once a month or once every two months, and always noted the smallest possible number of birds given the remains we found under each pylon. Initially, we removed all the corpses and remains we found to avoid duplicating counts and to be able to compare as accurately as possible the species, as well as the age and sex, of the birds we came across. All the birds we found with burns on wings and legs were classified as having been electrocuted, whilst those found under the lines themselves were noted down as collisions.
Each weekend the two of us walked 10–20 km under the power lines and returned home with enormous bags full of corpses strapped to the scooter’s luggage rack. We soon realized that many of the electrocuted corpses were quickly removed by scavengers since it was commonplace to find just a few of the bird’s back feathers stuck to the ground and very little else. We even often chanced upon early-rising foxes that would trot along the same route as us with the same intention of finding corpses (the difference being that the foxes would then eat them!). We thus decided that if we were to have any idea of the real mortality rates we would somehow have to estimate at what rate the corpses disappeared. So, we set up an experiment using 25 farm rabbits and 40 of the dead birds we had found to estimate the speed at which we were ‘losing’ the dead birds; in this way we would be able to estimate what proportion of dead birds we were finding on the basis of the time elapsing between each visit.

In October 1983, once our fieldwork was finished, it was time to sit down and analyze our findings in as much detail as possible. We asked Dr. Castroviejo if there was anywhere in the Biological Station where we could work. He let us use one of the cages behind the main building of the Biological Station that was normally used for housing griffon vultures temporarily before they were taken to be released in Doñana. We installed a light bulb so as to be able to work by night as well and together made a tour of the local rubbish tips until we found a couple of boxes and a wooden door that we set up in the middle of the cage as a work bench. For a period of four-to-five months, we proceeded to open one-by-one all the bags of birds we had collected and identified as best we could the species, age and sex of all the corpses. We established our own reference collection by cleaning the corpses of the 50 easiest-to-recognize species and stored the bones of the birds that were harder to identify.

The results of a year’s monitoring of 100 km of power line are given in table 1. In all, we collected 930 corpses, of which 778 were found during the study period and the rest during the initial cleaning tasks. We identified 55 species, 54 birds and a mammal (a genet *Genetta genetta*). Of the victims collected during the monitoring, 142 (20.6% of the total) were birds of prey belonging to 10 species, including five griffon vultures, one Spanish imperial eagle, one short-toed eagle, 66 black kites and 30 common buzzards, as well as the first ever record of a northern goshawk (*Accipiter gentilis*) for the National Park. In addition, three species of owl contributed 1.16% of victims, the commonest being the barn owl (*Tyto alba*) (five corpses). Other species of note were 52 common ravens (*Corvus corax*), six white storks, 79 cattle egrets (*Bubulcus ibis*), 84 geese and 163 ducks. Amongst the diurnal raptors, the commonest cause of death was electrocution by earthing, and only four raptors were found to have died from collisions (2.8% of all raptors). It seemed that collision with power lines was not a very important factor in the mortality of this group of birds, although this may have been somewhat of an underestimation since our methodology only enabled us to cover a 12-m-wide strip on either side of the power lines, and some victims may have died further away. Whatever the truth of the matter, death by collision in raptors was far less relevant than death by electrocution, as was also the case in ravens, storks, egrets and many other species. On the other hand, almost all waders and, in particular, geese, ducks and small passerines died having collided with the power lines.
Table 1. Dead birds recovered under the 1,127 electric pylons studied in Doñana in the period 1982–1983.

<table>
<thead>
<tr>
<th>Species</th>
<th>Total</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Griffon vulture</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>Spanish imperial eagle</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Short-toed eagle</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Booted eagle</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Black kite</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Red kite</td>
<td>82</td>
<td>66</td>
</tr>
<tr>
<td>Common buzzard</td>
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<td>30</td>
</tr>
<tr>
<td>Northern goshawk</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Common kestrel</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Peregrine falcon</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Kite sp.</td>
<td>36</td>
<td>3</td>
</tr>
<tr>
<td>Falcon sp.</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Tawny owl</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Barn owl</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Little owl</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Raven</td>
<td>70</td>
<td>52</td>
</tr>
<tr>
<td>Crow sp.</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>White stork</td>
<td>34</td>
<td>6</td>
</tr>
<tr>
<td>Eurasian spoonbill</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Greater flamingo</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Cattle egret</td>
<td>82</td>
<td>79</td>
</tr>
<tr>
<td>Heron sp.</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Goose sp.</td>
<td>88</td>
<td>84</td>
</tr>
<tr>
<td>Duck sp.</td>
<td>168</td>
<td>163</td>
</tr>
<tr>
<td>Gull sp.</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Wader sp.</td>
<td>77</td>
<td>77</td>
</tr>
<tr>
<td>Rail sp.</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Storm-petrel sp.</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Pin-tailed sandgrouse</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Common pheasant</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Coraciiformes</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Passerines</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>Genet</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>930</strong></td>
<td><strong>778</strong></td>
</tr>
</tbody>
</table>

Our loss-of-corpse experiments showed that dead birds disappeared as a function of the logarithm of elapsed time. Thus, if we walked the power line every 30 days, we would find only a very small proportion of the victims from day 1, a
slightly larger proportion of those from day 2 and so on – but we would find all the casualties from day 30. By taking into account which lines we had walked every 30 days and which every 60 days, we calculated that we had ‘lost’ around 70% of all corpses. Naturally, the rhythm of losses would depend on a number of factors such as the weight and size of the dead bird. In fact, by comparing the corpses found during the initial cleaning tasks with those of the same species found during the annual monitoring, we came to the conclusion that there was an inverse correlation between the rate of loss and the size of the bird. Thus, during the initial cleaning 28.5% of the birds we found were large raptors, but during the annual study they only represented 5.6% of the total.

We discovered that the scavenger species that removed the corpses included red fox, Spanish imperial eagle, griffon vulture, raven and kites. Some worked extremely rapidly as, for example, we found out one day when, in the minutes it took us to reach a pylon to collect a raven we had seen being electrocuted, another raven had time to devour half of the dead raven’s thorax. Interestingly, we found the dead genet underneath a pylon, on top of which there was a dead and seemingly electrocuted black kite.

Taking into account these estimated losses, we concluded that the true number of victims on the 100 km of power line we had studied ascended to 2,000 birds per year, of which almost 400 were raptors and, of those, 200 were kites. Furthermore, bearing in mind that in those days there were 300 km of similar power lines in Doñana and the surrounding area, we estimated that in all somewhere in the region of 6,000 birds annually were dying on the pylons and power lines in the area.

Of the five types of pylon studied – three with aligned (suspended or pin-type) insulators, two with strain insulators and the transformer pylon with circuit-breaker – the most dangerous was the triangular configuration consisting of two lateral crossarms and central projecting mast, with strain insulators and a jumper wire above the mast. On this latter type of structure, which represented 6% of all pylons, we estimated that 0.65 raptors were dying annually per pylon. The transformer pylon with circuit-breaker was the second most deadly type, with an annual death rate of 0.246 raptors. The greatest diversity in the size of casualty was found on this latter type of pylon, with victims ranging from starlings (Sturnus sps.) (21.5 cm) to storks (101 cm); fortunately, only five of the pylons studied were of this design.

The next most dangerous designs were the pylon with staggered crossarms and pin-type insulators, on which an average of 0.202 raptors were killed annually, followed by the pylon with a triangular configuration and pin-type insulators (0.168 raptors per post per year). The pylons with staggered crossarms and suspended insulators turned out to be the least dangerous, regardless of whether they had strain insulators (with jumper wires below the crossarm; 0.049 raptors killed per pylon per year) or aligned insulators (mortality of 0.027 raptors per pylon per year, that is, 24 times lower than the most dangerous design.
3 a. End-of-line pylon with exposed circuit-breaker on the mast. The jumpers have to be located above the central crossbeam because the circuit-breaker and transformer are on the side of the mast where there is no overhead cabling. The mortality rates on this type of pylon ascended to 0.246 raptors per year.

3 b. Pylon with three staggered crossarms and aligned pin-type insulators. This was the type of pylon used on the Matasgordas power line that accounted for 45% of all the electrocutions we recorded during our study (0.202 raptors killed per pylon annually).

3 c. Pylon with triangular configuration (two crossarms and central projecting mast) and aligned pin-type insulators. In this design, the central phase is located in the centre on a pin-type insulator on top of the mast. This is one of the most dangerous pylon designs for birds, with a mortality of 0.168 raptors per pylon per year in our study.

3 d. Pylon with three staggered crossarms and aligned suspended insulators. This configuration was the safest of all designs in Doñana, having an annual mortality rate of 0.027 raptors per pylon, 24 times less than the most dangerous pylon. This was the design that would eventually be recommended in bird protection legislation.
Our results clearly showed that landscape also has an important influence on mortality rates, with the lines located next to roads or tracks being 10-times safer than those in wood pastures (for the same type of pylon). In general, pylons in transformed landscapes were less dangerous than those in more natural unaltered landscapes such as salt-marshes and wood pastures.

Although our study centred on death by electrocution, we also found 315 waterbirds that had been killed by collisions, the majority of which were geese or ducks. These deaths occurred above all on one power line, barely 9-km long, crossing an area known as Lucio de Mari Lope, a site of exceptional concentrations of waterfowl, above all during winter. Death by collision was closely linked to water levels in the immediate area and rainfall.

Aside from pylon design and landscape, other factors such as climate, bird behaviour and the direction of the line also played a part in determining mortality rates on power lines. Of the climatic factors, rainfall has an important influence on collisions, although to have a more precise idea of its role we would have needed a specifically designed methodology. Even so, a number of broad considerations can be made. Feathers are generally good insulators when dry. Nevertheless, their conductivity increases as the relative humidity increases (although this will also depend on factors such as salt concentrations) and, naturally, when it is raining. In addition, on rainy days visibility falls and increases the chance of collision with a conductor. Wind can also play a part as it hampers flight control and makes perching more difficult. Thus, a bird perched on an electric pylon that is being forced by the wind to open and close its wings to maintain its balance has a greater likelihood of touching a live cable.

As well, certain types of behaviour may increase the chance of electrocution or collision. For example, during the mating season the fights that often take place on perches as one bird attempts to see off another force birds to indulge in manoeuvres that increase the possibility of touching an exposed cable. We even found on occasions, for example, electrocuted black kites with their talons still locked together that had died in mortal combat. Likewise, pairs of birds are often prone to accidents given that they tend to use repeatedly the same perches and beat their wings when mating. A further risk is suffered by gregarious species of bird such as the cattle egret that regularly perch together on pylons and are often electrocuted in groups of 4–7 birds. Birds such as kites and vultures also frequently use pylons to oil themselves or sunbathe with their wings widespread, a habit that increases the risk of touching a live cable. The use of pylons as places to tear up and eat prey also puts raptors at risk, as in the case of a black kite that was electrocuted when the leg of the black-winged stilt (Himantopus himantopus) it was devouring touched a conducting wire. Nesting on pylons is also very risky, although in our study we only found two raven’s nests on pylons – but in both cases at least one bird per nest had paid dearly for its choice of nesting site.
Flights in dense flocks and escape flights increase the chance of colliding with power lines. As well, the direction of the line can also increase the degree of risk: in the case of the Mari Lope salt-marshes, the power line that crossed the line of flight between the two lagoons took a much greater toll on birds than the line that ran parallel to the most commonly used flyway.

Another factor of considerable importance is the existence of pylons that are especially attractive to raptors and are therefore more frequently occupied. These pylons can become blackspots where many birds die if their design is of the most dangerous type. This is the case, for example, of the power lines that cross a contact zone between different habitats where the diversity and density of prey is very high. Posts and pylons are excellent vantage points and the mortality at the best such spots can reach spectacular levels. Under one such post we found 16 corpses, 15 raptors and a genet. On another similar pylon, we found in just one year five black kites, one common buzzard, two booted eagles, two griffon vultures and one Spanish imperial eagle.

In the case of birds of prey, we were able to determine the ages of 115 out of 142 dead birds during the year the study lasted. Two patterns appeared: in migratory birds, the majority of victims were adult birds, while amongst the sedentary species most dead birds were juveniles. This difference can be explained by the fact that in most migratory birds immature individuals do not return to breeding sites until they are sexually mature.

We estimated that in the case of the black kite, mortality on electric pylons and lines caused a loss of 12.5% in the adult breeding population. Depending on the size of the breeding population, losses of such magnitude are without any doubt unsustainable and alone could provoke a decline in breeding numbers in Doñana. Likewise, we estimated a mortality of 10% for booted eagles, 18% for common buzzards and 6.5% for short-toed eagles. These figures are stark reminders of the sheer scale of the impact of power lines and pylons on these protected species during the breeding season.

Another way of approaching the true effects of the mortality caused by power lines and pylons on raptor survival in Doñana was to analyze ringing recoveries (Table 2). We studied recoveries of ringed raptors in Doñana for the period 1974–1985 (excluding the ringed birds we had found during our monitoring walks). In all, 53 ringed birds were found dead during this period, of which almost half (45.3%) had been electrocuted on power infrastructures. These results were further evidence that pylons and power lines were a serious threat to Doñana’s raptor populations.
Table 2. Recoveries of ringed raptors in Doñana and surrounding areas in the period 1974–1985 (excluding birds that we found under power lines). Almost half of the deaths were through electrocution.

<table>
<thead>
<tr>
<th>Species</th>
<th>Electrocution</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spanish imperial eagle</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Black kite</td>
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<td>Common buzzard</td>
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<td>2</td>
</tr>
<tr>
<td>Booted eagle</td>
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<td>1</td>
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<tr>
<td>Common kestrel</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Peregrine falcon</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Short-toed eagle</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Barn owl</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Little owl</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Tawny owl</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>24</strong></td>
<td><strong>29</strong></td>
</tr>
</tbody>
</table>

The Spanish imperial eagle was in those days – and still is – a highly threatened species. In 1981, its world’s population – all in Spain – stood at an estimated 100 pairs. Of these, 15–16 lived in and around the salt-marshes and private estates of the Doñana National Park in what was the densest population of the species anywhere. It goes without saying that for us it was vital to study the impact that deaths on power infrastructures was having on this species. The corpses we had recovered and annual mortality rates indicated that this was one of the species most affected by power lines, but we still needed to know by how much and in what way this factor was increasing this eagle’s risk of extinction.

Using the daily information provided by the National Park’s rangers and the naturalists working in the Doñana Biological Station, we collated all the known deaths of this species since 1974. Out of a total of 25 deaths whose cause was known, 13 had died of electrocution on distribution lines, which turned out to be the commonest cause of death of this species in Doñana (52%). The age of the dead eagles was what was to be expected in a sedentary species: 27.3% of the electrocuted eagles were adults, and the remaining 72.7% juveniles or immature birds. If we bear in mind that the proportion of immature Spanish imperial eagles in relation to the whole Doñana population is 14.3%, it becomes clear that these non-adult birds are the most susceptible to electrocution. From 1979 onwards, the population of Spanish imperial eagles in Doñana was beginning to show worrying symptoms of being unable to sustain itself. For example, breeding pairs in which one of the two birds was still in its immature plumage had begun to be seen more frequently, and birds would take over a year to replace a lost partner (Ferrer and Calderón, 1990). Our data suggested that
deaths by electrocution alone could finish off Doñana’s imperial eagles for good, and the same was probably occurring in other populations, only that elsewhere nobody was checking power lines and so nobody was aware of the gravity of the situation. However much they were taking over our countryside – and even national parks such as Doñana – most naturalists and natural scientists still failed to see the presence of power lines as a threat.

By the beginning of 1984 our work was finished. We prepared a report for Dr. Castroviejo that he used in meetings with the National Park’s board to warn of the seriousness of the problem and to press for a solution. Our report not only described the relevance of deaths on power lines but also presented a series of solutions, including proposals to dismantle unnecessary lines duplicating circuits whose removal would prevent over half of the deaths from occurring in the future. Dr. Castroviejo said that he would like to publish the report but this never happened. Nevertheless, our data were presented at national and international congresses (Ferrer et al. 1986, Ferrer et al. 1987) and did appear in the specialist press (Ferrer et al. 1986, Ferrer et al. 1987, Ferrer and de la Riva 1987, Calderón et al. 1988, Ferrer 1988, Ferrer and De le Court 1988). Yet, it wasn’t until 1991 – and then only in reference to mortality in raptors – that our data first appeared in an international journal; but by that time, however, I was convinced that the monograph on the subject that Javier Castroviejo hoped to publish was never going to see the light of day.

Doñana without power lines

After the presentation of our study in Doñana, things began to happen. Dr. Castroviejo used our information to explain to the National Park’s governing body to what extent birds – and, above all, the Spanish imperial eagles – were dying on the power lines. I had no idea at that point that most of the dangerous power lines in Doñana had in fact been put up by ICONA (National Institute for the Conservation of Nature, the independent body belonging to the Ministry of Agriculture in charge of Spain’s national parks), which placed this organization in a rather uncomfortable situation. Indeed, the events that followed can only really be understood within the context of the permanent state of conflict that in those days existed between the scientists (EDB and CSIC) and those in charge of conservation in Doñana (ICONA).

In 1984 the Biological Station organized the first-ever workshops on research in the National Park, in which Manuel and I presented the results of our work. Neverthe-
less, without even having the opportunity to make any suggestions and contrary to the recommendations that we had made in our study, ICONA decided that it was going to protect the power lines on its land as per the recommendations made by Olendorff, Miller and Lehman in their publication *Suggested Practices for Raptor Protection on Power Lines — The State of the Art in 1981*. And so they did. Personally, I was not convinced by the efficiency of the techniques proposed in this publication since it advocated the placing of perches to avoid large raptors touching conductors, a measure that had been designed for wooden posts. And, as we had seen, on such posts very few raptors were electrocuted and the most habitual type of accident was contact between two phases. We knew that this was not applicable to pylons made of lattices of metal struts, as was the case in Spain, where most electrocutions occurred as a result of contact between a phase and an earthed cable. In the end, whatever our intuition was telling us, we could see clearly that our job from now on was to check to see just how effective the corrective measures were. The problem was serious and it was up to us to learn how best to resolve it.

We designed a monitoring project based on our previous work that included the study of both modified and non-modified pylons in order to evaluate any possible reduction in bird mortality. Our project was simple and low-cost, but still neither Dr. Castroviejo nor anybody else would help pay our expenses. Project in hand I asked for an interview with the then Director of the National Park to try to drum up support for our project, even if it was just help with our modest expenses (which to us seemed enormous). The meeting took place in ICONA’s headquarters in Seville in offices seemingly modelled on Kafka’s *The Trial*. After listening to me somewhat impatiently, the Park Director said that ‘ICONA does not pay for research – and if we did we would find someone like Ramón Margalef (a highly respected Spanish limnologist) and not students like yourselves’. Despite everything, when I left the office I was more convinced than ever that somehow we would find a way to get our study off the ground, even if it meant spending money we didn’t have.

Dr. Castroviejo had the idea that one way of putting pressure on ICONA to modify their power lines properly would be to petition what was then the European Economic Community, which Spain had just joined. He suggested that I find out the procedure for presenting complaints and then draft the relevant document. Once the documentation was ready, Dr. Castroviejo decided that we would present the complaint via a conservationist NGO he was close to and whose most active member in those days was frequently seen around the Biological Station. Just a few years later, the very same *modus operandi* that I explained to this group was used by the same ecologists to report me for putting radio transmitters on Spanish imperial eagles!

By the end of 1984 and once again without any financial support we began our new year-long study of the power line recently ‘protected’ by ICONA and of other non-modified power lines that would act as controls. Given that our relationship with the park management had worsened, this second year of study was rather more fraught than the first. Every time we visited the electric line belonging to the Park there would be a Park ranger waiting for us with instructions to ask to
see our identity cards and to report us for entering the area without a permit. We showed them the permit from the Biological Station and provided them with one of the dozens of photocopies of our ID cards that we had to carry with us at all times. They never did actually report us to the police, but soon the rangers were given instructions to remove all bird corpses from the foot of the pylons before we arrived. Fortunately, the rangers were more interested in solving the problem of the electrocutions than getting mired in political quarrels and so were happy to pass on to us all the corpses they collected, with details of under which post they had been found. The results of our study left no room for doubt: there was no fall in mortality rates on the modified pylons and, in fact, more birds died than we expected (although this result was not statistically significant) (Table 1). In 1985, two Spanish imperial eagles were electrocuted on posts ‘protected’ by ICONA.

Table 1. Results of the ‘protections’ installed by ICONA in the Doñana National Park. As can be seen from the table, mortality rates did not change after the Park management had placed metal perches on the top of the central mast of the pylons.

<table>
<thead>
<tr>
<th>Pylons</th>
<th>Year</th>
<th>Raptors</th>
<th>Other birds</th>
</tr>
</thead>
<tbody>
<tr>
<td>No protection</td>
<td>1982</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>No protection</td>
<td>1984</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>With protection</td>
<td>1985</td>
<td>9</td>
<td>6</td>
</tr>
</tbody>
</table>

In 1986, we presented the results of our studies at the International Congress of Mediterranean Raptors in Évora in Portugal and began to publish articles in specialist magazines aimed at publicizing amongst Spanish and foreign naturalists the extent of the problem we had detected in Doñana (Ferrer et al. 1986, 1987, Ferrer and De la Riva 1987, Ferrer 1988, Ferrer and De le Court 1988). Dr. Castroviejo asked to be included as co-author of all the articles because, as he reminded us, without him there would be no library in the Biological Station and with no library we would not have been able to finish our work. Likewise, when a magazine paid us something, he kept his part of the small amounts we received. Fortunately, the publication of this information in these magazines, as well as the news that appeared in the press and on the television, establish a framework for the positive atmosphere that was needed to put into practice possible solutions.

That same year I began my doctoral thesis on juvenile dispersion in the Spanish imperial eagle in Doñana. I placed solar-powered radio transmitters with a five-year lifespan on young eagles when they were still in the nest (at 45–55 days old). These apparatus emitted a strongly orientated VHF signal that under optimum conditions could be captured at a distance of up to 70 km. This enabled me to follow young birds as they dispersed and find out how and where they
lived until the survivors were old enough to form part of a breeding pair. These transmitters also provided us with a lot of valuable information on causes of death in the species since it was a technique with no bias in which the probability of finding a corpse was not dependent on the cause of death. This was of upmost importance because it was obvious that, by concentrating our efforts on power lines, we might be overestimating this factor as a cause of death relative to other factors such as the use of poison baits, which were more unpredictable in their location. In 1986, we equipped eight young eagles with radio transmitters, of which three were electrocuted on power lines in Doñana and the surrounding area before reaching the age of one.

At the end of 1986, Manuel and I were still walking the power lines. On one such day my fiancée Ester came with me and underneath one of the first pylons we examined in Matasgordas we found an electrocuted imperial eagle – a beautiful three-year-old female whose juvenile plumage was already beginning to be dappled with the dark feathers of the adult plumage. This ‘checkerboard’ bird, as we called this plumage type, must have died just minutes before we arrived as she was still warm and her eyes were still open. We were both especially saddened by this find as it was the thirteenth dead imperial eagle we had found since beginning our study and nothing seemed to have changed. In reply to my laments, Ester said, ‘if you as the only person who knows what’s happening don’t do anything to stop it, who do you think is going to do anything?’ From that moment on, removing all the power lines from Doñana became a personal crusade. The following morning I telephoned the local electric company (in those days Sevillana de Electricidad) and spoke to their head of public relations, Fernando Rubiales, who, incidentally, I had never met. I reminded him that, as he was probably aware from the press, at that very moment Felipe González, the Spanish Prime Minister, was a guest at the Doñana Biological Station and I explained that during our visit to Doñana we had seen yet another imperial eagle electrocute itself unnecessarily on a power line. I added that three eagles had died in recent months and that if they didn’t do something about it we would. The following morning three people from the electricity company were waiting for me at the Park reception centre to accompany me on a visit to the power line in question. On 21 January 1987, this particular stretch of line was turned off, with which we managed to reduce the raptor mortality rate in Doñana by 45%. Naturally, Felipe González never found out anything about all of this.

This was our first triumph in our fight to put an end to this problem, although the fact that for the first time ever we were actually collaborating with an electricity company was just as important as the taking out of service of this dangerous power line. In the end, Sevillana de Electricidad (henceforth, Sevillana) not only disconnected this line but also, before completing the removal of the all pylons, allowed us to try out prototypes on the now defunct line. Our aim was to test to see whether we could modify the ways in which raptors used pylons by placing artificial perches or perch guards, or a combination of both (Negro et al. 1988, Regidor et al. 1988). We had progressed from confrontation to collaboration.
Sr. D. J. Castroviejo
Director de la Estación Biológica de Doñana
SEVILLA

Muy Sr. mío:

Como Vd. conoce, llevamos varios días en contacto con esa Estación Biológica a través de D. Miguel Ferrer, en orden al estudio de las causas que motivan la electrocución de aves en varias líneas eléctricas existentes.

Conjointemente, hemos visitado la Zona, y hemos podido comprobar que la mayor mortalidad se ha producido por electrocución de aves en un trozo de una línea de 15 kV construida en su día por la Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO) y de su propiedad. Dicha línea, mediante los seccionamientos oportunos, ha sido puesta fuera de servicio la pasada semana, lo que, además de quitar el peligro de electrocución, nos va a permitir hacer diversas investigaciones orientadas a la protección de las aves.

También hemos mantenido reunión conjunta con ICONA. A este organismo le vamos a facilitar una nueva tecnología y asesoramiento sobre líneas aéreas para que construya un trozo de línea aérea que, además de permitir desmontar una línea existente clásica, nos sirva de experimentación de la nueva línea tanto para la seguridad de las aves como de la propia línea.

En la próxima semana, iniciaremos de acuerdo con su Sr. Ferrer las primeras experiencias, instalando en la línea propiedad de la FAD dispositivos protectores para, posteriormente, analizar el comportamiento de las aves. Dicho comportamiento nos orientará en las futuras experiencias a realizar.

Estamos muy interesados y complacidos en colaborar con esa Estación Biológica en orden a hacer compatible la obligada existencia de líneas eléctricas y reducir la mortalidad de aves que a causa de las mismas se puedan provocar.

Me es muy grato saludarle cordialmente.

Enrique Navarrete Fernández
Sr. D. Enrique Navarrete Fernández
Director General
Compañía Sevillana de Electricidad
Avda. de la Borbolla
41013 SEVILLA

Muy Sr. mío:

Deseo agradecer su carta del 28 de enero al tiempo que expreso mi satisfacción y alegría por la positiva labor que están realizando para aminorar el tremendo impacto de las instalaciones eléctricas en las aves del Parque y su entorno.

Saben que esta tarea cuenta con nuestra colaboración entusiasta; estoy seguro que su actitud será reconocida, asimismo, por el Patronato.

La información reunida en Doñana nos da una idea de lo que puede estar sucediendo en los tendidos eléctricos de otras partes de Andalucía y España. Así parece necesario que con la mayor urgencia se inicien investigaciones rigurosas al respecto, a fin de buscar soluciones a este problema, cuya gravedad no se le oculta a nadie.

Reiterándole mi gratitud, queda a su disposición.

Dr. Javier Estroviejo
The great mortality amongst the imperial eagles, together with the lack of effectiveness of the perches placed on pylons and the disconnection of the problematical line by Sevillana, ended up convincing the Park authorities that all power lines in Doñana had to be eliminated. With help from Rafael Cadenas and Manolo Mañez, the Park designed a project to put into practice the recommendations in our initial study and constructed a short stretch of power line with insulated cable in a single bundle (on which electrocution is impossible) that would render obsolete 29 km of conventional line and reduce raptor mortality by 75%. This project, along with proper protection for the power lines that were not dismantled, ensured that the electrocution of birds of prey in Doñana was finally a thing of the past. By the end of 1987 Doñana was freed forever of its electric ‘girdle’ that had caused so many victims.

This transformation of the Park meant that the problem of electrocution in this imperial eagle breeding population had all but been resolved. The results were spectacular: survival rates during the first six months of life in juvenile imperial eagles rose from 17.6% in 1986 and 1987 to 80% in 1988 and 1989 (Ferrer and Hiraldo, 1991). The elimination of dangerous power lines in Doñana was without doubt the single most successful conservation measure undertaken to protect the Spanish imperial eagle since the Park had been declared a protected area.

Spanish imperial eagles and power lines beyond Doñana

Throughout 1987, we continued equipping Doñana’s juvenile imperial eagles with radio transmitters as a way of studying their dispersal patterns. The Park’s power lines were gradually being corrected, but, even so, that year, of the eight eagles we marked, two died of electrocution. Our investigation of juvenile dispersal in this eagle revealed that in dispersal areas death through electrocution was also a serious problem (Calderón et al. 1988, Ferrer 1990). The Spanish imperial eagle only becomes reproductively mature in its fifth year of life; in the meantime, young birds spend their time in dispersion and, in the case of Doñana’s eagles, head for areas 90–150 km away from the National Park (Ferrer 1992a, 1992b, 1993a, 1993b, 1993c, 2001). Our dispersal study enabled us to locate with precision these areas, which included some of the most magnificent natural sites in Andalusia. Most were private estates that harboured a natural richness and diversity of species that we could barely believe. One of the most outstanding sites was Las Lomas in Vejer de la Frontera (Cádiz), a vast estate in La Janda, an enormous lagoon that, despite having been drained, still conserved exceptional natural values.
This was the most popular dispersal area for Doñana’s juvenile imperial eagles (Ferrer 1993c, 2001), but, like most of rural Spain, was unfortunately criss-crossed by numerous power lines, death traps waiting to slay the unwary eagle that perched there.

In autumn 1987, I was in Las Lomas following a juvenile imperial eagle that like so many others had chosen La Janda as its dispersal site. Come midday, I had stopped by the side of the entry track into the estate to watch through my telescope the young eagle, which had perched on a gigantic wild olive 300 m away. At that moment, out of the corner of my eye I noticed a Land Rover of the type used by the Guardia Civil pass by. Immediately, its brake lights flashed on and the vehicle reversed back to where I was standing. As I had expected, a pair of Guardia Civil emerged and asked, ‘Good afternoon. Might we know what you are doing here?’ I replied that I was studying the dispersal of imperial eagles from Doñana by putting radio transmitters on their backs because, unfortunately many were killed on power lines in their time away from the Park. The Guardia was not unmoved by what I had said and exclaimed, ‘What unfortunate beasts! But hasn’t it occurred to you to place an enormous net over Doñana to stop them escaping?’ Not wanting to show him up, the only thing I could think of to reply was, ‘Yes, we have. But if we do that the geese that come in winter from Sweden won’t be able to get in’. Immediately, the Guardia turned to his colleague and exclaimed, ‘Sod me! The things you don’t know!’ On many an occasion I’ve thought of just how right that Guardia was since working in the conservation of threatened species always guarantees that there are plenty of opportunities to lament ‘the things you don’t know’! A little while later one of the young eagles we had marked in Doñana was electrocuted in Las Lomas: it was time to set to work on the power lines again, but this time outside Doñana.

With the help of Ramón C. Soriguer, a friend and researcher from the Doñana Biological Station, I was able to get to know the owner of Las Lomas, José Ramón Mora Figueroa. He was already quite old when we met in his office. I had by then visited a number of the owners of the estates that the eagles used in dispersion and I was getting used to finding myself in offices adorned with a lot more hunting trophies than books. It was seemingly fashionable to have the Encyclopaedia of Andalusia on your bookshelves, along with just a few other books ordered according to size and colour. However, José Ramón’s office was full of books in a number of languages that, arranged according to subject, filled his ample bookshelves. I explained to him why I was there and he was keen to find out more about the eagles and our work. He told me that he had hunted throughout much of the world – which explained the trophies that filled the lobby to his office – but that he had reached the conclusion that if we continued in the same way for much longer the natural world as we knew it was doomed to disappear. Thus, he had decided a few years earlier that no one was going to hunt in Las Lomas, other than on the occasions that social commitments made it obligatory. He had declared as reserves large areas along the edge of what was once the lagoon, which was where many juvenile Spanish imperial, golden and Bonelli’s eagles, as well as many other species, fed and rested whilst immature. I asked for permission to enter the estate to be able to continue with the radio-tracking and monitor the power lines, and he not only gave me permission, but also put all the estate’s resources, including its rangers, their 4x4 vehicles and lodging if necessary, at my disposal.
In August 1987, once again with Manuel de la Riva, we began to monitor the power lines in Las Lomas. In the period up to February 1988 we checked 587 pylons, finding in all 362 dead animals, including 361 birds and one genet (Table 1). Of the birds, there were four imperial eagles, 15 Bonelli’s eagles and 45 common buzzards. To this figure, we should add another imperial eagle whose ring was sent to the Doñana Biological Station in 1980. Of the 361 birds, 324 had died by electrocution and only 37 as a result of collisions. Even so, given that our methodology was similar to the one we had used in Doñana, it is possible that the number of collisions was underestimated. In any case, as in Doñana, we found that accidents were concentrated on just 57 out of the 587 pylons (9.7%) we checked and, again just like in Doñana, the main cause of death was electrocution, collisions being relatively infrequent occurrences. Of the raptors, all were juveniles except two of the 46 common buzzards, two of the 12 northern goshawks, and two of the twelve black kites, which were adults; we also found two dead eagle owls.

This study of the power lines in Las Lomas, our third in all, was the first for which we managed to get any funding from the Department of the Environment of the Andalusian government to help pay for some of our costs. This was down to Rosario Pinto, one of the people in the Department who was most aware of this problem and who years later would become one of its director generals.

I personally handed a copy of our results, along with a number of suggestions for improving the pylon design, to José Ramón Mora Figueroa. He was shocked by the large number of raptors that were dying on the power lines in his estate. Within a month he called me to a meeting in his office with an engineer in which he asked me to supervise the project he had devised for correcting the power lines in Las Lomas to avoid the death of so many birds. Just three months later the pylons had been remodelled: those with two crossarms with pin-type insulators had all been replaced with staggered crossarms with suspended insulators; likewise, all jumper wires running above the crossarms were also eliminated and all circuit-breakers were protected with insulated cables and plug-in terminals. The carnage being suffered by birds of prey in the estate quickly became a thing of the past. The cost of all the work was paid for by José Ramón, who, years before the first law aimed at modifying pylons to protect birds, voluntarily had made one of the most generous contributions to saving the imperial eagle that I know of. And, what’s more, it worked. Years later I was lucky enough to be able contribute to the recognition of the altruistic work carried out by the Mora Figueroa family in Las Lomas to protect the imperial eagle. By then, José Ramón unfortunately had died, but his sons, Fernando and Ramón, accepted the well-deserved Fungesma (Foundation for the Management and Protection of the Environment) award for Nature Conservation in his stead. A number of years later the Mora Figueroa family would once again play a prominent role in the history of the Spanish imperial eagle by allowing us to use their estate to help bring a long-held dream come true – that the imperial eagle should once again hold court in the skies of Cádiz province. With their help imperial eagle chicks hatched in La Janda, which in the past had been one of the main bastions of this eagle.
Table 1. Birds found dead under 587 electric pylons on distribution lines in Las Lomas (Vejer de la Frontera) in 1987–88.

<table>
<thead>
<tr>
<th>Species</th>
<th>Electrocution</th>
<th>Collision</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle egret</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>White stork</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Mallard</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Marbled duck</td>
<td>1</td>
<td>0</td>
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</tr>
<tr>
<td>Duck sp.</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Spain imperial eagle</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Egiptian vulture</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Common buzzard</td>
<td>44</td>
<td>1</td>
<td>45</td>
</tr>
<tr>
<td>Bonelli's eagle</td>
<td>15</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Booted eagle</td>
<td>2</td>
<td>0</td>
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</tr>
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<td>Black kite</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Red kite</td>
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<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Kite sp.</td>
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<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Short-toed eagle</td>
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</tr>
<tr>
<td>Northerm goshawk</td>
<td>11</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Common kestrel</td>
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<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Raptor sp.</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
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<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Red-legged partridge</td>
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</tr>
<tr>
<td>Quail</td>
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<tr>
<td>Moorhen</td>
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</tr>
<tr>
<td>European golden plover</td>
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</tr>
<tr>
<td>Northerm lapwing</td>
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<td>Black-headed gull</td>
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<td>Black-tailed godwit</td>
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</tr>
<tr>
<td>Wood pigeon</td>
<td>13</td>
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<td>17</td>
</tr>
<tr>
<td>Turtle dove</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Eagle owl</td>
<td>2</td>
<td>0</td>
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</tr>
<tr>
<td>Garden warbler</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Song thrush</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Spotless starling</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Jackdaw</td>
<td>188</td>
<td>1</td>
<td>189</td>
</tr>
<tr>
<td>Raven</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Passerine</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Unidentified bird</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Genet</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>325</strong></td>
<td><strong>37</strong></td>
<td><strong>362</strong></td>
</tr>
</tbody>
</table>
When the news of the mortality of raptors in Las Lomas broke, a colleague remarked to me that they had known for a long time that La Janda was a graveyard for raptors. I couldn't help recalling the reflection that my fiancée Ester had made and wonder out loud why nothing had been done to solve the problem before. Naturally, the reply was the same cop-out as always: ‘there's nothing you can do, nobody cares about these things’. Nevertheless, my firm belief that the opposite was true had led to the removal of the power lines in Doñana and the protection of Las Lomas, and would take us much further still. I learnt then that when somebody says that something is impossible, what they are really saying is that they haven’t got the guts to give it a shot.

By the beginning of 1989 I was convinced that the situations we had found in Doñana and La Janda were by no means isolated cases and that the same thing must be occurring in all areas used by imperial eagles. Just as evident was the fact that it would be impossible to correct all electric pylons by installing insulated bundles of cables, as we had in Doñana, or by burying power lines. Although some types of pylons had already been outlawed and would soon be replaced, there were still thousands of kilometres of power lines in Andalusia that could be having a serious negative impact on raptors and, above all, on imperial eagles. Fortunately, as we now know, death rates were not uniformly spread across the landscape but, rather, tended to be concentrated on just a few pylons. This meant that if we could correct this relatively small group of pylons (those with dangerous design in areas of high raptor density) on which most deaths occurred we would be able to significantly reduce the overall death rate of raptors on pylons. The main problem consisted in locating these dangerous pylons. I decided that the priority was to check the power lines in areas of juvenile dispersion that we had identified through the monitoring of young birds with radio transmitters. The discovery of electrocuted birds in the mountains of Huelva province suggested that the problem was far from solved and encouraged us to try to identify which pylons were the most problematic.

At the end of 1989, an important change took place in the Biological Station. Dr. Castroviejo left, not without some divergences of opinion, and was replaced by Miguel Delibes. I was then working on the third year of my doctoral thesis, which was being directed by Dr. Castroviejo. After he left his post, I was left without a contract and with nobody to sign the papers I needed for the university. A little while earlier, I had come into contact for the first time with Fernando Hiraldo, scientist working for the CSIC at the National Museum of Natural Sciences in Madrid and specialist in birds of prey. For years Hiraldo had wanted to work in the Biological Station but Dr. Castroviejo, a sworn enemy, would not authorize the move. With the new Director in place, his move to Doñana was now possible. A few years before I had explained to Hiraldo that my thesis aimed to identify the causes and characteristics of juvenile dispersion in the imperial eagle; his reply was that such a line of work had no scientific interest whatsoever and was of no use as a doctoral thesis. As I had lost my original thesis director, I went to Miguel Delibes for some advice about finishing my work. He
recommended me to pack up my things and leave the Biological Station, which was when I first became aware of an all-too habitual practice in Spanish science: you get your revenge on your enemies by persecuting their pupils.

It was around this time that I got to know personally Fernando Rubiales, José Antonio Martínez and Fernando Manzanares from the electric company Sevillana-Endesa. These three people were all to play a vital role in initiating the much-required collaboration between us biologists and the engineers from the company that the solution to this problem was crying out for. The foresight of Fernando Manzanares led to the first formal agreement between Sevillana, the Andalusian government’s Ministry of the Environment and the CSIC to reduce mortality through electrocution in the Spanish imperial eagle. This agreement would also enable me to finish my thesis and its signing – and, above all, the financial support it implied – curiously changed Fernando Hiraldo’s scientific opinion of my work. He became my new thesis director and with this Miguel Delibes decided that I should continue working in the Biological Station.

Thus, in 1990 Sevillana paid for a study by the Biological Station (CSIC) whose aim was to locate dispersal areas with most eagle deaths. The main juvenile dispersal areas were identified by radio-tracking 32 young imperial eagles from Doñana in the period 1986–1989. Using harnesses, these birds were fitted with radio transmitters on their backs. The monitoring was carried out from the ground in 4x4 vehicles or from the air in collaboration with the Air Force, who twice a week flew us in a light plane over the whole of the eagles’ dispersal areas. Our results showed that within these areas, located in the provinces of Cádiz, Sevilla and Huelva, there were a number of small, intensely used patches that we christened Areas of Temporary Settlement (ATS) (Ferrer 1993a, 1993b, 1993c, 2001). These ATS were home to over 80% of all the young imperial eagles and were used by various eagles from Doñana during our four-year study (Ferrer 1993c).

Most of the electrocutions of imperial eagles outside Doñana were taking place in these ATS (birds under five years of age without the characteristic adult plumage). The next step was to locate the pylons on which most deaths were occurring within these areas and apply corrective measures in order to reduce eagle mortality. On foot, we investigated 4119 pylons that formed part, above all, of the second- and third-category distribution grid with nominal voltages of 15–45 kV. Not all belonged to Sevillana, as some were privately owned or property of local government. In this case, given that we knew that the blackspots could be detected by just a single visit, our methodology consisted of walking just once around 500 km of power line. We also carried out 106 hours of raptor census to gain some kind of idea of the relative density of birds in each area and to gather more information about how raptors used the pylons, that is, on which particular parts of the pylons they perched most often.
Table 2. Birds found dead under 4,119 pylons on distribution lines in dispersal areas of young imperial eagles in Cádiz and Huelva provinces.

<table>
<thead>
<tr>
<th>Species</th>
<th>Nº casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spanish imperial eagle</td>
<td>3</td>
</tr>
<tr>
<td>Northern goshawk</td>
<td>3</td>
</tr>
<tr>
<td>Black vulture</td>
<td>1</td>
</tr>
<tr>
<td>Common buzzard</td>
<td>126</td>
</tr>
<tr>
<td>Short-toed eagle</td>
<td>9</td>
</tr>
<tr>
<td>Falco sp.</td>
<td>4</td>
</tr>
<tr>
<td>Common kestrel</td>
<td>9</td>
</tr>
<tr>
<td>Griffon vulture</td>
<td>4</td>
</tr>
<tr>
<td>Short-toed eagle</td>
<td>17</td>
</tr>
<tr>
<td>Kite sp.</td>
<td>10</td>
</tr>
<tr>
<td>Black kite</td>
<td>25</td>
</tr>
<tr>
<td>Red kite</td>
<td>21</td>
</tr>
<tr>
<td>Falconiforme sp.</td>
<td>1</td>
</tr>
<tr>
<td>Little owl</td>
<td>2</td>
</tr>
<tr>
<td>Eagle owl</td>
<td>5</td>
</tr>
<tr>
<td>Tawny owl</td>
<td>7</td>
</tr>
<tr>
<td>Barn owl</td>
<td>2</td>
</tr>
<tr>
<td>Grey heron</td>
<td>1</td>
</tr>
<tr>
<td>Cattle egret</td>
<td>9</td>
</tr>
<tr>
<td>Cuckoo</td>
<td>1</td>
</tr>
<tr>
<td>White stork</td>
<td>9</td>
</tr>
<tr>
<td>Wood pigeon</td>
<td>2</td>
</tr>
<tr>
<td>Pigeon sp.</td>
<td>1</td>
</tr>
<tr>
<td>Raven</td>
<td>78</td>
</tr>
<tr>
<td>Jackdaw</td>
<td>92</td>
</tr>
<tr>
<td>Green woodpecker</td>
<td>2</td>
</tr>
<tr>
<td>Genet</td>
<td>1</td>
</tr>
<tr>
<td>Unidentified</td>
<td>8</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>453</strong></td>
</tr>
</tbody>
</table>
In all we found 453 corpses (including three juvenile imperial eagles) belonging to 24 different species, of which 249 were birds of prey (14 species) (Table 2, Cepeda et al., 1990). Birds of prey were not only the commonest species but also numerically the most frequently electrocuted type of bird (55% of all victims). Aside from the imperial eagles, of the birds of prey there were also 17 Bonelli’s eagles and 126 common buzzards. Given the size of the Spanish Bonelli’s eagle populations, these results, along with those from La Janda, highlighted the fact that death through electrocution was an exceptionally important cause of mortality for both the Spanish imperial eagle and Bonelli’s eagle. As in our previous studies, we also found a large number (78) of dead ravens.

In this and other studies (Ferrer et al. 1991) we showed that the main factors determining the distribution of death by electrocution are pylon type and habitat. Pylon design had a statistically very important influence on death rates and once again the most dangerous pylons were those with exposed jumper wires projecting above crossarms, followed by pylons with pin-type insulators and then pylons with strain insulators. Pylons with suspended insulators were once again the safest of the typical designs, above all if in a staggered configuration (Ferrer et al. 1991). The distribution of the victims showed how some pylons tended to be ‘contagious’ as 80% of corpses were found under less than 20% of pylons.

Based on their plumage, we classified all dead birds as either adults (five-years old or over) or immature (under five-years old) (Ferrer and Calderón 1990). Causes of death were determined by external signs on corpses and the location of corpses. All birds found under pylons or with burns, usually on claws or wing-tips, were considered to have been electrocuted (Ferrer et al. 1986). Shot birds were detected whenever possible using x-rays or by finding pellets during autopsies. Death by malnutrition was recorded if a bird was unable to fly, had no external signs of injury and was underweight. In eight out of 11 cases malnutrition was confirmed by blood analyses that revealed high levels of urea. Additionally, to avoid possible sex-related biases in causes of death, we used data on sex ratios taken from an analysis of 46 chicks, whose sex was determined just before leaving the nest (Ferrer and De le Court 1992).

Table 3 shows the causes of all imperial eagle deaths for which records had been kept since 1957. In all, 96 of Doñana’s imperial eagles had been found dead, of which 88.29% were immature birds, with an average of three deaths a year. In an analysis of only the post-1974 period, the year in which power lines began to proliferate around the park, the death rate rises to 5.53 eagles per year.
Table 3. Dead Spanish imperial eagles in Doñana by age in the period 1957–1989.

<table>
<thead>
<tr>
<th>Year</th>
<th>Immature</th>
<th>Adult</th>
<th>Unknown</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1957</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>1959</td>
<td>3</td>
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<td></td>
<td>3</td>
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<tr>
<td>1960</td>
<td>1</td>
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<td></td>
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</tr>
<tr>
<td>1961</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1966</td>
<td>1</td>
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<td>1967</td>
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<td>1968</td>
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<td>1</td>
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<tr>
<td>1969</td>
<td>2</td>
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<tr>
<td>1970</td>
<td>1</td>
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<td></td>
<td>1</td>
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<tr>
<td>1974</td>
<td>1</td>
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<td></td>
<td>1</td>
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<tr>
<td>1975</td>
<td>4</td>
<td>1</td>
<td></td>
<td>5</td>
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<tr>
<td>1976</td>
<td>5</td>
<td>1</td>
<td></td>
<td>6</td>
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<td>1977</td>
<td>3</td>
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<td>3</td>
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<tr>
<td>1978</td>
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<tr>
<td>1979</td>
<td>5</td>
<td>1</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>1980</td>
<td>3</td>
<td>3</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>1981</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
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<td>8</td>
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<td>1986</td>
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<td>1987</td>
<td>15</td>
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<td>15</td>
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<tr>
<td>1988</td>
<td>7</td>
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<td></td>
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<tr>
<td>1989</td>
<td>3</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>83</td>
<td>13</td>
<td>2</td>
<td>96</td>
</tr>
</tbody>
</table>

The main cause of death was electrocution on distribution lines (Table 4), which accounted for 46.1% of adult death and 39.8% of juvenile deaths. Taking into account only those deaths whose causes were known, at that moment in time electrocution was the cause of 60% of mortality in the species. In all cases, death came as a result of contact between a phase and an earthed wire. No deaths were caused by collision. No significant differences existed between causes of death in marked and unmarked birds (Table 5).
Table 4. Causes of death in the Spanish imperial eagle per age group.

<table>
<thead>
<tr>
<th>Cause</th>
<th>Adult</th>
<th>Juvenile</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrocution</td>
<td>6</td>
<td>33</td>
<td>39</td>
<td>40.6</td>
</tr>
<tr>
<td>Shooting</td>
<td>6</td>
<td>16</td>
<td>22</td>
<td>22.9</td>
</tr>
<tr>
<td>Malnutrition</td>
<td>11</td>
<td>11</td>
<td>11.5</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6.3</td>
</tr>
<tr>
<td>Unknown</td>
<td>1</td>
<td>17</td>
<td>18</td>
<td>18.7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>13</td>
<td>83</td>
<td>96</td>
<td>100</td>
</tr>
</tbody>
</table>

The sex ratio at fledging was 1:1. Nevertheless, there was a significant difference between the sexes in death by electrocution since more females than expected died in this manner. When grouping deaths by cause, very significant differences – 78.12% of electrocuted birds were females – were found in the frequency of death by electrocution. For all other causes of death, the sex-ratio was 1:1. This bias in the number of females killed on pylons was of the same magnitude in the Doñana National Park and outside (Ferrer 2001). Pylon-use did not differ between sexes as pylons were used on the same basis by both sexes.

Table 5. Cause of death in eagles fitted with radio-transmitters.

<table>
<thead>
<tr>
<th>Cause</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrocution</td>
<td>8</td>
<td>42.1</td>
</tr>
<tr>
<td>Shooting</td>
<td>4</td>
<td>21.0</td>
</tr>
<tr>
<td>Malnutrition</td>
<td>6</td>
<td>31.6</td>
</tr>
<tr>
<td>Others</td>
<td>1</td>
<td>5.3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>19</td>
<td>100</td>
</tr>
</tbody>
</table>

Thus, we had discovered that most deaths in the imperial eagles were caused, either directly or indirectly, by human activities: electrocutions and shooting accounted for 63.5% of all deaths. This figure meant that for Doñana, for example, there was a minimum of 3.51 eagles killed annually by human activity, a very high figure for a breeding population of just 15 pairs. The difference in the number of male and female birds that were electrocuted is attributable to the larger sizes of the females. Despite the fact that females dispersed further than males and were thus liable to reach areas with
differing numbers of dangerous pylons, if we only analyzed data from within Doñana the bias in the sex was the same as it was from outside the National Park. No differences between the sexes in the use of the upper parts of pylons were detected (Ferrer and Hiraldo 1992).

Nevertheless, it was known that in birds of prey electrocutions are most frequent in breeding populations of the larger species (Negro 1987, Ferrer et al. 1991) that use pylons as perches. Given that pylons are all of a similar type in distribution lines, and that the possibility of touching a cable rises as wingspan increases, it is possible that from a certain size upwards the risk of electrocution increases exponentially with increased wingspan. Such a notable difference between the sexes in mortality rates – whatever its cause – could have a serious effect on the extinction risk of such a small population.

According to an analysis of the potential effects on imperial eagle survival rates in Doñana of correcting power lines, we showed (Ferrer and Hiraldo 1991) that the elimination of the dangerous power lines in the area around the Park and in dispersion areas would have between 11.3 and 53.4 times more effect on population growth than the swopping of chicks between nests (a habitual practice at the time as part of attempts to increase productivity). These modifications would cause the population of imperial eagles to increase between 2.19 and 16.3 times more quickly than the sum of all the other conservation measures that were being used in the species (Table 6). This meant that if we were able to eradicate death by electrocution both in and outside Doñana in the species, the imperial eagle population could grow almost 6% annually. Years later we would see that we had been right as, after the correcting of the pylons in Doñana and in dispersal areas, the imperial eagle population began to grow at an annual rate of over 5%. We realized that there was now no question that we had to reduce the tremendous impact that power infrastructures were having on the survival rates in the imperial eagle.

At the beginning of the 1990s and in light of our findings in Doñana, Las Lomas and other dispersal areas, we were convinced that there were two ways forward that urgently needed exploring if we were to find a solution to the problem of bird electrocution on pylons.

Firstly, we had to stop the problem from growing and prevent more power lines with dangerous designs from being built. By this time we knew which designs were dangerous and which were not. It was clear to us that we had to somehow change the law since in those days, both in Spain and in the rest of Europe, the relevant legislation paid no heed to the risk that power infrastructures were to birds. Ideally, this would be carried out in a coordinated fashion, with all of Spain’s autonomous regions working together to produce similar regulations based on a basic body of national legislation; this would mean convincing all the regional environmental departments and ministries, as well as the Spanish Ministry of the Environment.
Tabla 6. Calculation of the effect of various conservation techniques on the rate of increase in Spanish imperial eagle populations (PAC = percentage of annual change; PAC +1.3% means that the population will be 1.3% larger the following year. Taken from: Ferrer and Hiraldo 1991).

<table>
<thead>
<tr>
<th>Technique</th>
<th>Parameter</th>
<th>Maximum PAC</th>
<th>Minimum PCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swopping chicks in Doñana</td>
<td>Fecundity</td>
<td>+0.626%</td>
<td>0.000%</td>
</tr>
<tr>
<td>Introduction of chicks from other populations</td>
<td>Fecundity</td>
<td>+0.399%</td>
<td>+0.112%</td>
</tr>
<tr>
<td>Restoration of nests and building of artificial nests</td>
<td>Fecundity</td>
<td>+0.547%</td>
<td>0.000%</td>
</tr>
<tr>
<td>Treatment of infections in chicks</td>
<td>Fecundity</td>
<td>+0.074%</td>
<td>0.000%</td>
</tr>
<tr>
<td>Correcting of power lines in Doñana</td>
<td>Mortality of adult and immature birds</td>
<td>+7.800%</td>
<td>+4.160%</td>
</tr>
<tr>
<td>Correcting of power lines in dispersal areas</td>
<td>Mortality of immature birds</td>
<td>+3.610%</td>
<td>+1.830%</td>
</tr>
</tbody>
</table>

The other main aspect of the problem was of even greater complexity: what should be done about the hundreds of thousands of dangerous pylons that were scattered throughout Spain? Obviously, the only realistic solution was to develop systems that diminished the risk to birds at a moderate cost since an enormous number of pylons would have to be modified. Given the accumulation of deaths on certain types of posts and our knowledge of the determining factors in these deaths, it seemed to us that it should be possible to identify high-risk areas without having to undertake expensive time-consuming annual surveys. All the studies conducted to date indicated that a very small proportion of pylons were responsible for a large proportion of deaths. The task of reducing mortality rates significantly by correcting pylons seemed to be feasible and, probably, the most efficient way of protecting species such as the imperial eagle.

These two projects would be carried out over the coming years: regional governments began to publish decrees regulating the construction of power lines and a research project (Project PIE) was set up to develop efficient ways of providing power infrastructures with protection.
4. No more dangerous power lines

Legislation in Andalusia

After the data obtained from our first studies on mortality on power lines it was evident that certain pylons and posts were especially dangerous to birds. We had shown that most of the variation in the distribution of deaths was related to the position of the insulators, the presence or not of jumper wires projecting above the crossarms, and other factors such as the presence of energized wires passing over places that birds would choose as perches. It was clear that we had to ensure that the problem didn’t continue to grow and that new power lines were not built with these dangerous types of pylons. We had to change the law that regulated the use of these infrastructures.

This new battle would not to be carried out in the field under the hundreds of kilometres of power line we had walked but in the offices of the electricity companies, the civil servants and the politicians, and – inevitably – in the press. I had come to realize just how much importance politicians and large companies give to the press, as well as the growing increase in interest in the media for environmental stories. It was during this period that I learnt to cultivate the natural alliance between scientists and journalists, which would subsequently become a feature of many moments of my professional life.

On 9 December 1987, Roberto Sáez Alcalde, member of the Mixed parliamentary group tabled a question in the Andalusian parliament for the Department of Presidency of the socialist government presided by Manuel Chaves. The question, which we had prepared weeks before, concerned the risk that the Spanish imperial eagle might become extinct due to deaths on power lines. After an exposition of the overwhelming facts that we had provided, including the fact that 70% of the imperial eagles born in Doñana died as a result of being electrocuted, Sáez Alcalde asked what steps had been taken or would taken by the government to solve this problem. During his reply, the Minister announced his department’s commitment to drawing up legislation to control new power lines as a means of halting the unchecked growth of the problem. I should point out that the Minister’s answer had been prepared with help from the Andalusian Environmental Protection Agency, who in turn had asked us for help; and so, to some extent, we both asked the question and answered it, thereby guaranteeing that everything would go as planned.

By the beginning of 1988 we were helping to draft the hypothetical new decree that would regulate the power lines. We held numerous meetings with the Department of
the Environment (in fact, then still a government agency), often with Rosario Pinto and representatives from Sevillana-Endesa, the largest electricity company in Andalusia. The debate on which types of pylons were going to be prohibited on new lines provoked few disagreements: the data were conclusive and changes in the designs of unbuilt lines – as opposed to existing lines – did not represent a problem for the electric companies. In fact, from the point of view of these companies, changes in the pylons made little significant differences to the overall cost of a power line. Economic interests did not come into play since the main factor that had led to this terrible situation was the ignorance amongst pylon designers of the effects that their work could have on birds. This gratuitous aspect of the death of so many raptors made it all so much harder to swallow.

More discussion arose over two key points: the geographical scope of the decree and what to do about existing power lines. Regarding the first point, our suggestion was that the new decree should cover the whole of Andalusia, although for some reason this idea never prospered – and to this day, I’m still not sure what the problem was. In the end, the decree only applied to protected natural areas or areas that the government, on the basis of a proper scientific enquiry, classed as priority areas for the protection of a particular species (e.g. imperial eagle dispersal areas). In future years, some of the other laws passed in Spain covered the whole of their respective autonomous regions, but in Andalusia we had to wait for a second decree to be published for the whole of the Andalusia to be covered by the legislation.

The second area of debate – how to tackle the problem of existing power lines – generated a lot more disparities of opinion. I, naturally, was in favour of legally enforcing corrective measures for pylons, albeit within a reasonable time framework. Nevertheless, we still knew very little about how to correct dangerous pylons; our experiences in Doñana had shown us that there was no point at all in copying protection systems used in other countries to safeguard different types of bird communities at risk on different types of power lines. Furthermore, the majority – if not all – of the protection systems available on the market were being sold without any guarantee of their true effectiveness. Thus, having reached this point it did seem somewhat precipitous to impose protection systems whose efficiency we couldn’t be sure of. Finally, for existing lines the only obligation was that they should adapt to the new law in those cases in which the tasks of protecting the power lines would imply the need for environmental authorization.

The debate on this point, which I undoubtedly lost, served, nevertheless, as the basis for an agreement between the electricity companies and the government aimed at developing low-cost, tried-and-tested protection systems that would solve the problem of existing power lines. This accord would soon bear fruit in the shape of the Electro-technical Investigation Programme.

During these meetings, I was aware that any new legislation passed on bird safety on electrical infrastructures would have to be implemented at both regional and national levels. Although Spain by then was practically a federal state, it was still beholden on the Spanish Ministry of the Environment to draw up basic legislation on the question. Thus, in 1988, at the same time as we were holding meetings in Andalusia, Juan
José Negro, a colleague in the CSIC, and I travelled to Madrid to propose to ICONA the national implementation of the same strategy as I was suggesting for Andalusia. After an interminable overnight coach journey, we met with two civil servants, one of whom was the Ministry’s expert in charge of the protection of the imperial eagle. After presenting our proposals, our interlocutors pleasantly wished us a safe journey home, commenting that they thought it would be difficult to persuade the electric companies to collaborate and that – although they would try – they were certain that the Ministry of Industry would veto any project along the lines we had suggested. I still recall their comment to the effect ‘why try if it is impossible?’, to which I responded by explaining that in Andalusia the electricity company was making a significant collaboration to the project and that I was convinced that, if the proposals made were reasonable, there wouldn’t be any significant problems. Finally, before leaving, I added that I could help with the negotiations with the electricity companies if necessary.

On 19 June 1990, the Andalusian government passed the first executive order in Europe regulating the construction of power lines to make them safer for birds (Decree 194/1990). The text of the Decree describes the type of pylons that are permissible (suspended insulators and staggered configuration), as well as the obligation to correct existing lines if the work involved required environmental authorization. Another aspect of the Decree referred to the use of markers on conductors. Nevertheless, the scope of the Decree was restricted to protected natural areas and other areas whose value could be scientifically recognized. Even so, it was still a large step in the right direction and one that paved the way for all the other Spanish autonomous communities and, finally, 18 years later, the Spanish Ministry of the Environment, to pass similar legislation. Seated next to Martínez Salcedo, then in charge of the Andalusian Environmental Agency, on the day the Decree was presented in public and during the subsequent press conference, I was convinced that we were witnessing the birth of a small but historically significant piece of legislation.

Two years later, news came through that a draft of a ministerial decree for Spain was being prepared by the Ministry. Endesa passed on to me a draft of the proposal that ICONA had sent to the Ministry, who, in turn, had sent it to the companies in the electricity supply sector. When I read it, I was horrified for it bore no resemblance either to the Andalusian Decree or to any of the proposals that Juan José Negro and I had presented to ICONA. The draft contained odd ideas such as marking all the conductors in Spain on both distribution and transmission lines with beacons (large balls with red and white stripes) like those used to warn aircraft of the presence of obstacles. Curiously, the draft was more permissive than the Andalusian Decree regarding the types of pylons that could be used on new power lines, which included some of dubious safety. It also included a number of vague and very general references to the burying of power lines. All these failings, along with a lack of consultation with representatives from the electricity sector, led to the predictable rejection of the draft; at the same time, the autonomous communities were going ahead with the drafting of more realistic legislation based on available scientific research. I never did find out why ICONA chose to present such a proposal, which seemed to have been conceived so badly on purpose. This whole
sorry tale reminded me of a documentary about Doñana that included interviews with people who had spent their whole lives in the salt-marshes: a old woman who lived in one of the charcoal-making settlements in the south of the National Park was asked, ‘And after living here for 70 years, what’s the most remarkable thing you’ve seen in all those years?’. To which she replied without hesitation, ‘The weirdest thing I’ve seen in my life is InCONA!’.

Legislation in other autonomous communities

In light of the Andalusian Decree on power lines, new legislation began to appear throughout Spain; despite the differences in their scope and in their treatment of existing power lines, as we shall see below, they were all essentially inspired by the Andalusian legislation of 1990.

Apart from Andalusia, six other autonomous communities developed their own legislation that coincided principally in the aim to establish technical parameters to be applied to high-voltage electrical installations in their territories that would reduce the risk of birds being electrocuted on or colliding with these type of infrastructures. In 2006, a second decree was passed in Andalusia (Decree 178/2006) that superseded the previous one and increased the areas requiring anti-electrocution measures to include all the Special Protection Areas for Birds (SPAs) and areas of special conservation interest included in the Inventory of Protected Natural Areas of Andalusia. Anti-collision measures became obligatory on new power lines, as well as on existing lines in all SPAs declared to protect both great and little bustards (*Tetrax tetrax*) and in all areas within a 2-km radius of the high-water level of all wetlands included in the Andalusian wetland inventory.

Other provisions of this new Decree included the prohibition of carrying out maintenance during the breeding season on posts and pylons harbouring nests of species included in the Andalusian catalogue of threatened species. All urgent work required permission from the provincial government, although anti-nesting measures that were compatible with conservation were allowed to be employed.

These new measures were to be implemented within a period of five years from the day the Decree came into force. Nevertheless, its period of validity ran out in 2011 with many of the corrective measures still awaiting final approval. The cost of implementing these measures was to be met by the owners of the power lines.
The second autonomous region to pass its own legislation regulating power lines was Navarre (Foral Decree 129/1991). In its declared objectives it differentiated between high- and low-voltage installations and also regulated existing power lines in areas affected by recovery or conservation plans for habitats that harbour species catalogued as ‘in danger of extinction’ or ‘sensitive to habitat alterations’. As well, it aimed to avoid the construction of new lines in areas previously declared integral or natural reserves. This Decree made anti-collision measures obligatory on lines crossing migration routes or located in areas near wetlands or bird breeding colonies. All relevant information was to be supplied by the Navarrese government’s Department of Territorial Planning, Housing and the Environment; there was no fixed period for carrying out the measures, whose cost would be met by the owners of the power lines in question.

During 1998, both the Autonomous Community of Madrid and of La Rioja passed legislation within the space of a couple of months (Decrees 40/1998 and 32/1998, respectively). In Madrid, the reduction of the visual impact of power lines on the landscape was included as one of the objectives of the legislation. As in Navarre, the Decree embodied the obligation to correct existing power lines crossing areas subject to recovery plans for species ‘in danger of extinction’ included in the Madrid Regional Catalogue of Threatened Species, as well as the need to avoid integral reserves in protected areas and existing regional and natural parks. No time-scale was fixed for the corrective measures to be carried out, although as an innovation government grants were to be made available for implementing corrective measures on existing lines.

In La Rioja, the new legislation increased the scope of protection to include all non-built-up land, all land legally considered apt for development and all land ear-marked for new industrial development, as well as all major structural changes to existing power lines that required an impact assessment. Power lines crossing protected natural areas would have to conform to planning measures already in force. As in Madrid and Navarre, all new lines were to avoid protected natural areas declared as natural reserves, as well as natural areas with recuperation plans for birds catalogued as ‘in danger of extinction’. All existing lines were to be classified in terms of their potential risk to birdlife as a way of establishing priorities regarding which pylons were to be modified. As in Andalusia, the new legislation also included regulations to be applied in case of maintenance work on lines with nests, which henceforth would have to take place outside the breeding season or exceptionally only with permission from the government’s General Directorate of the Environment.

The next autonomous community to pass legislation on power lines was Castilla-La Mancha (Decree 5/1999). In its technical specifications, this Decree established the differences between low- and high-tension lines, and specified additional measures to be implemented on high-tension lines in areas where threatened birds are at risk, that is, in breeding and dispersal areas, as well as in the home-ranges of particularly large-sized birds. Also specified were flyways, either migratory routes or regularly used corridors, above all in and around wetlands, breeding areas and areas with concentrations of large birds. The Decree also describes how maintenance should be carried out to avoid disturbing breeding birds, and, as in La Rioja, establishes mechanisms for working with
owners to identify existing dangerous power lines that require modification. One original aspect of this legislation was that the Department of Agriculture and the Environment was put in charge of supervising the implementation of corrective measures to ensure they were carried out appropriately.

Next on the list of autonomous communities to pass legislation on power lines was Extremadura (Decree 47/2004). This Decree included a number of new provisions such as the fact that the installation of anti-collision measures would be decided by the Directorate General of the Environment on the basis of the density of bird movements and/or the presence of protected species. To prevent electrocution, corrective measures were to be placed on all lines in non-built-up areas. The Decree also authorized the placing of dissuasive and anti-nesting devices and the installation of compensatory measures (e.g. artificial nest platforms, mentioned expressly in the case of the white stork). As well, a maximum of one nest only per pylon was to be permitted, and in cases of over-frequented pylons, excess nests could be removed with permission from the Directorate General of the Environment. The Decree also included a very complete set of recommendations regarding the minimization of the visual impact of power lines on the landscape. To install or modify a power line, an environmental impact study was necessary that should include in a separate section details of a plan for environmental monitoring.

Finally, in 2005 the government of Aragon passed Decree 34/2005 establishing the technical regulations applicable to overhead high-tension electric infrastructures and to new lines and their derivations, as well as the reforms to be carried out on existing power lines. A broad-based register of high-risk infrastructures for birds was created, which included details of lines running through areas in which habitat recovery or conservation plans are being undertaken, or where conservation plans for species catalogued as ‘in danger of extinction’, ‘sensitive to habitat alteration’ or ‘vulnerable’ according to the Catalogue of Threatened Species in Aragon (Law 49/1995) are in progress. Also included in the law were all SPAs plus a 1.5-km perimeter buffer zone, sensitive areas in protected natural areas and Sites of Community Importance (SCI), urban areas with populations of catalogued species of birds or of birds that could be a public menace, and high-risk power lines where accidents are frequent or where technical studies reveal a high risk of bird mortality.

In addition, new power lines crossing protected natural areas or areas with planning regulations in force regarding the presence of natural species were also prohibited. Power lines in these areas would only be authorized if they fulfilled the criteria demanded in relevant current territorial planning regulations and fulfilled certain technical specifications relating to the protection of the landscape. Control of all these factors would be exercised by the Aragonese Department of the Environment, although provision was made for the electricity companies themselves to submit technical reports to the relevant environmental authorities. Of interest in this regional legislation that preceded the Spanish Royal Decree was the requirement to inform environmental protection agents or the Guardia Civil in the event of finding dead or injured birds near power installations.
National legislation

On 29 August 2008, 18 years after the Andalusian legislation had been passed, Royal Decree 1432/2008, drafted by the Spanish Ministry of the Environment and Rural and Maritime Affairs entered the statute book. This new legislation established technical specifications to be applied to overhead high-tension power lines with non-insulated conductors located in the protected areas defined in Article 4 of the legislation in question. Its aim is to reduce the risks of birds being killed by collisions with power lines and electrocutions, which in turn will lead to improvement in the quality of the service provided by electrical installations.

Such measures are obligatory on new overhead high-tension power lines in protected areas. They are also applicable to existing power lines that for one reason or another have to be modified or extended. Although anti-electrocution measures are obligatory on existing lines, anti-collision measures are still only voluntary. This Royal Decree also defines the protected areas in which these measures have to be implemented: Special Protection Areas for Birds (SPAs), areas in which recovery and conservation projects executed by autonomous communities are in operation, and priority areas for birds for breeding, feeding, dispersal and flocking. The bird species in question are those that appear in either the Spanish national or regional catalogues of threatened species. As a means to these ends, the new legislation also obliges all autonomous communities to publish within a year a list of the protected areas within their regions, as well as an inventory of all existing power lines known to cause significant mortality through collision in birds included in the Spanish List of Specially Protected Wild Species.

Another important point included in the Royal Decree relates to the maintenance of power lines. Maintenance work on sections of power lines that house nests or that are near to nesting sites of birds included on the List of Specially Protected Wild Species is prohibited during the breeding season. Nevertheless, exceptions are contemplated, but only with the appropriate authorization or in the case of technical problems that threaten to interrupt energy supplies.

Surprisingly, this law included provisions for funds to pay for the implementation of these corrective measures, which would be paid for by the Ministry of the Environment and Rural and Maritime Affairs within a period of five years. However, the inclusion of this proposal had the effect of paralyzing the ongoing implementation of corrective measures that had been initiated under the tutelage of earlier regional legislation, in which protocols co-funded by private landowners and regional governments were already in place. With the passing of the new national legislation, companies placed work on corrective measures on standby whilst the payment procedures enshrined in the new Decree were systematized, thereby losing precious time in the struggle to solve this global problem.
Two negative aspects of the new Decree were the lack of regulation of power lines outside the so-called ‘protection zones’ and the leaving of the installation of anti-collision measures up to the owners of power lines (unless they were new installations). Also excluded from the law were the overhead lines used on railway lines.

By the date the new Decree came into effect only seven of Spain’s 17 autonomous communities had passed specific legislation on the subject but now all were obliged to take into account the effects on birdlife of the installation or modification of power lines. Although the Decree established a series of minimum requirements, in some cases regional legislation is more restrictive, whilst in other cases it is more permissive. This is the inevitable consequence of publishing essential legislation 18 years too late, by which time – in the absence of any national guidance – many autonomous communities had already enacted their own decrees in accordance with their own particular criteria. At the time of writing, the problem created by the new Decree, whereby, instead of being at least part-funded by electricity companies (as was occurring in many autonomous communities), modifications and corrective measures were to be wholly financed by public money, had not been resolved. Once again, I cannot help but think of what the old woman in Doñana had said to me.
5. Project PIE: much-needed research

Despite a few failings, the 1990 Decree on the security of birds on power lines had at least enabled us to guarantee that the problem of electrocutions and collisions in Andalusia would get no worse. Moreover, slowly but surely similar laws began to be passed in other autonomous communities. Nevertheless, we still had another problem to tackle: what should we do about the hundreds of thousands of pylons throughout the rest of Spain that still had highly dangerous designs? It was clear that the methods we had employed so successfully in Doñana could not be applied on such a large scale. For example, although the cost of switching to bundled cables was a little less than burying power lines, per kilometre it was still six times more expensive than conventional non-insulated cabling. Such a price was justifiable in Doñana, but we couldn’t expect to solve in this fashion the rest of the country’s problems with overhead power lines. The sheer extent of the network of power lines crossing natural areas meant that an across-the-board substitution or modification of pylons to avoid or reduce the risk of electrocution, and the implementation of anti-collision measures on all power lines, was financially completely out of the question.

With help from Fernando Manzanares, we decided that one possible way ahead would be to present a research proposal to the Programme of Electrotechnical Investigation (PIE). In those days, the Office for the Coordination of Electrotechnical Investigation and Development (OCIDE), dependent on the Ministry of Industry, still existed and one of its tasks was to coordinate the investment of the fund financed by an obligatory levy on companies in the electrical supply industry. Fernando Manzanares came to the conclusion that this fund could pay for our research whose three main objectives were to typify the effect on bird communities of power lines in natural areas throughout Spain, to develop protection systems and then to test their effectiveness.

After a number of meetings in Madrid and Seville, as well as a presentation in Sevillana open to all company employees and attended by the company’s COE, Emilio Zurutuza, the project was ready to be presented to the Ministry of Industry (OCIDE). Participants would include three electricity companies (Sevillana, Iberdrola and Red Eléctrica de España), the Departments of the Environment of the autonomous communities of Andalusia and Extremadura, the Ministry of Agriculture (ICONA, Doñana National Park) and the Spanish National Research Council (Doñana Biological Station), this latter body to be in charge of the research.

During the initial presentation of the project, we had held meetings with all the participating bodies including, naturally, ICONA. Our aim was to use the bird
rehabilitation installations in Doñana to test protection systems for pylons under control conditions using captive birds. Numerous debates regarding the project took place during these meetings, which the ICONA representative – incidentally, the same person to whom some years ago I had passed on our suggestions for the national law – didn’t regard as being that necessary. Despite the fact that our studies had shown over and over again that the type of pylon, along with the density of birds, explained most of the variance in the distribution of bird deaths, and that this provided us with an excellent predictive tool for deciding where to act on existing power lines, ICONA still thought that it would be best to correct just the pylons on which eagles had been killed – and leave it at that. In other words, we were to wait for eagles to make the supreme gesture and sacrifice themselves on pylons and in doing so tell us where we should intervene. When an eagle died on a pylon, that pylon alone would be corrected and no others. It may seem hard to believe now, but this was the criterion used – as recommended by ICONA – in the autonomous communities with imperial eagles that did not take part in the PIE. These differences in criteria regarding modifications of power lines ensured that, years later, the imperial eagle population would grow much faster in Andalusia than in any other autonomous community. Once again, as the old women in Doñana would have remarked, ICONA was truly moving in a mysterious way.

Before undertaking the research project, various partial aspects of the problem had already been studied and a number of different solutions had been tried out, but without any attempt to quantify the real magnitude of the problem; likewise, no economically viable solution for existing power lines or safe design that would not incur additional costs for new lines had yet been found. Ever since our first studies in Doñana had been published, the number of studies of Spanish power lines aimed at locating blackspots with accumulated victims had multiplied, as had the studies – some more interesting than others – aiming to identify factors relating to bird electrocution and collisions. Nevertheless, proper coordination was still lacking; most of these studies were purely descriptive and only served to highlight higher or lower mortality rates in specific areas or in certain species.

As knowledge of the dimension of the difficult co-existence between power lines and birds grew, a number of electricity companies made the point of studying the problem to find viable technical and economic solutions. By the end of the 1980s, the conditions for promoting collaboration between all the implicated parts in the project were favourable and so, finally, an ambitious and rigorous research project gradually began to emerge whose aim was to research the problem in great depth and find viable solutions for resolving it.

In 1991, three Spanish electric companies, Sevillana (to become Sevillana-Endesa), Iberdrola and Red Eléctrica de España put their weight behind a research project to be carried out within the framework of the Programme of Electrotechnical Investigation (PIE) coordinated by the Office for the Coordination of Electrotechnical Investigation and Development (OCIDE). This initiative was brought to life by the signing of a collaboration agreement between the three electricity companies and
the Spanish National Research Council (CSIC), which was to become the core of the project and absorbed eventually 60% of its funding. Besides the studies conducted by the CSIC, the participating companies also carried out a certain amount of research that fitted in well with the aims of the project, as well as gathering information for and designing the prototypes of the corrective measures that were under study.

The study began in April 1991 with the triple aim of evaluating both quantitatively and qualitatively mortality in birds on power lines, identifying its causes and developing viable solutions that could be implemented on a large number of pylons throughout the country. Most of the fieldwork was contracted out to a consultancy, Asistencias Técnicas Clave S.L. The project was made unique by its ambitious objectives and by the fact that three large electricity companies, scientific institutions and government protection agencies were all committed to working together on a long-term scientific study.

Right from the start and on the basis of knowledge we had garnered in previous studies, we made a clear distinction between two types of problems – collisions with power lines and electrocution on pylons – and studied them independently using appropriate methodological techniques. The work ahead consisted of two phases: the first would involve essentially the quantification of the number deaths of birds on power lines and an analysis of the causal factors in the chosen study areas, while the second would entail an analysis of the effectiveness of measures for mitigating both collisions with power lines and electrocution on pylons.

The electrocution study also involved an additional phase that was not present in the collision study: in the laboratory, we would test bird behaviour and evaluate the effectiveness of different types of anti-electrocution measures, the best of which would be installed on the studied power lines to evaluate their real contribution to reducing accidents. We were unable to set up a similar study for collisions given the impossibility of finding a laboratory in which we could study anti-collision systems in circumstances that resembled natural conditions.

The first phase lasted a year and was finished by March 1993. The following month we launched phase two, which involved installing the first anti-electrocution mitigation measures on distribution lines. This took us in some cases through to February 1994. The final anti-collision devices were installed in October 1994 and the study of their effectiveness, as in the anti-electrocution study, lasted a further year, until February 1995. Each phase of the study meant a year of intense fieldwork, carried out in 1991 and 1992 (first phase) and 1993 and 1994 (evaluation of the corrective measures). Approximately 30 km of transmission lines and over 3,000 pylons on distribution lines were monitored during the study, with controls carried out twice a month in the first phase and every month in the second.

Both the collision and the electrocution studies were conducted in five different areas, some of which were common to both studies. These areas were located in the provinces of Badajoz, Cáceres, Huelva, Sevilla and Navarra, and were chosen due to their bird populations and the type of power lines present.
6. Project PIE: a collision study

Mortality estimates

Even though birds may collide with any type of overhead cable, most collisions take place with transmission lines and, more specifically, with the ground-wires that on many power lines run above the conductor cables (phases). The immediate cause of collisions seems to be the difficulties birds have in detecting in time and then evading these cables. Typically, birds that fly in large flocks at dusk or when visibility is low are the most likely candidates to suffer collisions. Other factors that also affect the risk of collision include the characteristics of the power line itself: the height of the cables, the number of circuits, the number of planes formed by the conductors, and the presence or not of ground-wires. In addition, landscape features can also affect the risk of collision. All these factors were taken into account during the first phase of the study in our attempt to determine with precision the effects of these features on the overall risk to birds.

The aims of the first phase of the collision study included the typification of the selected power lines (nominal tension, height of pylon, number and arrangement of cables, type of habitat and the composition and density of bird flocks) and the obtaining of approximate estimates of mortality rates. In the second phase, anti-collision markers were placed on cables and for a year, we studied whether or not they significantly reduced mortality due to collisions.

The areas chosen for the collision study were as follows (Figure 1):

1. **Valdecaballeros-Almaraz/Morata.**

   Transmission line belonging to Red Eléctrica de España; 400 kV in a double circuit with two ground-wires. Located in the provinces of Badajoz and Cáceres (Extremadura); 20 spans selected (approximately 13 km).

2. **Almaraz-Guadame (embalse de Orellana).**

   Transmission line belonging to Red Eléctrica de España; 400 kV with two ground-wires. Located in the province of Badajoz; 18 spans selected (approximately 10 km).
3. *Foz de Lumbier.*

Transmission line belonging to Red Eléctrica de España; 220 kV with pylons with staggered crossarms and only one ground-wire. Located in the pre-Pyrenees in Navarre; 5 spans selected (approximately 1,000 m).


Transmission line belonging to Iberdrola; 132 kV with two ground-wires. Located in the province of Cáceres in an area with a high density of great bustards; 15 spans selected (approximately 6 km).

5. *Marismas del Odiel (Huelva).*

Distribution line belonging to Sevillana; 13 kV with no ground-wires. Vaulted pylons. Located in the province of Huelva; 10 spans selected (approximately 1,200 m).

Figure 1. Study areas used in the collision study.
All the selected power lines were walked to determine the number of avian victims. Moreover, experiments were carried out to test for the detectability and loss of corpses. In the latter case, one of the monitoring team would plant previously found dead birds at different points of and different distances from the survey route. Another member of the team would then carry out the survey as always – without knowing about the planted birds – and the results enabled us to determine how many corpses were detected by the team during the surveys and how size affected detectability. Surveys in the collision study were conducted in a wide sweep under the cables in which fieldworkers aimed to find remains of birds in a band at least 50-m wide. Censuses of birds flying over the power lines were also conducted to allow us to estimate the collision rate per thousand birds.

After a year of surveying, the power line in Llanos de Cáceres held the dubious honour of harbouring most victims (34 birds died as a result of collision; 5.7 casualties per kilometre of line). Nevertheless, the highest figure per kilometre was in the Odiel salt-marshes, where 19.1 birds/km of line were found dead. Valdecaballeros (1.5 birds/km) and Orellana (1 bird/km) had intermediate values. In Foz de Lumbier, contrary to expectations given the large numbers of griffon vultures flying over the line, no victims were found. In all, 86 birds killed due to collision were found in the study areas (Table 1). Of the victims, 16 dead great bustards were found in Llanos de Cáceres; this species, under threat in Spain and the object of special study, was found to be one of the birds that most often collided with power lines.

Table 1. Collision casualties by species and by area. No casualties were found in Foz de Lumbier.

<table>
<thead>
<tr>
<th>Species/Area</th>
<th>Valdecaballeros</th>
<th>Orellana</th>
<th>Cáceres</th>
<th>Odiel</th>
<th>TOTAL</th>
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<td><strong>TOTAL</strong></td>
<td><strong>19</strong></td>
<td><strong>10</strong></td>
<td><strong>34</strong></td>
<td><strong>23</strong></td>
<td><strong>86</strong></td>
</tr>
</tbody>
</table>
We found no correlation between data from local bird censuses and the number of victims found under power lines; this finding revealed that birds were not dying in the study area as a result of their numbers but, rather, that certain species were more prone than others to collide with power lines. The least liable to collide were raptors and crows, whilst the most likely were great bustards and common cranes (Grus grus). Subsequent analysis revealed that biophysical differences between birds helped explain the results: the larger birds possessing greater wing loads, that is, the least manoeuvrable species, were disproportionately more likely to die due to collision with a power line.

The results of the loss experiments enabled us to estimate that the true number of victims was in fact much higher. At Valdecaballeros, estimates were of 48 birds/km per year, at Orellana only 5 birds/km per year, 171 birds/km per year in the Odiel salt-marshes and 36 birds/km per year in the Llanos de Cáceres. Even so, the number of kills was low in comparison to the annual number of bird crossings per kilometre of line. In other words, most birds are, fortunately, able to avoid power lines. In conclusion, although deaths due to collisions with power lines were relatively infrequent and localized, our results did reveal that the impact of this cause of death can reach worrying proportions at local scale and on occasions may be concentrated in populations of threatened or emblematic species.

**Effectiveness of anti-collision measures**

With the mortality rates for the five sites established, in 1993-1994 the second phase of the anti-collision study got underway: the testing of the effectiveness of the corrective measures. We selected the areas from the first phase of the study that had produced enough victims to ensure that the sample size would be large enough to draw statistically significant conclusions, that is, the Odiel salt-marshes, Valdecaballeros and Llanos de Cáceres. In each area, a single stretch of power line was chosen, consisting of the spans under which most fatalities were found during phase one and which had the most homogenous distribution of collisions. We also established control spans: alternating with the corrected spans we left the same number of spans without marking to confirm that any differences in the results were due to differences in the corrective markings (with or without) and not to any interannual variation in mortality in the area. In all, we marked 14 stretches (4 in Odiel, 3 in Valdecaballeros and 7 in Llanos) and left 16 as controls (4 in Odiel, 4 in Valdecaballeros and 8 in Llanos) as part of the study of the effectiveness of the corrective marker systems.
The aim of the measures employed was to make the cables more visible to birds. The corrective markers used and their positions were as follows:

- **Odiel salt-marshes**: Plastic strips, 70-cm long and 8-mm wide, wound around the central phase and hanging from the central conductor in groups of three every 15 m.

- **Valdecaballeros**: White PVC spiral flight diverters, 30 cm in diameter and 1-m long (“scarecrow” effect) placed in a staggered formation on both groundwires every 10 m to give a visual effect of a warning marking every 5 m.

- **Llanos de Cáceres**: Black neoprene bands (5 x 35 cm), fixed by a polyurethane peg with luminescent stripes, placed in a staggered formation on the external conductors every 20 m to produce a visual effect of a marking every 10 m.

During this second phase and with the aim of increasing the likelihood of detecting differences between the marked spans and the controls in the number of casualties, two changes were made in the surveying methodology. Firstly, the surveys were conducted at one-month and not two-month intervals and, secondly, searches for dead birds were carried out in a 100-m-wide transect area centred on the power line by two observers walking the power line simultaneously in both directions.

To evaluate the effect of the installation of the markers we compared the results for the casualties found under marked spans with those found under control spans, both before and after the placing of the markers.

**Odiel salt-marshes (marker: strips)**

- Casualties on unmarked spans (before-after): 16-12
- Casualties on marked spans (before-after): 1-6

The marking did not alter the danger posed by this line and the number of casualties in fact increased, albeit not significantly, after the placing of the strips.

**Valdecaballeros (marker: spiral flight diverters)**

- Casualties on unmarked spans (before-after): 4-21
- Casualties on marked spans (before-after): 8-4

The marking significantly reduced the danger posed by this power line.

**Llanos de Cáceres (marker: neoprene bands)**

- Casualties on unmarked spans (before-after): 19-16
- Casualties on marked spans (before-after): 15-4
The results for this third corrective measure were not totally convincing; the use of this type of marker did have a positive effect on the number of accidents, although the results were only marginally significant.

Summarizing the results of the experiment, we can draw the following conclusions:

1) Methodological limitations in the design of this type of study may affect the validity of the data obtained. The non-detection of casualties by observers and the loss of corpses to scavengers may cause true mortality figures to be seriously underestimated.

2) The risk of collision is more closely related to the nature of the species present in an area than to the frequency that birds fly (abundance of birds) over the power line.

3) We should talk of dangerous spans or sections of power lines rather than dangerous power lines per se. Collisions are localized phenomena and depend on the presence of susceptible species. It is difficult to evaluate the effect of the technical specifications of power lines on bird casualties.

4) Collisions occur more often in the case of gregarious birds that flock in feeding or breeding areas. The most at-risk species are waterfowl, cranes, storks and great and little bustards, although wintering flocks of passerines and northern lapwings (Vanellus vanellus), for example, are also at risk.

5) For species such as the great bustard death by collision has a considerable impact on their populations.

6) White spiral flight diverters (scarecrows) are an effective measure for reducing the risk of collision. The effect of the neoprene bands could not be properly demonstrated, although there was some indication that they may be just as effective. The strips used in Odiel did not lead to any reduction in bird casualties.
7. Project PIE: an electrocution study

Mortality estimates

As in the collision study, the aim of the first phase of the electrocution study was to determine the relative magnitude of bird electrocutions in areas of the country with different bird communities and pylon designs, and then to try to identify the reasons why the number of causalities continued to build up. Essentially, our aim was to identify the variables relating to pylon design and to habitat that most affected the distribution of casualties. As well, we hoped to be able to determine the relative importance of death by electrocution in different groups of birds since we had seen that the magnitude of the problem varied from one group of birds to another. Some groups of species may be much more affected than others and within these groups some species may be particularly prone to die on pylons. In general, the susceptibility of a species to this kind of accident depends on its behaviour (e.g. use of pylons as perches or for nesting) and its size, as large birds are more likely to be electrocuted.

The study areas were chosen because of the birdlife they possessed and the presence of distribution lines, and all were located in natural areas of great ornithological interest (Figure 1). In each study area, we decided to monitor enough pylons to provide a representative sample of the diversity of pylon types that was present. Thus, the number of pylons to be monitored was calculated in proportion to the number of pylons in the area (but without ever exceeding a figure of 800). The spans and pylons to be studied in each particular area were chosen at random.

1. Doñana Natural Park.

Located in the provinces of Sevilla and Huelva and consisting of the area surrounding the National Park of same name. In all, 800 pylons on a series of 13 kV lines belonging to Sevillana and private owners were selected.

2. Portil Lagoon and Odiel salt-marshes.

Located in the province of Huelva. In all, 256 pylons on a 15 kV grid belonging to Sevillana and private owned were monitored.
3. Sierra de San Pedro.

Mountains situated in south-west Cáceres province and north-west Badajoz province. In all, 586 pylons with nominal tensions of 13 kV and 44 kV belonging to Iberdrola and private owners were selected.

4. Llanos de Cáceres.

This zone in the province of Cáceres was also monitored in the collision study. It is famous for its large flocks of great bustards. In all, 800 pylons on 44 kV and 13 kV lines belonging to Iberdrola and private owners were selected.

5. Monfragüe Natural Park.

Located between the passes of Miravete and La Serrana, this area is one of the most important sites in Spain for threatened birds such as black vulture, black stork (Ciconia nigra) and Spanish imperial eagle. In all, 572 pylons on 44 kV and 13 kV lines belonging to Iberdrola and private owners were monitored.

Figure 1. Areas chosen for the electrocution study.
To estimate mortality rates pylons in the selected stretches were surveyed periodically in search of electrocution causalities. All dead birds found underneath power lines that showed signs of having been electrocuted were counted. In the case of old or scattered remains the smallest number of birds possible were recorded. All remains were collected and sent to the Doñana Biological Station to avoid double counts during subsequent surveys. Surveys were conducted on foot. For each stretch of power line, seven surveys were carried out: an initial cleaning survey followed by six surveys every two months until the end of the study period. Surveys began in September 1991 and finished in November 1992. Tests to detect the number of corpses lost to scavengers were carried out in each locality in order to estimate the true annual mortality of birds.

Given the enormous number of different types of pylons, we decided to establish a synthetic classification based on the following features:

- Function of pylon
- Position of conductors
- Pylon mast material
- Type and position of insulators
- Presence of jumper wires
- Type of crossarm
- Presence, type and position of circuit-breakers

During the study 11 habitat types were selected (eucalyptus plantation, pinewood, Mediterranean forest, closed wood pasture, open wood pasture, uncultivated ground or scrub, non-irrigated crops, irrigated crops, rice-fields, salt-marsh and built-up area). At the same time, raptor censuses were carried out in vehicles (in all, over 1,800 km travelled at a fixed speed of 40 km/h). Results showed that the greatest densities of raptors are found in Monfragüé, (1.381 birds/km), followed by Sierra San Pedro (0.845), Doñana Natural Park (0.795), Llanos de Cáceres (0.607) and, with least density, the Odiel salt-marshes (0.283).

In all, 221 electrocution casualties were recovered, including those found during the initial cleaning survey. Of those, 124 were birds of prey including an imperial eagle in the Doñana Natural Park and 40 common buzzards. Once again, the number of ravens (39) was only exceeded by the number of raptors. No significant relationship was found between survey dates and casualties – as was the case with the collisions – and as such there seemed to be no direct link between density and accidents, probably because the type of pylon, the specific risk it poses to birds and its location are much more relevant factors in the distribution of bird deaths by electrocution.

Estimates of losses to scavengers were very uneven. The speed of disappearance of corpses was greatest in the Sierra de San Pedro; during the monthly surveys we assumed that we only detected 8.5% of all dead birds, whereas in Doñana this percentage was 66.7%. These data underline the importance of
including a loss-to-scavenger factor in surveys of deaths by electrocution on power lines if a true idea of the impact of this cause of death on bird populations is to be estimated.

The total number of birds killed per pylon was highest in Doñana and lowest in the Sierra de San Pedro (Table 1). Results according to habitat are shown in Tables 2-6. As in Doñana, the most altered habitats (Mediterranean forests) were also the most dangerous places for power lines. Results according to pylon design and insulator position are shown in Tables 2-6: once again, pin-type insulators were much more dangerous than suspended insulators, jumper wires below the crossarm were much safer than exposed jumper wires running above the crossarms, and the presence of an exposed circuit-breaker on top of the pylon was found to be very dangerous.

Table 1. Electrocution casualties.

<table>
<thead>
<tr>
<th>Species/Area</th>
<th>Doñana</th>
<th>Cáceres</th>
<th>Monfragüe</th>
<th>Odiel</th>
<th>Sierra de San Pedro</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern goshawk</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Spanish imperial eagle</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Eagle owl</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Cattle egret</td>
<td>8</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Common buzzard</td>
<td>26</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>White stork</td>
<td>8</td>
<td>3</td>
<td>16</td>
<td></td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>Black stork</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Short-toed eagle</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Raven</td>
<td>13</td>
<td>11</td>
<td>11</td>
<td>4</td>
<td></td>
<td>39</td>
</tr>
<tr>
<td>Jackdaw</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Azure-winged magpie</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Peregrine falcon</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Common kestrel</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Griffon vulture</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Bonelli’s eagle</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Lesser black-backed gull</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Black kite</td>
<td>16</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Red kite</td>
<td>13</td>
<td>9</td>
<td>2</td>
<td>1</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Kite sp.</td>
<td>7</td>
<td>4</td>
<td></td>
<td>2</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>Magpie</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Tawny owl</td>
<td>5</td>
<td></td>
<td>1</td>
<td>3</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Spotless starling</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Barn owl</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Northern lapwing</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Unidentified</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>TOTAL</td>
<td><strong>115</strong></td>
<td><strong>42</strong></td>
<td><strong>22</strong></td>
<td><strong>35</strong></td>
<td><strong>7</strong></td>
<td><strong>221</strong></td>
</tr>
</tbody>
</table>
Table 2. Estimated casualties per year per pylon according to type of insulator.

<table>
<thead>
<tr>
<th>Insulator</th>
<th>Average/Year</th>
<th>Nº Pylons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended</td>
<td>0.033</td>
<td>1,460</td>
</tr>
<tr>
<td>Strain insulators, jumper wires below crossarm</td>
<td>0.102</td>
<td>204</td>
</tr>
<tr>
<td>Pin-type</td>
<td>0.305</td>
<td>971</td>
</tr>
</tbody>
</table>

Table 3. Estimated casualties per year per pylon according to crossarm design.

<table>
<thead>
<tr>
<th>Basic types of pylon</th>
<th>Average/Year</th>
<th>Nº Pylons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended insulators</td>
<td>0.032</td>
<td>1,475</td>
</tr>
<tr>
<td>Pin-type insulators</td>
<td>0.381</td>
<td>1,130</td>
</tr>
<tr>
<td>Strain insulators with jumper wire below crossarm</td>
<td>0.120</td>
<td>332</td>
</tr>
<tr>
<td>Strain insulators with jumper wire above crossarm</td>
<td>1.120</td>
<td>52</td>
</tr>
<tr>
<td>Pylon with circuit-breaker on top</td>
<td>0.238</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 4. Estimated casualties per year per pylon according to type of jumper wires.

<table>
<thead>
<tr>
<th>Jumper</th>
<th>Average/Year</th>
<th>Nº Pylons</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Jumper</td>
<td>0.142</td>
<td>2,431</td>
</tr>
<tr>
<td>At least one jumper above crossarm</td>
<td>1.057</td>
<td>190</td>
</tr>
<tr>
<td>All jumpers below the crossarm</td>
<td>0.109</td>
<td>287</td>
</tr>
</tbody>
</table>

Table 5. Estimated casualties per year per pylon according to type of circuit-breaker.

<table>
<thead>
<tr>
<th>Circuit-Breaker</th>
<th>Average/Year</th>
<th>Nº Pylons</th>
</tr>
</thead>
<tbody>
<tr>
<td>No circuit-breaker</td>
<td>0.192</td>
<td>2,779</td>
</tr>
<tr>
<td>Three-conductor circuit-breaker on top</td>
<td>0.238</td>
<td>25</td>
</tr>
<tr>
<td>Three-conductor circuit-breaker on pylon mast</td>
<td>0.177</td>
<td>93</td>
</tr>
<tr>
<td>One-conductor circuit-breaker under crossarm</td>
<td>0.000</td>
<td>73</td>
</tr>
<tr>
<td>One-conductor circuit-breaker above crossarm</td>
<td>0.000</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 6. Estimated casualties per year per pylon according to the material pylons were made of.

<table>
<thead>
<tr>
<th>Pylon material</th>
<th>Average/Year</th>
<th>Nº Pylons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>0.189</td>
<td>1,346</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.223</td>
<td>1,292</td>
</tr>
<tr>
<td>Wood</td>
<td>0.106</td>
<td>376</td>
</tr>
</tbody>
</table>
It is worth highlighting the fact that the difference between the number of casualties accumulated under pylons with dangerous designs and under other designs was greater during the annual surveys than during the initial cleaning survey. One explanation could be that scavengers learn where most bird casualties occur and visit these pylons more often. Thus, our losses to scavengers under dangerous pylons were greater and caused us to underestimate their dangerousness during the single initial cleaning survey.

Laboratory trials

The aim of the laboratory trials was to make an initial selection of the most appropriate ways of preventing birds from being electrocuted on the pylons of the country’s distribution lines. The idea was to test the effectiveness of a wide range of possible solutions for existing pylons, which ideally would be cheap to manufacture and to install since they would have to be installed on a vast number of pylons. Nevertheless, it is worth pointing out that these laboratory trials in no way guaranteed the effectiveness of any particular device since the only real way to judge their success was to try them out in the field. Our experiments enabled us to test many devices in a short period of time and to rule out some that were obviously flawed, thereby reducing the number of trials we would have to carry out in the field. Our experiments were directed towards characterizing the way in which birds use different types of pylons and testing how different devices might affect birds’ use of the potentially hazardous parts of a pylon’s structure.

We had at our disposal a large cage located in ICONA’s bird rehabilitation centre in El Acebuche in the Doñana National Park. Inside we installed two 4-m-high pylons linked by conductors in a single short span, to which we attached different types of crossarms.

To test the effectiveness of the different corrective measures we only modified one of the pylons in the cage at a time, the other being used as a control. Likewise, to eliminate any possible effect on birds’ behaviour of the position of the pylon in the cage, the modifications were tried out first on one pylon and then on the other for equal lengths of time.

Data on the birds’ use of the pylons were collected by filming continually with two video cameras, each one focused on one of the pylons. Recordings were analyzed on a high-resolution screen on which we were able to freeze the images or play the film
at low speed. For each recording period, we noted the following information: species using each pylon, the part of pylon on which they perched, and the time spent on each perch. In the final tests, we used a device developed by Dr. Nuñez de Celis whereby a light would flash if the bird broke an infrared signal on the cable.

The aim of the dissuasive measures placed on the pylons was to make birds change the intensity with which they used the most dangerous parts of the pylons and thus to ensure that the most used parts of the pylon were also the least hazardous. For a particular type of pylon to be considered as successful in the laboratory, we would have to note a significant variation between the modified pylons and control pylons in the birds’ use of the different parts of that pylon.

The birds used in the experiments were red and black kites and common buzzards (medium-sized raptors), common kestrel (*Falco tinnunculus*) (small raptor) and Bonelli’s eagle (large raptor). As well, we occasionally used white storks and short-toed eagles. The birds used were all recuperating in the centre and were all good flyers. Our cage came to be used as a pre-release flight cage for birds that were about to be returned to the wild. In our experiments, we used many birds of the above-mentioned species to lessen the possibility that individual perching choice might affect our results.

Four basic types of pylons were tried out in the laboratory, three with aligned insulators (staggered configuration with suspended insulators, pin-type insulators and a pylon with triangular configuration and pin-type insulators) and one with a three-conductor circuit-breaker on top. In all, we recorded 917 hours 23 minutes of useful film. The basic variable generated was the number of times a bird perched per minute on different parts of the pylon. This variable had a normal distribution and so we were able to apply parametric tests in its analysis (analysis of variance).

Figure 1. Staggered crossbeams with suspended insulators
As a way of studying the possible variation in the frequency of use of different parts of the pylons, a post with staggered crossarms and suspended insulators was considered to have six separate parts (see figure). The overall frequency of use of this type of pylon did not vary between the different species of medium-sized raptors we used. Nevertheless, differences in their use of different parts of pylon did emerge, with the upper crossarm being the most used. When grouping in terms of degree of risk, no differences appeared, which indicates that birds used equally often the outer-most part of the upper crossarm and the part nearest the post, which is the safest. The least used part of the pylon was the inside half of the middle crossarm.

In the case of small raptors, no significant differences were found in the use birds’ made of the different parts of the pylon nor in their use of the more dangerous as opposed to the safer parts of the structure; in fact, smaller raptors used the different parts of this type of pylon indiscriminately. By contrast, both large and medium-sized raptors used certain parts of this pylon more often, the upper crossarm being their preferred perching site. There were no differences in their use of the most dangerous as opposed to safest parts of the pylon. Thus, medium- and large-sized raptors preferred any part of the upper crossarm, while smaller raptors used all the pylon without favouring any particular part.

Figure 1.1. PVC plates

This modification consists of placing 15-cm-high rectangles of PVC at the far end of the crossarms to prevent birds from perching on this, the most dangerous part of the pylon. The results of our experiments showed that in medium-sized raptors this measure had no effect on either which part of the pylons birds perched or on their selection of the more or less dangerous parts.
In this corrective measure a 6-mm-diameter metal bar was placed at a height of 15 cm above and running parallel to the end of each crossarm. The aim of this installation was to stop birds using the end – the most dangerous part – of the crossarm. In medium-sized raptors this bar led to a significant difference in birds’ use of the most dangerous parts of the crossarm since birds perched more often on the part of the crossarm furthest from the conductors and nearest the mast. The same was true for small and large raptors. With the installation of these bars we hoped to achieve an estimated 63% drop in bird mortality; experiments conducted by Iberdrola on vaulted pylons generated similar results.

In this corrective measure, 35-cm-high T-shaped perches were placed directly above the insulators on the far end of each of the three crossarms; our aim was to encourage birds to use these perches instead of the dangerous parts of the crossarms. During the experiment medium-sized raptors showed no preference for the modified pylons as opposed to the control pylons. If we regard the perch as the safe part of the pylon, there were no significant differences between the use of safe or dangerous parts of the pylon as birds often chose to perch on the end of the crossbeams even in the presence of a perch. Thus, despite the non-significant tendency for birds to use the most dangerous parts of the pylon less frequently, this measure was considered ineffective.
This arrangement is similar to the previous modification, but with the perches placed perpendicularly to the crossbar. This measure did not manage to change the frequency with which birds used the most dangerous parts of the pylons and so was ruled out.

On the edges of each crossarm we placed 12, 20-cm-high PVC strips in a comb-shaped arrangement to discourage birds from using the far end – the most dangerous – of the crossarm. During the experiment, medium-sized raptors used the modified and the control pylons with the same frequency. Although there was significant variation in birds’ use of the different parts (both safer and more dangerous) of the control pylon, birds’ use of the most dangerous parts of the modified pylon fell by 74%. In spite of having no effect on electrocution rates in small raptors, our data showed that this corrective measure would lead to a fall of 66% in the use by large raptors of the most dangerous part of pylons.
For the study of different patterns of use, the pylon with staggered crossarms and pin-type conductors was divided up into six zones as in the case of the pylons with suspended insulators. Significant differences in use patterns were recorded: birds preferred the upper crossarm, above all the part nearest the post, whilst the least-used part was the inner part of the middle crossarm. In total, 63% of the birds that used the outer-most part of the upper crossarm perched on the insulator itself.

This dissuasive measure, aimed to stop birds from perching on the most dangerous parts of the pylon, consisted of a 50-cm-long metal bar with three insulated, vertically projecting 40-cm-long comb-like ‘teeth’. The ‘comb’ was placed at an angle of 60º to the crossarm, 20 cm from its end. No differences in use patterns were detected compared to the control pylon, and the use of the most dangerous parts of the pylon also remained unchanged. Birds still used the insulator as a perch and the ‘comb’ did not prevent their wings and tails from coming into contact with the crossarm. This measure, thus, was considered to be inadequate.
This design was similar to the previous one, with the difference that the bar with the ‘teeth’ was placed parallel to the crossarm. Once again, there was no change in use intensity compared to the control pylon. Unfortunately, neither were there any changes in the use of the most dangerous parts of the pylon and so this measure was also ruled out as being unsuitable.

This corrective measure consisted of small right-angled triangles (30 cm at the base and 50 cm high) placed at the outer-most end of the crossarm next to the insulator. Triangles were smooth, made out of PVC and placed with their right angles near the base of the insulator. After installation, use patterns did change and, compared to the control pylon, birds used the modified pylon significantly less. Nevertheless, significant differences in birds’ use of the most dangerous parts of the pylons were not recorded; the only change was that, with the triangles in place, birds perched more often on the insulator and so risked contact between wings and tail and the crossarm. Thus, this measure alone was not considered to be recommendable.
This corrective measure belongs to a different group of proposals from those described so far. Its objective was not to change birds’ perching habits but, rather, to make their perches much safer. The prototype consisted of a PVC tube, moulded to fit the upper part of the insulator, which would also cover the cabling on either side (40 cm on each side of the insulator). No change in birds’ intensity of use of the modified pylon compared to the control pylon was detected; neither were any differences in birds’ preference for insulators with tubes or without noted. Thus, the effectiveness of this system will depend on factors that were not analyzed during the experiment such as the weather-resistance of the tubes and their capacity to act as insulators. If these additional considerations can be resolved satisfactorily, this corrective measure is recommendable.

This measure consists of another PVC tube but, in this case, one that fits over the crossarm and juts out 10 cm beyond its outer-most part. To enable its installation without having to dismantle the insulator (in other words, to enable the tube to be placed without de-energizing the line), the tube is split longitudinally and has a small slit that fits around with the base of the insulator. The prototype of the tube measured 70 cm in length. No change in the intensity of use between the modified and control pylons was detected, nor in the use of the different parts of the pylon (with or without the protective device). As in the case of the previous measure, the success of this tube depends on the durability and insulating capacity of the material used; if sufficient, this is also a recommendable corrective measure.
This dissuasive measure consists of small, 30-cm-high perches placed parallel to the conductors at the outer end of the crossarm. A strut runs from the top of the perch to the base of the crossarm. Each crossarm has a perch with a strut. No differences in the intensity of birds’ use of the modified pylon compared to the control pylon were noted. The only difference detected in birds’ use of the different parts of the pylon was that birds tended to perch more often on the insulator than on the outer-most end of the crossarm. As a result, this corrective measure alone is not considered sufficient.

This measure is a combination of the two previous devices and aims to solve the problems arising from the use of the triangular perch guards alone, which, as we describe above, still allow birds perched on the insulator to touch the crossarm. This combination allowed birds to use the insulator more often since the protective tube prevented birds earthing themselves via the crossarm. If the tube’s insulating properties are adequate, this combination is recommendable.
Given its bilateral symmetry, this type of pylon was divided into three parts for the study of possible variations in the frequency of use of different parts of the structure. Significant differences were found in birds’ use of different parts of the pylon since there was a clear tendency for birds to use the top of the central mast of the pylon, followed by the outer-most parts of the crossarms, that is, the most dangerous parts of the pylon. When on the outer part of the pylon, most birds chose to perch on the insulators.

This corrective measure consists of PVC tubes and a PVC plate. The tubes were 70-cm long and were designed as in a previous experiment to fit snugly around the base of the insulator. The plate was placed underneath the insulator on the central phase and projected 5 cm from around the central mast to prevent birds perched on the insulator of the central phase from earthing themselves. Birds’ intensity of use did not differ in comparison with the control pylon and their use of different parts of the pylon likewise did not vary. Once again, as in all corrective measures making use of insulation, if the material is of sufficient quality, this corrective measure is recommendable.
This measure did not affect birds’ use of pylons and there were no differences in the use of different parts of the pylons. Thus, this corrective measure is not recommended given that the struts did not lead to a reduction in birds’ use of the most dangerous parts of the crossarm.

This corrective measure is similar to but easier to install than the measures incorporating PVC tubes. Results were also similar and, once again, if the basic product is appropriate in terms of its resistance and insulating properties, it is recommendable.
Given the exceptional danger that this particular design supposes, our study of the effectiveness of corrective measures were designed to prevent birds from perching on this type of pylon, or to provide an alternative and safer perching site. In the initial tests, birds tended to use the cables projecting above the central part of the pylon most of all, followed by the porcelain insulators, and used the external part of the structure least.

This dissuasive measure consists of a series of white PVC rods fixed with clips to the pylon’s upper framework where the circuit-breaker is located. The rods project vertically above the wire loops of the circuit-breaker by 40 cm. During the experiments, there was no fall in birds’ use of the modified pylon and so this measure is not recommendable.
Figure 4.2. Group of multi-coloured PVC rods

This corrective measure is the same as previous example but incorporates coloured rods with black-and-yellow bands designed to provide a more pronounced dissuasive effect. Nevertheless, results were similar to the previous design and so this measure is not particularly recommendable.

Figure 4.3. Insulating covering

This corrective measure consists of a rigid PVC covering, the same size as the pylon’s upper framework, attached by rigid legs in each corner to the upper-most part of the pylon. The covering is situated at the minimum height that still enables the circuit-breaker to operate without risk. Taking into account the frequency with which birds perched on it, we estimated that this measure would lead to a reduction of 94% in the risk of electrocution.
The object of this experiment was to determine whether or not the risk to birds of a new design known as quincunxes or ‘Canadian’-type pylons was less than the best of the tested pylons (staggered crossarms with suspended insulators). In this new type of pylon, the insulators are staggered and suspended, but the crossarms are placed at an angle. When testing this design we used the classic staggered arrangement as a control pylon and results showed that birds used both designs with the same frequency and had no preference for either one. Nevertheless, on the new design raptors used the safer parts of the pylon more often and in this sense the differences with the classic design were highly significant. The new design was thus safer and turned out to be the safest of all the pylons we tested. Its safeness seems to depend on the degree to which the crossarm is tilted and, above all, whether or not the top-most part of the whole structure projects above the upper crossarm.

Effectiveness of anti-electrocution systems

The main aims of Project PIE were to develop measures for correcting the impact of power lines and then to assess their true effectiveness in field trials. In the first phase of the electrocution study, we identified which aspects of pylon design were key in explaining risk to birds, whilst in the second phase we carried out laboratory tests aimed at selecting with a degree of confidence which corrective measures were going to be tried out in the field with energized power lines. Despite the usefulness of these tests, only after trials in the field would we be able to confirm that our pro-
tection systems had led to a reduction in bird mortality. The third and final phase of the electrocution study were the field trials.

Of the 3,014 pylons analyzed during the first phase of the Project, around 500 were selected to test the effectiveness of the anti-electrocution measures in the field. The sample size – in other words, the minimum number of posts required to detect hypothetical reductions in bird mortality as a result of applying corrective measures – was calculated on the basis of the observed mortality for each type of post and habitat. We estimated the minimum sample size needed to detect significant differences of over 70% in the average number of deaths before and after the installation of the protective devices. For our calculations, we assumed a Type I error of 5% (\(\alpha = 0.05\)) and a Type II error of 5% (\(\beta = 0.05\)), as well as a homogeneous interannual distribution of deaths. The lower the mortality on a pylon, the greater the sample size needed to detect significant differences given the established error values. We chose those stretches of power line that had sufficiently large numbers of pylons, as well as the highest average values and the least variance. In general, the stretches that fulfilled these criteria were those located around Doñana and in the Odiel salt-marshes.

The selection of the pylons for the trial was based on their design; some of the pylons would be corrected and others would be left as controls to rule out the possibility of interannual variations. Most of the modified pylons were in Doñana (232), Odiel (11) and Llanos de Cáceres (28). The control stretches were chosen for their proximity to the corrected stretches. Both sets of power lines, corrected and non-corrected, were monitored once a month to estimate mortality rates.

In general, we used three types of corrective measures: insulation on the conductors, insulation on the crossarms and dissuasive measures (perch guards) to stop birds perching. On the pylons with suspended insulators we used strips, triangles and bars; on pylons with pin-type insulators we used insulating sleeves and geosynthetic materials to insulate the crossarm, along with plates under the insulators on the central phases; on pylons with jumper wires suspended below the crossarms we used plates; on pylons with jumpers above the crossarms we insulated cables with sleeves; and lastly, on pylons with circuit-breakers on the upper-most part we used various types of white PVC rods.

To study the effectiveness of the measures we compared the number of casualties found under each post before and after the installation of the corrective measure, as well as the number of dead birds found under corrected pylons and control pylons. On average, we checked 388 pylons per month.
Results of the corrective measures by type of pylon

1. Suspended insulators
   - Type of pylon: staggered
   - Corrective measure: triangle, strips and rods (analyzed together given the small number of casualties)
   - Casualties on control pylons (before-after): 0-2
   - Casualties on corrected pylons (before-after): 3-1
   - Not significant
   - Reduction in the accumulation slope of 50%

2. Pin-type insulators
   - Type of pylon: aligned
   - Corrective measure: rigid insulating sleeve
   - Casualties on control pylons (before-after): 7-12
   - Casualties on corrected pylons (before-after): 7-1
   - Significant reduction
   - Reduction in the accumulation slope of 84%

3. Pin-type insulators
   - Type of pylon: aligned
   - Corrective measure: insulating blanket on crossarm and plate under central phase
   - Casualties on control pylons (before-after): 7-12
   - Casualties on corrected pylons (before-after): 7-1
   - Significant reduction
   - Reduction in the accumulation slope of 84%

4. Strain insulators with jumpers below crossarm
   - Type of pylon: staggered with strain insulators
   - Corrective measure: plates
   - Casualties on control pylons (before-after): 0-3
   - Casualties on corrected pylons (before-after): 1-2
   - Not significant
   - Reduction in the accumulation slope of 0%

5. Strain insulators with jumpers above crossarm
   - Type of pylon: aligned
   - Corrective measure: insulated cover on jumpers and plates on crossarms
   - Casualties on control pylons (before-after): 5-13
• Casualties on corrected pylons (before-after): 16-2
• Significant reduction
• Reduction in the accumulation slope of 91%

6. Circuit-breaker on top
• Type of pylon: circuit-breaker
• Corrective measure: bars
• Casualties on control pylons (before-after): 1-5
• Casualties on corrected pylons (before-after): 1-4
• Not significant
• Reduction in the accumulation slope of 0%

The placing and testing of the anti-electrocution measures was carried out satisfactorily. Some of the corrective measures were shown to be effective, whereas others were found to be of no use. In general, the dissuasive measures on pylons with staggered alignments had little effect and our results indicate that a generalized modification of this type of pylon with these dissuasive measures would not be recommendable (other than in the case of certain specific types of pylon that are a threat to large raptors). Pylons with a staggered alignment and suspended insulators are intrinsically safe and mortality rates are low; as such, it is perhaps better to invest time and money in the modification of pylons of other designs that represent a true threat to birds.

The insulation of jumper wires passing above the crossarms (pylons with a projecting central mast, for example) is an efficient corrective measure. On the other hand, as the laboratory tests revealed, the placing of dissuasive rods on circuit-breakers situated on the top of pylons had no effect. Corrective measures placed on pin-type insulators were highly effective in reducing bird mortality. Pylons with circuit-breakers on top can be modified by moving them to the side of the pylon mast and by ensuring that no exposed jumper wires run above the crossarm. Bearing in mind the threat that this type of pylon poses to birds and the fact that relatively few such pylons exist, this measure – despite its cost – is undoubtedly the best solution for this pylon design.

The results of the post-modification surveys revealed a surprising relative increase in the number of small birds found dead under corrected pylons as opposed to non-modified pylons. Nevertheless, this result agrees intuitively with the laboratory tests with birds of different sizes since we noted that small birds use pylons – above all, the lower crossarms – in a different way to the medium-sized and large birds. The corrective measures tested are possibly more effective for medium-sized and large birds and so, in cases in which smaller birds are under threat, a more complete type of protection will have to be installed on pylons.
The main conclusions of the electrocution study can be summarized as follows:

1) The way in which casualty searches are undertaken may affect the validity of the data obtained. Thus, the results of a single ‘cleaning’ survey do not provide a good basis for an estimate of annual mortality, although they do reveal where the blackspots on the distribution grid are.

2) Comparisons of mortality rates between different areas are only valid if estimates of the number of corpses lost to scavengers are available.

3) Raptors and corvids are the two bird groups that are most likely to be electrocuted on pylons. Within these two groups, accidents occur at different rates, which are determined by the size of the bird and how it uses the pylon.

4) Bird abundance in the area around power lines does not have a direct effect on casualty numbers, which depend more on the type of birds present and the technical design of the power lines.

5) Variations detected between habitats in bird mortality are due to differences in the composition of bird communities and the density and activity of scavenger communities.

6) Exposed jumper wires above crossarms and pin-type insulators are the two most dangerous elements in pylon design.

7) The design of the upper-most part of the pylon may have little effect on mortality rates once the above-mentioned factors have been corrected.

8) Although the type of material used in the construction of the pylon itself does influence mortality, it is a less relevant factor than the arrangement of the energized elements above the crossarms.

9) Unlike dissuasive measures, which have little or no effect, the installation of anti-electrocution measures to insulate conductors is a very effective way of reducing the number of casualties. The insulation of crossarms is a good alternative to the insulation of conductors.
8. Project PIE: conclusions and beyond

The conclusions we drew from this long period of research became an indispensable point of reference for decades in the execution of bird conservation projects designed to reduce the threat posed by existing power lines, as well as in the design of new power lines and the drafting and application of new legislation. Our studies gave rise to many scientific (Janss and Sánchez 1997, Janss 1998, Janss and Ferrer 1999, Janss et al. 1999, Janss and Ferrer 1999, Janss 2000, Janss and Ferrer 2000, Janss and Ferrer 2001) and general publications (Ferrer et al. 1993, Janss et al. 1996), papers presented at congresses (Ferrer et al. 1993, Janss and Sánchez 1994, Ferrer and Janss 1996, Janss and Ferrer 1996a; 1996b, Janss et al. 1996, Janss 2000), books (Ferrer and Janss 1999), technical manuals (Technical manual, 1996) and even a doctoral thesis read at the University of Utrecht (the Netherlands) (Janss 2001). During Project PIE over 21,000 pylons and 520 spans (the stretch of line between two pylons) were checked throughout the whole of the study area, which works out at a total of 10 million square metres of land searched for collision casualties! It was – and still is – the most ambitious and rigorous project ever undertaken worldwide on the effect of power lines on birds. Thanks to the collaboration between all the various parties involved, the project culminated successfully in 1995 and, for the first time ever, all those affected directly or indirectly by this problem in Spain and beyond had at their disposal a trustworthy standard for finding the optimum solutions in each particular set of circumstances.

Of all the factors affecting electrocution in birds the most important are the technical characteristics of the pylons themselves. The evaluation of the scale of the problem and the use of all the accumulated data relating to accidents on certain types of post were hampered by the lack of any standardized pylon design. Within the study area alone we identified over 800 different types of pylons and the subsequent analysis revealed which aspects of their design were most relevant to bird mortality rates. The material out of which the pylons were constructed, the arrangement of the insulators and the presence of jumper wires above the crossarms were shown to be the most determinant factors in levels of risk. Wooden posts without earthing cables were much safer than metal-strut pylons; pin-type insulators were much more dangerous than suspended insulators and their presence often converted pylons into veritable death-traps; and exposed jumper wires above the crossarms, whether on standard pylons or on circuit-breakers, caused extremely high electrocution rates.
Other characteristics of the pylons such as the arrangement of the conductors, the presence of jumper wires below crossarms or circuit-breakers on the main pylon mast have less effect on the danger posed by a pylon. Thus, a pylon possessing some of the most dangerous characteristics can kill up to 35 times more birds than the estimated number for a similar pylon without these characteristics.

The analysis of the risk of electrocution as a product of pylon design enabled us to classify all known designs according to their level of risk. This classification would turn out to be highly useful in the initial analysis of distribution lines and in their eventual correction.

The project also revealed that there was no clear link between bird densities and the number of accidents, in both electrocution and collision, although the existence of such a relationship cannot be totally ruled out since, for there to be accidents, there have to be birds. The fact of the matter is that there are factors besides variations in local bird densities that influence to a much greater extent the number of accidents: in a site with many raptors and safe pylons there are many fewer accidents than in other areas with fewer raptors but with dangerous pylons.

The laboratory tests with captive birds were reinforced by the field tests in which the corrective measures were installed and studied for real. Even some of our more subtle findings, such as the fact that the installation of some corrective measures would mean a relative increase in the number of electrocuted medium-sized raptors, were confirmed by field data. This confirmed that our original and robust methods could be used under laboratory conditions to test quickly, precisely and cheaply the risk posed to birds by any new pylon design or device. Our laboratory trials showed that in single-circuit lines the staggered alignment with suspended conductors and, above all, the new Canadian-type pylons (suspended insulators on staggered but tilted crossarms) are overall the safest for birds. We were thus able to identify which pylon designs will minimize the risk of electrocution in new power lines.

In general, anti-electrocution measures aimed at insulating energized elements give better results than the dissuasive techniques whose aim is to make perching more difficult. Insulation on crossarms and conductors and on pylons with pin-type insulators, as well as on all of the circuit-breaker structure on pylons on which triple-conductor circuit-breakers are placed on top of the structure were found to be the most effective of all corrective measures. Even so, anti-electrocution measures were not uniformly effective for all species and mortality on corrected pylons in small raptors was reduced less than in large birds. The resilience of the implemented measures depends on the durability of the material used and the continued performance of insulating devices. It is thus very important to establish monitoring and control protocols to guarantee that the desired effects of the implemented measures are fulfilled, and to use wherever possible materials and devices that are not likely to degrade or fail.
Work carried out on the collision risk demonstrated that the overall incidence of transmission power lines on birds was proportionally low, very localized and easily resolved by the marking of earth cables and conductors. Such power lines seem to have the greatest impact on populations of certain species that are more likely to suffer this type of accident. The results of our study showed that, while some species suffer few collisions (e.g. raptors and corvids), others are much more susceptible (great and little bustards, common cranes, greater flamingos, black-winged stilts and certain wildfowl species) due to their way of flying, size and gregarious behaviour, or their habit of forming large flocks around breeding or feeding sites. Of the three anti-collision measures tested, the placing every 10 metres of white, 30-cm-diameter spiral flight deflectors in a staggered formation on power lines turned out to be the most effective corrective measure.

Our research involved a specific methodology for identifying the incidence of power lines on birds that included specially designed surveying techniques and rigorous scientific treatment of the data generated by the fieldwork. We managed to characterize how birds die, determine how many die and identify which species and groups of birds were most at risk. We also analyzed the influence of a number of factors on mortality rates and tested a whole series of corrective measures that enabled us to choose, finally, which were the most effective. For all these reasons, our results and proposals are a basic point of reference for any future work in this field.

Limiting our studies to protected natural areas and the emphasis put on endangered, threatened and protected species does not diminish the value of our work since our results can be applied to any natural area or any group of birds. Our work has been of great use to government conservation bodies, conservation NGOs, electricity companies and the companies that install power lines for private clients, who have all derived from our conclusions reliable, low-cost solutions for nullifying or mitigating the impact of power lines on birds, and, at the same time, have solved problems relating to the operation and maintenance of power grids.

Before our study, many of the actions undertaken to protect birds from the impact of power lines had no prior basis that guaranteed that the corrective measures they were advocating would work. This uncertainty led to continual delays in their installation. The effectiveness of commercially available anti-electrocution measures are debatable, while most of the other proposed solutions such as the burying of lines or the use of bundled cables are either too complex or too expensive.

At the beginning of our laboratory tests on the effectiveness of anti-electrocution systems, an engineer from one of the electricity companies participating in the project – undoubtedly convinced that in Spain nobody ever invented anything, and that everything had already been invented by somebody from a different country – arranged a meeting with the French company EDF, who had just published a glossy brochure of their anti-electrocution systems for birds. During EDF’s presentation of
their products, I asked on how many pylons they had tested the effectiveness of their systems and what was the resulting decrease in the percentage of birds killed. The French engineer looked at me in surprise: in his opinion, as they were selling ‘solutions’, there was nothing to test. They worked, end of story. One of their star products were white PVC strips that could be placed on circuit breakers located on the top of pylons; however, when we used them in the field there wasn’t the slightest reduction in bird mortality on this dangerous type of pylon.

By contrast, the systems proposed by Project PIE were simple, demonstrably effective and cheap, which meant that, cost- and time-wise, they could be installed on a large number of pylons relatively easily. The protection prototypes we tested were designed for use on all existing lines regardless of the type of pylon.

The electric companies behind the investigation adopted our preliminary conclusions even before we had finished our study. Their power lines are today some of the safest in Spain, a fact that contrasts with the high risk of privately owned lines. The resolution of this problem required government intervention, and local government bodies had to enforce the installation of safe designs on new lines and encourage the modification of existing lines. To this end, the Manual for the Evaluation of Risks and Solutions, one of the end-products of Project PIE, was – and still is – the basic reference document in which the most appropriate solutions for each type of pylon are to be found.

One of the most important conclusions of the project was that the majority of accidents occurred on just a few pylons (electrocution) and spans (collisions). The information we generated enabled us to identify in theory the potentially most dangerous pylons, propose the most appropriate modifications and predict the fall in mortality rates that would occur as a result. Before our study, such predictions would have required months of work and considerable effort but now this was possible with just a few surveys and at relatively low cost. For example, let’s take the case of a natural park of great ornithological interest in which the local power lines are thought to have a serious impact on bird life. The conclusions of our research applied to this hypothetical case would enable us to predict a drop by 40% in bird mortality after the installation of corrective measures on just 10% of distribution lines, and a drop of 80% with a modification of 20% of pylons. It would be possible to say which pylons would have to be modified in order to reach these figures and which measures would have to be applied in each case.

The results of Project PIE made it clear that accidents tend to be contagious. Fortunately, most deaths occur on just a few pylons and on the remainder there are never any casualties. Technically speaking, the occurrence of deaths on pylons is not homogenous in distribution; it does not have a normal distribution but a Poisson distribution, also known as the law of rare events. This is good news from the point of view of mitigating the problem since it means that by modifying a small fraction of pylons we can reduce mortality rates very significantly. We also illustrated two
other key aspects of the question in relation to solutions: firstly, the distribution of deaths is stable from one year to the next as the same pylons always cause most of the deaths and, secondly, the basic factor influencing the risk of death in birds is pylon design and, more specifically, certain aspects of their design. These findings enable us to determine theoretically the expected distribution of casualties on any distribution line. We may not be able to estimate the real mortality rates of power grids but we can estimate, nevertheless, how casualties will be distributed between different pylons and so can know by how much each corrective measure will reduce the overall number of deaths (Fig. 1).

Figure 1. Accumulated reduction in mortality in a distribution line network if pylons to be corrected are selected according to the risk they suppose.

Unfortunately, as on other occasions, our results were not implemented everywhere. Some autonomous communities with imperial eagle populations decided that the funds available from a recently awarded European LIFE project, in which there was a provision for correcting power lines, would be best employed following the recommendations of a certain employee of ICONA, that is, only the pylons where an eagle had already died would be corrected. It seems incredible now, but for years eagles continued to die on pylons, thereby drawing attention to the most dangerous
structures, which could have been corrected before if the recommendations of Project PIE had been followed. As further evidence of this disdain, it is worth recalling that, when the electricity companies behind Project PIE had to protect their power lines at the start of the study of the effectiveness of the corrective measures (which coincided with the awarding of the LIFE project), we tried to optimize our efforts by calling a meeting between the companies and the departments of industry of the autonomous communities with imperial eagles. The idea was to foster mutual knowledge in business and conservationist circles and analyze ways of using existing resources to smooth out the process of correcting power lines. This was how I made my pitch to the representative from ICONA who was in charge of the conservation of the imperial eagle. He agreed and we set a date for a meeting in Doñana. All of the implicated autonomous communities consented to attend (Madrid, Castilla la Mancha, Castilla León, Extremadura and Andalusia), as well as ICONA’s representative. However, come the day of the meeting, neither ICONA nor any autonomous region other than Andalusia sent a representative to the meeting, which was attended by all the companies and the Ministry of Industry. Later on, we found out thanks to a rather indiscreet fax that the autonomous communities had boycotted the meeting because ICONA, the provider of the LIFE funds for correcting pylons, had insisted that they confirm their presence at the meeting but that they should not attend. This was the saddest failure that I have ever had in my dealings with those in charge of our natural heritage, supposedly the natural allies of scientists. Up to that point, I firmly believed that, despite our differing opinions, we had similar objectives. But then I came to the conclusion that we had different opinions precisely because our aims did not coincide. We were interested in stopping eagles from dying – they were only concerned that it wasn’t us who did so.

Nevertheless, some of Project PIE’s recommendations were put into practice almost immediately in large areas of Spain. In October 1994, Iberdrola, one of the participating companies, decided to implement the measures aimed at reducing imperial eagle mortality in south-west Madrid. Despite being somewhat patchy, the relevant data were worrying. Electrocution in this area, as we had seen in other areas, was the main cause of death in imperial eagles. The company had already contracted a foundation to analyze the data and propose solutions. Nevertheless, their proposals did not satisfy Iberdrola since once again they merely involved installing perches or insulating material on those pylons on which an eagle had died. Iberdrola decided to employ our methodology to determine which were the most dangerous points in the whole of the electricity grid in south-west Madrid and apply wherever appropriate the corrective measures that had been shown to be successful. They contracted the CSIC and Clave SL, the consultancy that had worked on Project PIE during the fieldwork for our study, on the understanding that they would use our methods. In all, 19,057 pylons were characterized on over 200 distribution lines. This information enabled priorities to be established that coincided with proposals for optimizing investment and so the corrective measures that would reduce most mortality within viable financial limits were put forward. In the end, the work carried out by Iberdrola in south-west Madrid aimed at reducing
mortality in imperial eagles was based on this proposal. From then onwards, the number of electrocuted imperial eagles fell significantly.

Nevertheless, despite its importance for imperial eagles, due to its singular position of belonging to the state and depending on the Royal Family, we were not able to gain access to Monte el Pardo for a further couple of years. In 1996 at a reception organized by Juan Carlos I for the board of Doñana National Park, headed in those days by the Minister of the Environment, Isabel Tocino, the King asked me about the situation of the Spanish lynx and the imperial eagle in Doñana. I replied by explaining the excellent results of the adoption of corrective measures on power lines and went on to add that the only place we hadn’t been able to enter was El Pardo, despite being home to one of the world’s most important populations of imperial eagles. The King’s answer came in a low voice, ‘Send me a letter tomorrow explaining all this’ – which, I did and barely a week later I received an invitation to attend a meeting on the subject in the Palacio Real in Madrid, along with representatives of the State Heritage department. The representative of Royal Family explained to me that he had been asked to find out more about the subject since, as predicted, birds died frequently on the power lines in El Pardo. Nevertheless, the financial resources of State Heritage were insufficient to change all the power lines in the area at once, as they would have liked. I made it clear that the correction of the power lines would not necessarily be that traumatic; rather, all we had to do was identify the most dangerous pylons and modify them. As well, I added, I thought it might be possible to find financial support for the work to be done.

After the meeting, I got in touch with the people in Iberdrola who had recently worked on the improvements in power lines in south-west Madrid and explained how the meeting had gone. Iberdrola offered to correct the necessary pylons for nothing. We carried out the study of the pylons and made the appropriate recommendations for modifications. Thanks to this work, the power lines in Monte el Pardo stopped gathering their tributes in the form of electrocuted imperial eagles and today this population has the greatest density of imperial eagle pairs anywhere in the world. We must be thankful to Iberdrola, for without their altruism this would not have been possible.

Besides Iberdrola, we should highlight the role of the Department of the Environment of the Andalusian government, whose work affected a much greater surface area. Whilst other autonomous communities decided to ignore the scientific advances in the solution of this type of problem proposed in Project PIE, Andalusia used the funding from the LIFE programme to determine which pylons were the most dangerous in juvenile imperial eagle dispersal ranges and in Andalusian natural parks. The aim was to calculate the relative contribution of each type of pylon on the distribution grid to the overall mortality by electrocution of birds in the study area. The result would be a project whose outcome would optimize decision-making and investment of funds aimed at reducing the impact of power lines. With this information and the help of a number of computer programmes, Andalusia decided where
to invest the LIFE funds to obtain the best possible results from a point of view of reducing death by electrocution in raptors in general and in the imperial eagle in particular.

Thus, in the period 1992–2009 6,560 pylons with dangerous designs were corrected throughout the whole of Andalusia, leading to spectacular results in imperial eagle survival rates, as we shall see below.

For many years, the autonomous communities that had followed the dictates of ICONA continued to watch as their imperial eagles died unnecessarily. Meanwhile, the other communities such as Andalusia that applied the results of Project PIE to predict the distribution of deaths and to optimize mitigation procedures witnessed a spectacular drop in mortality due to electrocution and, as a result, the largest ever recorded growth in imperial eagle populations (21 to 71 pairs in just 15 years). As always, time puts things in their place.
9. Results of the protection of power lines

After developing effective corrective measures and a methodology for selecting on which pylons they should be implemented, and, above all, after having applied both in large parts of Spain, the next step was to ask what effect all this has had on our bird life. Do our results justify all the effort we put in?

The reply to this question is not easy. For a start, to be able to respond with confidence and precision we would have to monitor mortality before and after modifying power lines in all the areas we implemented corrective measures and in all others in which we didn't. We would have to use objective methods regarding the locating of casualties (for example, radio-tracking, in which the probability of locating dead birds does not depend on the cause of death) and do so for a number of different species. Nevertheless, in the absence of such studies we can use other types of estimates and the specific case of the imperial eagle, probably the rationale behind the majority of corrective measures implemented in Spain and a species for which we do have sufficient high-quality information to evaluate the effects of our efforts on species survival.

One way of compensating for a lack of data is to calculate the estimated fall in mortality rates in areas in which pylons have been corrected. In the case of the Doñana National Park, we have already commented that the elimination of unnecessary power lines and the placing of bundled insulated from the rest of the pylon reduced mortality rates amongst juvenile Spanish imperial eagles in their first six months of life from 82.4% (before the corrective measures) to 20% (afterwards), that is, a reduction of 75.5%. We should point out that here we are referring to total mortality and not just to that caused by power lines. These data are based on radio-tracked birds that we monitored during my doctoral thesis, which is a suitable source of information as it is not affected by bias in the cause of death. This enormous increase in juvenile survival rates was without doubt the most effective conservation measure implemented for the species up to then. As a result, in the following years, density and fecundity levels in the Doñana population of imperial eagles reached record highs. The percentage drop in mortality was spectacular and, since the contribution of electrocutions to the total number of deaths also fell, the differential mortality by sex that it caused also dropped, thereby also diminishing its effects on this small, monogamous and relatively isolated population of eagles.
If we assume that the correction of the distribution lines in Doñana reduced by 95% the number of deaths of birds by electrocution, from now on in Doñana and its surrounding area, where 6,000 birds had once died each year, 5,700 birds would be saved from death on a power line every year. Of these, 1,100 were raptors and, in the case of the black kite, annually around 500 birds would be spared a tragic death. After disconnecting the Matasgordas line, the most deadly of all those we studied in Doñana and alone responsible for 45% of deaths, the black kite population that breeds near this power line doubled from 200 to 400 pairs in just four years.

According to data from Project PIE, the fall in mortality by collision fell by 90.5%. In the case of the power line in the Odiel salt-marshes, the data generated by the loss and detectability studies suggested that 171 birds were killed by collision on every kilometre of this line annually. With the corrective measures in place (for example, white spiral flight deflectors), we would prevent around 150 birds from dying per year on every kilometre of power line we marked.

Yet, aside from its direct effect on bird populations due to the loss of individuals or differential death rates between the sexes, casualties on power lines also had more subtle effects that altered the distribution and density of affected species (Sergio et al. 2004). In a study conducted using information on the mortality and distribution of the eagle owl in Italy, we compared estimates for the risk of electrocution in territories occupied by the species with those that had been abandoned or were only infrequently occupied. We found significant differences between both groups of territories in terms of the risk of electrocution, which was greater in those areas in which territories were frequently abandoned. We were also able to show that the high risk of electrocution was associated with a continual negative tendency in population numbers. We estimated that 17% of young eagle owls were killed on power lines every year. The species’ breeding density was negatively correlated with the risk of electrocution and hence led to variations in density that did not correspond to aspects of habitat quality.

How protecting power lines has affected survival in the Spanish imperial eagle

The most studied case of how large-scale modifications to the electricity grid have mitigated the effect of electricity infrastructures on birds is probably that of the imperial eagle in Andalusia. This shouldn’t come as any surprise since, if you have read this far, you will already know that this species was the inspiration for all the studies,
transformations, protective legislation, corrective measures and then the implementation of these measures on power lines throughout Spain.

It was by studying mortality rates in this species that we were able to calculate electrocution rates, which are fortunately not distributed randomly between pylons but, rather, follow a Poisson distribution whereby just a few pylons are the scene of most electrocutions. Knowledge of the causes of the risk enabled us to protect large stretches of power lines just by correcting a small percentage of pylons, which was enough to generate highly significant drops in mortality.

The electricity grid has not stopped growing in the last 50 years and will probably continue to expand in the near future. By correcting the power lines in Doñana we learnt that, when a locally important factor in mortality such as electrocution is identified, it can be completely corrected — or at least reduced significantly — through appropriate action. But, at a much greater scale — is it possible to correct or at least reduce significantly mortality on power lines in an area as big as the whole of Andalusia? Said in another way, can we really hope to resolve the problem posed by the enormous number of existing power lines whose most dangerous pylons are hidden away amongst thousands of relatively innocuous structures?

Below, we will see that this problem does have a solution and how the modifications implemented in Andalusia have led to positive tendencies in the demography of the imperial eagle. With the installation of corrective measures in Andalusia, imperial eagle populations moved from a worrying state of stagnation (or even decline) to one exhibiting a continual increase in population numbers that has been sustained since power lines were corrected in breeding and juvenile dispersion areas.

As we have already commented, the Spanish imperial eagle is a long-lived sedentary species that breeds in trees. Its ancestor and that of the closely related eastern imperial eagle (*Aquila heliaca*), reached the Iberian Peninsula 980,000 years ago during the first great Quaternary glacial period (Ferrer and Negro 2004). During this period, the advance of the ice-sheets from the north of Europe pushed steppe species such as hamsters, lemmings and squirrels southwards. Remains found in La Sima de los Elefantes excavation at Atapuerca (northern Spain) show that these mammals reached Iberia in this period and that with them came their predators, an eagle from the steppes and the boreal lynx, who found in Iberia an alternative prey item, the rabbit, that had been living in the Peninsula for over a million and a half years. Thanks to this find, both the eagles and the lynx were able to survive in the Peninsula, something they failed to do in either Italy or Greece, where there were no rabbits. After almost a million years of isolation from the rest of its family, the Spanish imperial eagle evolved as a different and unique species — in fact, excepting island species, the eagle with the smallest range anywhere in the world. As a result of this historical happenstance, our eagle is condemned to live in areas of high rabbit density, just like the Iberian lynx. In both cases, rabbits make up 88% of their diets and today both these top predators are
restricted to the south-west corner of the Iberian Peninsula, the area that also boasts the highest densities of their favourite prey.

The imperial eagle is regarded as one of the scarcest raptors in the world and today no more than 300 pairs survive. The main threats to its population are electrocution on power lines (almost 60% of casualties before lines were corrected), with an important bias towards mortality in females, the laying of poison bait and the decline in its main prey item due to the introduction of diseases such as myxomatosis and viral haemorrhagic disease.

Large-scale corrective measures were employed throughout our study area, Andalusia, which covers a surface area of 87,598 km², that is, 17.3% of the whole of Spain. To evaluate the effect of the corrective measures we used a database with 35 years of observations (1974–2009) containing data on the number of pairs and the number of deaths by electrocution or other causes. We used all the resources at our disposition, including the archives of the Doñana Biological Station, ringing recoveries, data generated by 32 birds with radio-tracking devices and other data provide by the Andalusian Department of the Environment. As well, all the data from all the birds radio-tracked since 1992, 150 eagles in total, were also put at our disposal.

As we now know, electrocutions took place primarily on distribution lines (16–45 kV). Nevertheless, unlike the less numerous transmission lines, for which information was available, we were unable to obtain precise, reliable data concerning the increase in cover of the grid of distribution lines during the 35 years we hoped to analyze. For this reason, we used as an indicator of the growth of the power line network the data that was available for 110-200 kV lines.

The corrective measures that were applied in Andalusia followed the procedures developed by Project PIE, that is, the points where electrocutions were accumulating were located using predictive models for deaths. Given that pylon design and habitat explain 82% of variance in the distribution of deaths by electrocution, most of the corrective measures were carried out proactively, that is, dangerous pylons were protected before accidents occurred. Naturally, corrective measures were also applied retroactively to pylons on which deaths had already occurred. Our work included the substitution of pin-type insulators with suspended insulators, the insulating of energized elements, above all jumper wires, and, of course, guaranteeing that new power lines were built with safe pylons in accordance with the 1990 Decree.

To analyze the effect of these measures on imperial eagle populations, we divided the study period into two, with the passing of the legislation protecting birds on power lines (Decree 194/1990 of the Andalusian government, 19 June) as the watershed between the two periods. Although the Decree was passed in 1990, the generalized implementation of the corrective measures did not begin until 1992 and so we will consider the following two periods for comparison: 1974-1992 and 1993-2009. To compare the intensity of mortality rates, we can compare the deaths by electrocution
per pair present in a population and per kilometre of power line, both throughout the whole of Andalusia and just in Doñana. Clearly, for the same number of eagles, if the number of pylons increases, the number of electrocuted birds may also increase. Likewise, if the number of pylons does not increase but the number of eagles does, this will also lead to an increase in the number of electrocutions. Thus, it is essential to fix the number of pylons and the number of eagles if we are to compare any possible variations in the risk of electrocution.

From 1974 onwards, a total of 158 imperial eagles were found dead in Andalusia, 101 inside the Doñana National Park (see fig 1). During the study period, electrocution was the most frequent cause of death, being responsible for 39.87% of casualties. Since 1974, the year in which the first electrocuted imperial eagle was found, 63 eagles are known to have died in this way, 37 in Doñana. During this same period, the Andalusian population of imperial eagles rose from 22 in 1974 to 60 in 2009, or, in other words, an annual average rise of +3.46% in the population. In 2009, the Andalusian population of this species represented 24% of its world population.

Figure 1. Annual mortality by electrocution in imperial eagles, expressed as a percentage of the whole population, and population trends (in Andalusia and specifically for the whole of Doñana, taken from Pascual et al. 2011). The black arrow indicates when the corrective measures started to be implanted (Decree 194/1990 Government of Andalusia).
If we now compare the two periods, growth in the Andalusian population of imperial eagles rose from +2.24% annually in 1974–1992 to +4.74% in 1993–2009, over twice as much. In terms of eagles killed by electrocution, a comparison of the two periods shows a fall of 96.9% in the area of Doñana and 61.95% in the rest of Andalusia (see fig 2.). These falls have changed the growth curves of this eagle’s populations significantly. In other words, after correcting power lines the trend in the Andalusian population of imperial eagles changed to a clear pattern of growth at more than twice its previous rate. This has occurred despite the continued increase during this period in the number of kilometres of power lines.

Figure 2. Trends in electrocutions of imperial eagles for the two periods analyzed: a) before (1974–1992) and b) after (1993–2006) corrective measures were applied. The number of deaths is relative to the number of kilometres of power line (110-200 kV, taken from Pascual et al. 2011).
From 1992 to 2009 a total of 6,560 dangerous pylons on 1,446 km of power lines running through imperial eagle territories were corrected. The cost of these measures was 2,624,000 €, around 15% of the total invested in the conservation of this species in Andalusia during this period. An annual investment of 154,000 € ensured that this effort had the greatest effect that any conservation action has ever had on any species. It is undoubtedly a shame that some autonomous communities decided to follow the dictates of ICONA and not apply the recommendations of Project PIE. In fact, the Andalusian population of the imperial eagle has grown faster than any other in Spain. The corrective measures applied in other areas – with a few notable exceptions – were carried out as a knee-jerk reaction to electrocutions and did not optimize investment, neither in an economic sense nor, most importantly, in terms of preventing more imperial eagles from dying so unnecessarily.

It is interesting to note that, after the publication of this information in an important scientific journal (Pascual et al. 2011), scientists from the now defunct ICONA somewhat unsurprisingly argued that in truth the increase in the imperial eagle populations was due to other conservation actions carried out in that period. They claimed that it was the supplementary feeding in problem nests that had led to this increase. Curiously, I was in fact the first to introduce this technique into imperial eagle conservation, specifically in Doñana in 1987 (Ferrer and Penteriani 2007). Nevertheless, despite the claims to the contrary, a demographic analysis of the imperial eagle’s populations leaves no room for doubts (Ferrer and Calderón 1990, Ferrer and Hiraldo 1991, Ferrer and Donázar 1996). However spectacular it might be, an increase in fecundity rates could only ever lead to an annual increase in the rate of growth of this species’ populations by +0.59%; the only variation that can explain growth rates approaching +5%, as occurred from the moment we started to correct pylons, is a change in the mortality rates of immature and, above all, adult birds (Ferrer and Penteriani 2007). This is due to the fact that the imperial eagle belongs to a group of species known as ‘k-selected species’ that have slow demographic growth rates. This type of species is characterized by being long-lived (over 20 years in the case of the imperial eagle), low fecundity rates (0.75 chicks per pair per year), high juvenile mortality (84% of young die before reaching sexual maturity) and very high adult survival rates (above 94% annually), on which the population’s stability depends. This type of species is not particularly sensitive to changes in fecundity, but is very sensitive to variation in mortality rates. By 1991 (Ferrer and Hiraldo 1991) we had already predicted that, if we could solve the problem of electrocution, the population would grow by almost 6% annually. As we have seen, the mortality of imperial eagles throughout Andalusia has fallen by an average of 82% and as a result the population has grown by almost +5% annually.

The Andalusian experience showed that even a problem on the scale of the whole power grid of a densely inhabited developed country can be solved if we fully understand all its ramifications and if all implicated parties show sufficient will and resolve. Scientific information is the basis for the fact that today, many years on, it is possible to declare that imperial eagles can live in natural areas with power lines – it’s just a question of doing things properly.
Although we have no objective data to prove it, the benefits the corrective measures have had for other raptors affected by power lines will almost certainly have been the same or even greater than for the imperial eagle. Using the average mortality rates we estimated during our study in Doñana, Las Lomas and other dispersal areas, as well as data from Project PIE in Andalusia, it is likely that over 1,000 raptors and over 15,000 birds of other species per year are today being saved from a tragic and gratuitous death by electrocution and thus continue to grace our skies. For all those who for so many years have worked on this question it is this saving of lives that undoubtedly gives us the greatest satisfaction.
10. Recent advances in anti-collision and anti-electrocution systems

In 2007, my colleague and friend, Bob Lehman, published a review of all the work carried out on the electrocution of birds of prey throughout the world over the last 30 years (Lehman et al. 2007). Lehman drew attention to the general lack of studies into the true impact of modifications of power lines and into their success in protecting target species. He stated that, except in just a few cases such as Spain, results regarding the effectiveness of corrective actions do not usually find their way into print. This is particularly serious for, if the successes and, above all, the failures, are not made public, we will be condemned to repeat the errors committed by our predecessors and our knowledge of the subject will not advance. Thus, we have always been especially interested in publishing the results, both positive and negative, of the protection systems that we have been able to study. Although the greatest progress in knowledge of the effectiveness of anti-electrocution and anti-collisions undoubtedly took place during Project PIE, a number of new ideas have appeared since then that warrant our attention.

In 2002, a young master’s student from Brazil, Cecilia Pérez Calabuig, turned up in my office. She was hoping to study the effect of power lines on a threatened species of South American wildfowl, the coscoroba swan *Coscoroba coscoroba*, for her thesis. It was impossible to refuse help to a person with such determination, drive and capacity for work and together we designed a study to gather data regarding the impact power lines were having on this species in order to evaluate the effectiveness of marking systems on power lines since, like in other wildfowl species, the problem essentially consisted of collisions with conductors.

In her thesis, she aimed to calculate the effect of conventional marking (PVC spiral flight detectors – ‘scarecrows’) on this species in particular in a very different environment from those in which trials had been conducted up to then – the great coastal wetlands of the Rio Grande do Sul and, in particular, the Bañado de Taim in the far south of Brazil.

For five years we evaluated both mortality and the effectiveness in different habitats of marking systems whose results up to then we had only been able to study in Spain. The transmission lines consisted of 29 spans covering 16 km at a nominal voltage of 138 kV. Cecilia gathered 604 collision casualties that, once adjusted using estimates for losses to scavengers, gave a figure of around 1,300 deaths annually. She found 58 different species of bird, with the coscoroba swan accounting for 29.5% of all casualties.
She was able to show that the scarecrow-type markers significantly reduced the frequency of collisions by 90–92%, similar values to those we had obtained in Spain.

This result was particularly important because it seemed to support the idea that, in the case of anti-collision measures, successful marking systems are reasonably exportable to other areas, unlike anti-electrocution systems. The differing needs for specific designs for the two types of accident is not surprising if we bear in mind that, as we have already seen, the probability of electrocution depends essentially on specific and at times very subtle factors regarding pylon design, which vary enormously from one electricity company to another and, logically, from one country and continent to another. This means that the design of corrective measures must be much more specific in the case of electrocution. In the case of collisions, on the other hand, the essential feature of importance is the visibility of the cable. If we assume that all birds’ visual perception is relatively similar (at least within each taxonomic group), it seems reasonable to believe that the same type of anti-collision measure will work well under very different circumstances.

Nevertheless, at the behest Red Eléctrica de España we had the chance to test in Spain the effectiveness of a new marking system. This electricity company had had maintenance problems with its habitual markers, the spiral ‘scarecrows’. Despite their undeniable effectiveness in reducing the number of collisions, this system had a design fault. Due to their shape and positioning, the scarecrows tended to act as the vibration centre of the cable span on which they were placed. This excess of mechanical movement seemed to be reducing their life expectancy and within just five years they were beginning break due to fatigue and fall off conductors. For an electricity distribution company the actual placing of corrective devices on lines to prevent collisions presents few problems, above all in the case of companies such as Red Eléctrica de España that are committed to environmental improvements. What is difficult for them, however, is programming the de-energizing of operational lines to be able to replace faulty or fallen markers. Thus, it is very important that the marker systems under real dynamic conditions should last as long as possible. This consideration took us to La Palma del Condado, Huelva, where we tested a new marker that we baptized aspas (blades).

During 2004–2006 and then 2008–2009 we marked spans on stretches of power line with the conventional scarecrow markers and the new aspa markers, and left some spans unmarked as controls. The results indicated that the new aspas were between 73% and 76% more effective than the conventional markers. In collaboration with the Mechanics of Environmental Fluids Group from Granada University, we also carried out tests in wind tunnels whose results, after perfecting the design of the anchoring to the ground-wire, indicated that the new design had the potential to be much longer-lasting.

In Córdoba we carried out another experiment that may help in the future to solve one specific problem with power lines and birds for which to date we had found no solution: how to stop great bustards colliding with power lines. During Project PIE in
the study area of Llanos de Cáceres we observed that the anti-collision systems worked very well for all species except the great bustard. Perhaps its aerodynamic flight qualities, unique amongst European birds, explain its striking inability to avoid obstacles. I was once witness to a collision in Llanos de Cordoba, watching helplessly as a great bustard flew towards a marked power line and then swerved and collided with the pylon! Up to then we had been unable to find a satisfactory solution for one of the species most affected by collisions with power lines, which was also a species of great conservation concern. Now, however, we had the chance to work with Red Eléctrica de España on a different strategy: the idea was not to mark power lines but rather to encourage bustards not to use as often the area around the power lines by providing alternative high-quality habitat where birds would be safer. After the first year in which we managed crops in certain areas to create new good-quality habitat, we managed to get bustards to breed in the managed area. This alternative of habitat management could be an interesting solution for certain species when all other systems fail.

In terms of protection systems aimed at preventing electrocution, in recent years we have been most interested in lowering costs of both emplacement and re-emplacement. An important problem with anti-electrocution systems is that they have limited life-spans, largely due to exposure to the elements, which reduces their usefulness as the material begins to break up and lose its insulating properties. The cost of the work involved in replacing corrective measures is usually much greater than the cost of the material or device itself. It is thus essential to improve positioning and anchoring techniques to reduce considerably the time specialist teams need to work, thereby reducing significantly the cost per pylon.

In recent years, with support from Endesa and the Andalusian Department of the Environment, together the CSIC and the Migres Foundation have developed new anti-electrocution systems. In 2010, a model was patented whose great advantage is the ease with which it can be put in place. We also developed insulating material that can be placed on a conductor using just a long pole. In fact, the use of an insulated pole means that the anti-collision device can be put in place while the power line is still energized. The life-span of the new material is three times greater than the material in use at the moment, which greatly reduces costs – not of the initial protection, but of the permanent maintenance of the corrective measure.
Both transmission and distribution power lines are here to stay, at least for the moment. This means that new problems – but also new opportunities – will continue to arise.

In terms of possible problems, I feel that the lessons learnt in Europe and the United States should ensure that the same errors are not committed in developing countries, where future development will mean an important increase in the extension of electricity grids. Appropriate designs of pylons on distribution lines will go a long way to precluding future problems of the magnitude of those that exist in developed countries, which demand so much time and energy to correct. It is surprising that in some cases the energy companies themselves, with plenty of accumulated experience of these problems in their own countries, seem to forget all they have learnt when it comes to constructing a new power line in one of these developing countries. If we carry on in this way, sooner or later we will be forced to put in the same effort all over again to correct power lines as the corpses begin to pile up around pylons. In my opinion, it is vital that environmental technology works hand-in-hand with industrial technology in the construction of new power lines in developing countries – in the long run it will work out a lot cheaper for all.

Although birds of prey have been the main victims of electrocution in Europe and North America due fundamentally to their size and the intense use they make of pylons, there is another taxonomic group that is even more at threat – monkeys and apes. Indeed, it is hard to imagine a group of animals that is more inclined to scale pylons and grab hold of conductors. In Europe and North America there are no species of monkey or ape that have ever provided information on this problem – if there had been, this book would probably be about their relationship to power lines. Nevertheless, monkeys and apes are widespread in developing countries, including in the countries of South America and Africa that we have already discussed, and are perfect candidates as a group that will suffer a significant impact from the appearance of power lines. Currently, we lack anything other than anecdotic information on cases of electrocution in monkeys and apes. Nevertheless, in light of the many difficulties that primates experience due to human activities, one of our priorities must be to avoid adding to the factors that already threaten their survival; an additional cause of mortality could devastate some primate populations. Electricity companies and governments must design safe pylons for these mammals, whilst scientists must provide information on the impact that poorly designed pylons have had on these and other groups of animals.
The location of blackspots where dead birds accumulate enabled us to efficiently correct the problem throughout much of Spain. Nonetheless, protection systems have their own ‘best-before’ dates: materials lose their insulating capacities when exposed to the elements and need to be replaced periodically. Funds for correcting power lines tend to be seen as ‘one-off’ provisions and only very rarely are funds made available annually to replace devices whose ‘sell-by’ dates have expired. This must change in the future and costs must be reduced by ensuring that corrective measures last longer through the implementation of more definitive transformations to power lines.

One of the most costly components in both time and money of correcting large distribution grids is the work classifying the types of pylon present. To date, this has been done by walking along lines, in the same way that inspections are made to check that corrective devices are still in place and have not fallen off. The search for quicker and cheaper ways of monitoring distribution lines encouraged us to set up Project Aeromab (Aerospace Technologies applied to Biodiversity Conservation). This project, undertaken in collaboration with the Engineering School of the University of Seville, has developed an application that uses unmanned radio-controlled planes to monitor power lines and gather information regarding their type and the state of the protection systems. We hope thus that this type of inspection will be carried out much more cheaply and quickly in the future.

We have come a long way in our understanding of the problem and in the search for viable solutions. Nevertheless, the types of pylons being used are still the same as 30 years ago. The industrial designers working on pylon design seem to have taken no interest in the problem. It would be very welcome if somebody would invest time in designing safer pylons that cut the number of electrocutions to zero. It seems clear that if the pylon leaves the factory with the protection system already incorporated the subsequent need to place and then maintain corrective measures disappears. The staggered alignment with suspended insulators is still the least dangerous of all designs, but that is not to say that it couldn’t be improved. The work we undertook in the laboratory during Project PIE showed that trials with captive birds do provide a faithful reflection of field situations and so can be used to test new types of pylons. Thus, the Canadian-type pylons turned out to be even safer than the familiar staggered alignments but have never been used in Andalusia. Perhaps it is time for the electricity companies, who in the end have to bear the brunt of the consequences, to insist on the need for the development of new pylon types that will finally reduce bird mortality to zero.

Even so, aside from merely representing a problem, power lines do in fact offer birds certain opportunities. The clearest case of birds benefitting from a power infrastructure is that of birds that breed on the pylons of transmission and distribution lines. In the case of some species, the percentage of birds that breed on pylons has increased notably in recent years and, indeed, in certain areas most pairs of some species actually breed on electricity pylons. Studies on the white stork in Spain and the osprey (*Pandion haliaetus*) in Germany have shown that pairs of these birds breeding on
electricity structures have greater reproductive success than those that use traditional sites such as trees. This difference can probably be put down to the greater difficulty that predators have in climbing up slippery metal pylons and their greater stability (i.e. less likelihood that a gust of wind will destroy the nest). In any case, the modification of pylons to allow or even encourage birds to nest in a way that does not threaten the stability of the power supply is an excellent way of favouring many species of birds, some of which may be endangered. For example, the osprey has increased its central European populations in recent years essentially by building its nests on pylons on transmission lines. In Spain, after seven years of releasing young ospreys from Germany, Finland and Scotland, in 2009 we were successful in encouraging this species to nest – to be precise, to nest on the pylon of a distribution line – once again in the Iberian Peninsula. The first two pairs that nested in Spain after 60 years of absence did so on pylons in the Guadalcacín reservoir and in the Odiel salt-marshes. The futures of these birds will be closely linked to the use they make of power infrastructures. Work to solve potential problems caused by nesting birds and to create sites where birds can build their nests safely without affecting the proper working of the power lines have been successful in the case of transmission lines, although there is still much work to be done in the case of the distribution network.

In recent years a new variable has affected perception of the conservation of our biodiversity: climate change. From the point of view of biodiversity, the fact of climate change is probably less remarkable than its speed of progress. The July isotherms in the northern hemisphere are moving northwards at a rate of 4–5 km annually, which means that the climate is changing 25 times more rapidly than it did during the final Ice Age. In this context, those creatures that have less capacity to disperse are likely to suffer much more in the future, above all due to the combined effects of habitat fragmentation caused by human activities and the vertiginous rate of climate change. In this situation, many species will need biological corridors to overcome the artificial barriers that hinder their already limited powers of dispersal if they are to be able to respond adequately to climate change. Thus, the use and intelligent adaptation to long-distance power infrastructures could represent a golden opportunity for this type of species. The first experiments that we conducted with transmission lines in which we planted shrubs and bushes and created refuge areas at the bases of pylons (100 m²) were successful. We managed to increase significantly insect, arachnid, reptile and micro-mammal biodiversity at a local scale under pylons and showed that the speed of colonization of the new pylons is quickly than the current rate of climate change. Properly modified power lines could become biological corridors that so many species need so desperately. It is likely that power lines will end up providing a lifeline for animals and to biodiversity in general in their eternal struggle to combat the effects of change.
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ATTACHMENTS
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   1. Staggered or ‘wishbone’ designs
   2. Vault-type
   3. Horizontal alignment

B. Pylons with pin-type insulators
   1. Staggered and similar designs
   2. Vault-type
   3. Horizontal alignment
   4. Triangular alignment

C. Pylons with strain insulators and jumper wires below insulators
   1. Staggered
   2. Vault-type
   3. Horizontal alignment

D. Pylons with strain insulators and jumper wires above insulators
   1. Horizontal alignment
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ATTACHMENT 1

Most frequent types of pylons
Most frequent types of pylons

A. Pylons with suspended insulators

1. Staggered or ‘wishbone’ designs

**Characteristics:** phases are suspended from a string of insulators (two or more discs) in a staggered or vertical arrangement with a single (three phases) or double (six phases) circuit.

**Risk:** low, in general, although this will depend on the length of the string of insulators (preferably three or more three discs) and the size of the bird. The ‘Canadian-style’ crossarm is the safest; in general, the risk is greatest for larger birds.

**Recommended corrective measures:** no cheap and effective dissuasive measures have been developed given the low levels of mortality detected on this type of pylon. In cases where risk does occur with large birds, if possible we recommend modifying the insulator (expensive), modifying the crossarm with insulating material (less expensive) or the placing of protective barriers.
2. Vault-type

**Characteristics:** the (three) phases are on two different levels: the central phase is raised above the other two and is attached to an insulator (two or more discs) suspended from the underside of an arched crossarm.

**Risk:** low, in general, but this will depend on the size of the birds (greater for larger birds) and the length of the string of insulators: although lateral insulators should have at least three discs, this is impractical for the central phase. For small and medium-sized birds, a risk of electrocution exists when they perch underneath the central phase on the central node of the frame: the larger they are, the smaller the distance between the central phase and the bird.

**Recommended corrective measures:** no specific corrective measures were developed for this type of pylon. Where a high risk of electrocution does exist, conductors can be insulated, the length of the lateral insulators can be extended or the central ‘perching’ area under the central conductor can be covered with insulating material.
3. Horizontal alignment

**Characteristics:** three phases on the same horizontal plane, attached to suspended insulators with two or more discs.

**Risk:** low, in general, but this will depend on the size of the birds (greater for larger birds) and the length of the string of insulators, preferably three or more discs. In triangular designs, it is difficult to increase the length of the central string of insulators and so small and medium-sized birds perching on the top of the central tower are at risk from electrocution. The risk of electrocution is greater as the gap between the central phase and top of the central node of the frame gets smaller.

**Recommended corrective measures:** no specific corrective measures were developed for this type of pylon. Where a high risk of electrocution does exist, the conductors or the crossarms can be insulated, or the length of the string of lateral insulators can be extended.
B. Pylons with pin-type insulators

1. Staggered and similar designs

**Characteristics:** the three phases are supported by single-body pin-type insulators in staggered (with or without crossarm) or vertical arrangements with a single (three phases) or double (six phases) circuit.

**Risk:** high in all cases for all birds other than for wooden posts without earthed ground-wires.

**Recommended corrective measures:** the placement of insulating material on the cross-arm is the cheapest effective measure. Alternatively, a rigid sleeve could be used to cover the insulators and part of the cables.
2. Vault-type

**Characteristics:** the three phases are at different levels: the central phase is raised slightly above the other two and all are supported on single-body pin-type insulators situated on an arched crossarm.

**Risk:** high for all birds.

**Recommended corrective measures:** either a rigid insulating sleeve covering the insulator and part of the cable, or insulation on the crossarm in combination with insulation on the central phase to avoid electrocution produced by contact between two cables.
3. Horizontal alignment

**Characteristics:** three phases on the same level attached to simple or double one-body pin-type insulators.

**Risk:** high for all birds.

**Recommended corrective measures:** either rigid insulating sleeves covering each insulator and part of the cable, or insulation on the crossarm in combination with insulation on the central phase to avoid electrocution produced by contact between two cables.
4. Triangular alignment

**Characteristics:** three phases on two levels, with the central phase raised above the other two. Each phase is supported on simple, single or double pin-type insulators situated on crossarm in a triangular, cross-like configuration.

**Risk:** high for all types of birds.

**Recommended corrective measures:** either insulating plates underneath the central insulator in combination with insulating material underneath the insulators covering the lateral crossarms, or all insulators and parts of conductors covered with rigid insulating sleeves.
C. Pylons with strain insulators and jumper wires below insulators

1. Staggered

**Characteristics:** phases staggered on three different levels, tensed by strain insulators consisting of two or more discs on both sides of the crossarm, with jumper wires suspended below.

**Risk:** moderate, in general, but this will depend on the size of the bird. Given that larger birds are more prone to touch jumper wires, the length of the insulator strings should be as long as possible (three or more discs). Pylons with an angle of less than 90º between the cable and the upper crossarm (the part of the pylon most used by birds) are more dangerous as the distance between the conductor and the crossarm is less.

**Recommended corrective measures:** insulation on the crossarm or the jumper wires, including the clips. The most costly part is the lengthening of the strings of insulators.
2. Vault-type

**Characteristics:** three phases on two levels, with the central phase raised above the two lateral phases, subjected by strain insulators (two or more discs) on both sides of an arched crossarm, with jumper wires beneath.

**Risk:** moderate, in general, but this will depend on the size of the birds (greater risk in larger birds). The strings of insulators should preferably include two or more discs; the length of the central jumper is difficult to adjust in this design. In small and medium-sized birds there is a risk of electrocution if they perch on the inner portion of the arch: the smaller the distance between the central phase and the upper-most part of the framework, the greater the risk of accident.

**Recommended corrective measures:** placing of insulation material on the jumper wires or crossarm (including the upper-most part of the arch and/or the central node of the frame).
3. Horizontal alignment

**Characteristics:** three phases on a single level, subjected by strain insulators (two or more discs) on both sides of a horizontal crossarm, with jumper wires beneath.

**Risk:** moderate, in general, but this will depend on the size of the bird (greater risk in larger birds). The strings of insulators should preferably include three or more discs; the length of the central jumper is difficult to adjust in this design. In small and medium-sized birds there is a risk of electrocution if they perch on the inner portion of the arch: the smaller the distance between the central phase and the upper-most part of the framework, the greater the risk of accident.

**Recommended corrective measures:** placing of insulation material on the jumper wires or crossarm (including the base of the interior angle at the central node of the frame and the central cable).
D. Pylons with strain insulators and jumper wires above insulators

1. Horizontal alignment

**Characteristics:** three phases on the same level, subjected by pairs of strain insulators (two or more discs) on both sides of the crossarm; jumper wires above the three pairs of insulators (or at least only above the central pair).

**Risk:** very high for all birds.

**Recommended corrective measures:** insulating material covering jumpers or substitution of jumper by insulated cables. If just one jumper is projecting, this particular jumper could be insulated and insulation placed on the crossarm.
2. Triangular alignment

**Characteristics:** three phases on two levels, the central phase on central mast raised above the two lateral phases. Phases subjected by strain insulators on both sides of the crossarms and central mast, with jumper wires projecting above all three pairs of strain insulators or, at least, above the central pair.

**Risk:** very high for all birds.

**Recommended corrective measures:** insulating material on the jumper wires or substitute the jumpers with insulated cables. If just one jumper is projecting, this particular jumper could be insulated and insulation placed on the crossarm.
E. Circuit-breakers

1. Single-conductor circuit-breakers below crossarm

**Characteristics:** pylons with strain insulators of different designs, but with three independent circuit-breakers on each phase positioned below the crossarm.

**Risk:** moderate, in general, but similar to the risk posed by pylons with strain insulators and jumpers below crossarms.

**Recommended corrective measures:** either insulation on the jumpers that run to each circuit-breaker or insulation on the crossarm.
2. Single-conductor circuit-breakers above crossarm

**Characteristics:** pylons with strain insulators of different designs, but with independent circuit-breakers for each phase positioned above the crossarm.

**Risk:** very high for all types of birds.

**Recommended corrective measures:** move circuit-breakers to below the crossarm and apply the measures for the previous design, insulate the jumper wires connected to the circuit-breaker or insulate the crossarm.
3. Triple-conductor circuit-breaker on pylon mast

**Characteristics:** pylons of various types, usually with strain insulators and often with transformers, with a triple-conductor circuit-breaker located on the side of the pylon mast.

**Risk:** in general, the presence of a triple-conductor circuit-breaker on the side of the pylon mast has little effect on the risk associated with a pylon (although this will depend on the design of the upper-most part of the pylon).

**Recommended corrective measures:** installation of appropriate measures for the design of the upper-most part of the pylon, and the insulation of the circuit-breaker. On anchor or dead-end pylons, circuit-breakers and transformers, if present, should be placed underneath the span to avoid the need for jumper wires projecting above the crossarm.
4. Triple-conductor circuit-breaker on top of pylon

**Characteristics:** pylons of horizontal or occasionally triangular design, normally with strained insulators and a triple-conductor circuit-breaker on top of the structure.

**Risk:** high for all types of birds.

**Recommended corrective measures:** move circuit-breaker to the side of pylon mast and placement of insulating material. On anchor or dead-end pylons, disconnecting switches and transformers, if present, should be placed underneath the span to avoid the need for jumper wires projecting above the crossarm.
ATTACHMENT 2

Anti-electrocution corrective measures
Anti-electrocution corrective measures

A. Insulation of conductors

1. Aerial bundled cable

**Action:** complete insulation  
**Effect:** eliminates possibility of electrocution  
**Placement:** whole new installation required  
**Size:** -  
**Mounting:** de-energized line  
**Material:** cable  
**Team:** unknown  
**Time:** unknown  
**Cost:** very high  
**Effectiveness:** good  
**Resistance:** over 20 years
2. Thermoretractable insulation

Action: partial insulation of phases
Effect: prevents earthing of phase
Placement: on jumper wires and part of phases
Size: 1 m on both sides of insulator
Mounting: de-energized line
Material: thermoretractable tape
Team: 2 people
Time: 30 min per pylon
Cost: high
Effectiveness: good
Resistance: 3-5 years
3. Rigid insulating sleeve

**Action:** partial insulation of phases  
**Effect:** prevents earthing of phase  
**Placement:** covers insulator and part of conductor  
**Size:** 40 cm on both sides of insulator  
**Mounting:** de-energized line  
**Material:** various  
**Team:** 2 people  
**Time:** 5 min per post  
**Cost:** moderate  
**Effectiveness:** good  
**Resistance:** over 3 years
4. Insulation of jumper wires

**Action:** partial insulation of phases  
**Effect:** prevents earthing of phase  
**Placement:** covering of the jumper wires and clips with insulation or substitution of jumper with dry cable  
**Size:** depends on length of jumper wire  
**Mounting:** de-energized line  
**Material:** various  
**Team:** 2 people  
**Time:** 7 min per post  
**Cost:** low-moderate  
**Effectiveness:** good  
**Resistance:** depends on the material
B. Insulation on crossarm

1. Insulating plate below insulator

Action: partial insulation of crossarm  
Effect: prevents earthing of phase  
Placement: plate protects pylon below central insulator (in triangular configuration)  
Size: 30 x 30 cm plate  
Mounting: de-energized line  
Material: plastic  
Team: 2 people  
Time: 5 min per pylon  
Cost: low  
Effectiveness: good  
Resistance: over 3 years
2. Insulating plate above insulator

**Action:** partial insulation of crossarm phase  
**Effect:** prevents earthing of phase  
**Placement:** plates protect upper part of central insulator (in triangular configuration)  
**Size:** 30 x 30 cm plate  
**Mounting:** de-energized line  
**Material:** plastic  
**Team:** 2 people  
**Time:** 5 min per pylon  
**Cost:** low  
**Effectiveness:** good but difficult to put in position  
**Resistance:** unknown
3. Insulating blanket covering crossarm

**Action:** partial insulation of crossarm  
**Effect:** prevents earthing of phase  
**Placement:** blankets cover and insulate a large part of the crossarm below the insulators  
**Size:** 50 cm  
**Mounting:** de-energized line  
**Material:** various  
**Team:** 2 people  
**Time:** 5 min per pylon  
**Cost:** low  
**Effectiveness:** good  
**Resistance:** over 3 years
4. Insulating plate in combination with insulating blanket on crossarm

**Action:** partial insulation of crossarm  
**Effect:** prevents earthing of phase  
**Placement:** insulating plate placed under central insulator with insulating blanket covering a large part of crossarm below lateral insulators  
**Size:** 30 x 30 cm plate, 50 cm insulating material  
**Mounting:** de-energized line  
**Material:** plastic and various insulating materials  
**Team:** 2 people  
**Time:** 5 min per pylon  
**Cost:** low  
**Effectiveness:** good  
**Resistance:** over 3 years
C. Dissuasive devices

1. Narrow bars

**Action:** placement of dissuasive device  
**Effect:** makes earthing of phase very unlikely  
**Placement:** on the end of the crossarm above suspended insulator  
**Size:** 30 cm  
**Mounting:** de-energized line  
**Material:** metal  
**Team:** 2 people  
**Time:** 5 min per pylon  
**Cost:** low  
**Effectiveness:** not properly tested  
**Resistance:** over 3 years
2. Plastic triangular perch guard

**Action**: placement of dissuasive device  
**Effect**: makes earthing of phase very unlikely  
**Placement**: on the end of the crossarm above suspended insulator  
**Size**: 30 cm base, 30 cm high  
**Mounting**: de-energized line  
**Material**: plastic  
**Team**: 2 people  
**Time**: 5 min per pylon  
**Cost**: low  
**Effectiveness**: not properly tested  
**Resistance**: over 3 years
3. Comb-like pegging on crossarm

**Action:** placement of dissuasive device  
**Effect:** makes earthing of phase very unlikely  
**Placement:** four vertical spokes at the end of the crossarm above suspended insulator  
**Size:** 30 cm base, 30 cm high  
**Mounting:** de-energized line  
**Material:** plastic  
**Team:** 2 people  
**Time:** 5 min per pylon  
**Cost:** low  
**Effectiveness:** not properly tested  
**Resistance:** over 3 years
4. Vertical plastic plates

**Action:** placement of dissuasive device  
**Effect:** makes earthing of phase very unlikely  
**Placement:** on the end of the crossarm above the jumper wires and below the crossarm  
**Size:** 50 cm base, 20 cm high  
**Mounting:** de-energized line  
**Material:** plastic  
**Team:** 2 people  
**Time:** 5 min per pylon  
**Cost:** low  
**Effectiveness:** poor  
**Resistance:** over 3 years
5. Vertical white pegging

**Action:** placement of dissuasive device  
**Effect:** makes earthing of phase or contact phase-phase very unlikely  
**Placement:** eight vertical spokes on circuit-breaker on top of pylon  
**Size:** 50 cm long, 25 cm apart  
**Mounting:** de-energized line  
**Material:** plastic  
**Team:** 2 people  
**Time:** 20 min per pylon  
**Cost:** moderate  
**Effectiveness:** poor  
**Resistance:** over 3 years
6. T-shaped perches on top of pylon

**Action:** placement of dissuasive device  
**Effect:** makes earthing of phase very unlikely  
**Placement:** on top of pylon  
**Size:** 0.7 m high, 1 m wide  
**Mounting:** de-energized line  
**Material:** metal  
**Team:** 2 people  
**Time:** unknown  
**Cost:** moderate  
**Effectiveness:** poor  
**Resistance:** over 5 years
7. T-shaped perch on end of crossarm

**Action:** placement of dissuasive device  
**Effect:** makes earthing of phase very unlikely  
**Placement:** on the end of the crossarm  
**Size:** various (approximately 50 cm high)  
**Mounting:** de-energized line  
**Material:** metal  
**Team:** 2 people  
**Time:** unknown  
**Cost:** moderate  
**Effectiveness:** poor  
**Resistance:** over 5 years
8. Rectangular perch

**Action:** placement of dissuasive device  
**Effect:** makes earthing of phase very unlikely  
**Placement:** on the end of the crossarm  
**Size:** various  
**Mounting:** de-energized line  
**Material:** metal  
**Team:** unknown  
**Time:** unknown  
**Cost:** unknown  
**Effectiveness:** unknown  
**Resistance:** unknown
9. Brush or comb

**Action:** placement of dissuasive device  
**Effect:** makes earthing of phase very unlikely  
**Placement:** on the end of the crossarm  
**Size:** approximately 30 cm  
**Mounting:** de-energized line  
**Material:** metal  
**Team:** unknown  
**Time:** unknown  
**Cost:** unknown  
**Effectiveness:** poor  
**Resistance:** unknown
10. Perch with angled struts

**Action:** placement of dissuasive device  
**Effect:** makes earthing of phase very unlikely  
**Placement:** on pylons with T-shaped perches, struts form triangles with perch (or pylon mast) and crossarm  
**Size:** approximately 70 cm  
**Mounting:** de-energized line  
**Material:** metal  
**Team:** 2 people  
**Time:** 10 min per pylon  
**Cost:** low  
**Effectiveness:** poor  
**Resistance:** unknown
11. Angled plate

**Action:** placement of dissuasive device to stop birds perching or nesting on insulators  
**Effect:** makes earthing of phase very unlikely  
**Placement:** at an angle on the end of the crossarm  
**Size:** 20 cm x 50 cm  
**Mounting:** de-energized line  
**Material:** plastic  
**Team:** 2 people  
**Time:** 5 min per pylon  
**Cost:** low  
**Effectiveness:** not properly tested  
**Resistance:** six-week trial period overcome in climatic chamber
D. Combination of insulators and dissuasive devices

1. Insulating plate on insulator and dissuasive triangles

**Action:** partial insulation and placement of dissuasive measures  
**Effect:** makes earthing of phase very unlikely/impossible  
**Placement:** insulating plaque above three insulators and triangle at end of crossarm  
**Size:** 30 cm x 30 cm  
**Mounting:** de-energized line  
**Material:** plastic  
**Team:** 2 people  
**Time:** 10 min per pylon  
**Cost:** low  
**Effectiveness:** good but difficult to install  
**Resistance:** unknown
2. Insulating blanket on jumper wire and vertical plates on crossarm

**Action:** insulation and dissuasive measure  
**Effect:** makes earthing of phase very unlikely/impossible  
**Placement:** insulation on jumper wires above insulators and plates at the end of the crossarms above suspended jumper wires  
**Size:** depends on length of jumper wire, 50 x 20 cm plate  
**Mounting:** de-energized line  
**Material:** insulators of various different material and plastic plates  
**Team:** two people  
**Time:** 8 min per pylon  
**Cost:** low  
**Effectiveness:** good  
**Resistance:** over 3 years
E. Change of design

1. Substitution of pin-type insulators by suspended insulators

**Action:** change of design  
**Effect:** makes earthing of phase very unlikely  
**Placement:** reverses projection of insulators  
**Size:** -  
**Mounting:** de-energized line  
**Material:** -  
**Team:** unknown  
**Time:** unknown  
**Cost:** very high  
**Effectiveness:** good  
**Resistance:** excellent
2. Change circuit-breaker from top of pylon to side of pylon mast

**Action:** change of design  
**Effect:** makes earthing of phase very unlikely  
**Placement:** changes circuit-breaker from top of pylon to side of pylon mast  
**Size:** -  
**Mounting:** de-energized line  
**Material:** -  
**Team:** unknown  
**Time:** unknown  
**Cost:** high  
**Effectiveness:** good  
**Resistance:** excellent
3. Lengthen insulator string

**Action:** change of design  
**Effect:** makes earthing of phase very unlikely  
**Placement:** lengthen insulator string  
**Size:** lengthen installation to over 50 cm  
**Mounting:** de-energized line  
**Material:** unknown  
**Team:** unknown  
**Time:** unknown  
**Cost:** high  
**Effectiveness:** good  
**Resistance:** over 20 years
ATTACHMENT 3

Anti-collision corrective measures
Anti-collision corrective measures

1. White polypropylene spiral flight diverters

Soporte: ground-wire or conductor
Placement: manually (with wheeled cradle)
Mounting: de-energized line
Frequency: every 5 metres (single cable), every 10 metres in staggered alignment
Team: 3 people
Time: 0.2km/hour
Cost: high
Effectiveness: good
Resistance: over 3 years. Six-week trial period overcome in climatic chamber
2. Orange polypropylene spiral flight diverters

Soporte: ground wire or conductor  
Placement: manually (with wheeled cradle)  
Mounting: de-energized line  
Frequency: every 5 metres (single cable), every 10 metres in staggered alignment  
Team: 3 people  
Time: 0.2km/hour  
Cost: high  
Effectiveness: good  
Resistance: over 3 years. Six-week trial period overcome in climatic chamber
3. Yellow polypropylene spiral flight diverters

**Soporte:** ground wire or conductor  
**Placement:** manually (with wheeled cradle)  
**Mounting:** de-energized line  
**Frequency:** every 5 metres (single cable), every 10 metres in staggered alignment  
**Team:** 3 people  
**Time:** 0.2km/hour  
**Cost:** high  
**Effectiveness:** very good  
**Resistance:** over 3 years. Six-week trial period overcome in climatic chamber
4. X-shaped neoprene strips attached by elastomer clips with luminescent tape

**Soporte:** ground wire or conductor  
**Placement:** robot or manually  
**Mounting:** de-energized line  
**Frequency:** every 10 metres  
**Team:** 4 people  
**Time:** 0.4km/hour  
**Cost:** high  
**Effectiveness:** good  
**Resistance:** over 3 years. Six-week trial period overcome in climatic chamber
5. Suspended black plastic strips

Soporte: ground wire or conductor
Placement: manually
Mounting: energized lines (on ground wire)
Frequency: every 8 metres
Team: 3 people
Time: 0.4km/hour
Cost: low
Effectiveness: unproven
Resistance: over 3 years. Six-week trial period overcome in climatic chamber
6. Black plastic strips on conductors

Soporte: conductor
Placement: manually (with crane)
Mounting: de-energized line
Frequency: 3 strips every 15 metres
Team: 2 people
Time: 0.4km/hour
Cost: high
Effectiveness: poor
Resistance: over 3 years. Six-week trial period overcome in climatic chamber
7. **Fluorescent plastic bird silhouette flight diverter**

**Soporte:** ground wire  
**Placement:** manual (with helicopter)  
**Mounting:** de-energized line  
**Frequency:** every 5–10 metres  
**Team:** unknown  
**Time:** unknown  
**Cost:** very high  
**Effectiveness:** unknown  
**Resistance:** unknown
8. Yellow balls each with single black vertical stripe

**Soporte:** ground wire  
**Placement:** unknown  
**Mounting:** de-energized line  
**Frequency:** every 75–100 metres  
**Team:** unknown  
**Time:** unknown  
**Cost:** high  
**Effectiveness:** good  
**Resistance:** unknown
9. Three-bladed rotating flight diverter with reflecting panels

**Soporte:** ground wire or conductor  
**Placement:** manual  
**Mounting:** de-energized line  
**Frequency:** every 5 metres (single cable), every 10 metres in staggered alignment  
**Team:** 2 people  
**Time:** unknown  
**Cost:** low  
**Effectiveness:** very good  
**Resistance:** over 3 years
This book was written by Miguel Ferrer, Research Professor for the Spanish National Research Council (CSIC), who currently works in the Doñana Biological Station, where he served as director from 1996 to 2000. He has been Director at Large of the Raptor Research Foundation since 1998 and President of the MIGRES Foundation since 2003. In 2007 he joined the Expert Group on Biodiversity and Climate Change for the Council of Europe and in 2011 was named Adjunct Professor at Boise State University. Currently, he is the Institutional Coordinator for the CSIC in Andalusia.

Miguel has published over 130 papers in scientific journals included on the Scientific Citation index (SCI) and authored several books, and has presented more than 80 papers at congresses in various universities worldwide. His research has followed three main lines of work: firstly, he has studied the dynamics of small populations and the conservation of endangered species, above all the Spanish imperial eagle. A second line of research centres on the applied study of the impact of various different infrastructures such as wind farms, power lines, roads and railways on the environment, and how corrective measures can mitigate their impact. Thirdly, he has studied the effects of global change on species distribution and bird migration.

This book is the result of work on two of his lifelong passions, the study of population dynamics in the Spanish imperial eagle in Doñana, and his highly successful study and correction of the impact of power lines on this species, which has given a new lease on life to this raptor and led to an increase in its populations.

This book was possible thanks to the commitment of the Migres Foundation, a private non-profit organization founded in 2003 to promote scientific research on bird migration and to boost sustainable development activities. This foundation believes that these policies offer the best tools for biodiversity conservation.

Moreover, the Migres Foundation has evolved into an association that aims to reconcile sustainable development and biodiversity conservation, providing solutions for environmental challenges, which, if properly tackled, will become perfect opportunities for sustainable economic and social growth.

This book was also made possible by the support received from Endesa, the largest electricity company in Spain. This company looks to the future and seeks intelligent solutions to develop realistic proposals addressing present and future energy challenges. This corporation is also strongly committed to preserving the environment because it firmly believes that service provision can and must be compatible with the protection of the environment. Thus, they are pioneers both in studying the impact that the power lines crossing our landscape cause and in finding solutions to these impacts.
This book, written in the first person, is evidence that numerous different interest groups (scientists, electricity companies, local government, technicians, landowners, ecologists) are able to reach compromises and cooperate in the search for a solution to the negative impact that power lines have on wildlife in general and, in this case, on the Spanish imperial eagle (*Aquila adalberti*) in particular.

Miguel Ferrer, Research Professor for the Spanish National Research Council, is the world’s foremost expert in the study of this eagle and in the problems that have led it to be considered Europe’s most threatened eagle and one of the world’s scarcest raptors. It was precisely the discovery of the high mortality rates of this species on power lines that encouraged the development of studies aimed at mitigating their impact. The practical application of the fruits of this work has helped double the imperial eagle population in Andalusia, truly a significant feat in applied conservation biology.

The integrated management of this all too real problem, which affects both birds and electricity companies throughout the world, represents a new way of working. Power lines are here to stay and will continue to cause problems, but at the same time also provide opportunities for developing new working methodologies. Detailed knowledge of this problem and the combined efforts of all implicated parties are essential components in the search for and discovery of viable solutions.