GUIDELINES FOR THE CONSERVATION OF BONELLI'S EAGLE POPULATIONS

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MAVA FONDATION POUR LA NATURE

Equip Biologia de la Conservació

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Photographs on page 12 and 40 courtesy of Àlex Ollé in Oman.

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PREFACE

This document was produced in the frame of the project entitled "*Establishing conservation targets for guaranteeing the long-term viability of the endangered Bonelli's Eagle Aquila fasciata population in NE Iberian Peninsula*" funded by the MAVA Foundation (en.mava-foundation.org/). The project objectives were to establish the conservation targets in terms of both the species' life-cycle and geographic areas to guarantee the viability of the Bonelli's eagle populations from Catalonia (NE Iberia), and to create suitable synergies with practitioners to apply the required actions and to allow their long-term sustainability.

The development project lasted from January 2014 to March 2016 and was carried out by two key partners: the Conservation Biology Group from the University of Barcelona (CBG-UB), that develop the scientific aspects of the project and draft this document, and the Diputació de Barcelona, that participate as a governmental institution with responsibilities in conservation practice, promoting and applying the management and conservation results of the project.

The team involved in this project from the MAVA Foundation was composed of Paule Gros, Marko Pecarevic, Julien Sémelin and Carol Wuersch, in charge of supporting the two key partners of this project. The core team from the Diputació de Barcelona was composed of Carles Castell, Head of Land Analysis and Planning, and David Carrera, technician from the Land Analysis and Planning Office. Finally, the team from the CBG-UB was composed of Joan Real, Director of the research team, Antonio Hernández-Matías, researcher in charge, Francesc Parés, field technician, Àlex Rollan, conservation technician, and Elisabet Paül as public relations and administrative tasks. This project has been also supported institutionally by the University of Barcelona.

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Finally, we are immensely grateful to the MAVA foundation for its financial support that allowed some of the most recent research carried out by the CBG-UB and the drafting of these guidelines.

SUMMARY

This document provides a comprehensive suite of protocols and methods summarized in the form of guidelines aimed at solving conservation problems applicable at different spatial scales, from territories to populations. Bonelli's eagle is a characteristic raptor of Mediterranean environments in Europe and plays a key role as top predator in these natural systems. For this reason, this species can be considered as an 'umbrella species' and, therefore, conservation actions aimed at its protection may also benefit other species in these communities.

These guidelines are aimed to generate an example of applied research and achievable conservation practice easily exportable to other populations of Bonelli's eagle as well as other endangered raptors, thus promoting networking efforts between actors involved in conservation at several levels, from local to international.

Chapters are grouped into two general sections that relate to two different stages required to implement conservation actions: (1) Identifying conservation targets, that is, evaluating the problem, and (2) Implementing conservation actions, that is, solving the problem. While this is a broadly sequential ordering, all the issues raised by the guidelines should be considered together to obtain a comprehensive picture. To enhance its understanding and offering a clear roadmap for conservation of Bonelli's eagle populations a decision tree is provided and described in the first introductory chapter. By answering the set of questions in order, the reader will end up to one of the chapters of this document.

Five different 'methodological' chapters are included in the first section, (1) Population monitoring, (2) Determining territorial home-ranges and dispersal areas, (3) Population viability analyses, (4) Determining prey consumption and (5) Estimating mortality causes, where different approaches and methods are described in order to identify major threats for the species conservation and the resulting conservation targets.

Furthermore, three different chapters are included in the second section, (1) Legal tools for conservation, (2) Improving food supply and (3) Mitigation of mortality causes, where conservation actions are described to solve particular conservation problems identified in the first section.

To end, managers should bear in mind that the uncertainty on the effectiveness of conservation actions will increase as much as these actions would be based on little or poor scientific evidence, although there always exists a delicate balance between the wish for more rigor in the planning and the need of having results as soon as possible. In this sense, management decision making should be understood as an iterative process on which actions previously undertaken need to be evaluated and, if necessary, reoriented for future conservation actions. This cyclical process is known as adaptive management, where scientific research plays a key role and a strong interplay between key partners is essential for a deep understanding on how to implement on-the-ground conservation actions derived from research.

1. INTRODUCTION

1.1. The purpose of these guidelines

Bonelli's eagle is a characteristic raptor of Mediterranean environments in Europe and plays a key role as top predator in these natural systems. For this reason, this species can be considered as an 'umbrella species' and, therefore, conservation actions aimed at its protection may also benefit other species in these communities.

Most of Europe's Bonelli's eagle populations, such as that found in Catalonia in the northeast corner of the Iberian Peninsula, have undergone a dramatic decline in numbers and range in recent decades. Given this alarming situation, during the early 1980s naturalists and researchers at the University of Barcelona began monitoring this population in an attempt to understand the causes of this regression and draw up conservation actions. Since then, the Conservation Biology Group of the University of Barcelona (CBG-UB) has led research into this species' ecology and the search for ways to improve its conservation.

The CBG-UB has also a long history of collaboration with private and public institutions, as well as with other stakeholders such as electric power companies, landowners, farmers and hunting societies, among others. This close interplay with key partners has been essential for obtaining deep understanding of how to implement on-the-ground conservation actions derived from research and thus contribute more efficiently in restoring Bonelli's eagle threatened populations.

This document provides a comprehensive suite of protocols and methods summarized in the form of guidelines aimed at solving conservation problems applicable at different spatial scales, from territories to populations. These methods are encompassed into a general framework that emphasizes the idea of adaptive management, which implies a constant interaction between researchers and practitioners, taking into account the fact that actions undertaken need to be evaluated in the mid- and long-term and, if necessary, reoriented for future conservation. The previous experience of the CBG-UB when working with local communities and conservation practitioners, as well as the feedback obtained during the drafting of these guidelines, reinforces our belief that the methods and protocols proposed here are based on solid scientific knowledge and are also realistic and achievable in the real world. These guidelines aim to generate an example of applied research and achievable conservation practice that is easily exportable to other populations of Bonelli's eagle, as well as other endangered raptors, thereby promoting networking efforts between actors involved in conservation at several levels, from local to international.

Although these guidelines are primarily aimed at the key partners most directly linked to the conservation of the species such as conservation policy planners, managers and practitioners, they will be useful for anybody interested either in Bonelli's eagle or in the conservation biology of threatened species. On the other hand, most of the information set out in this document is based on Western Europe, where ~80% of the European population of the species is found. However, the information and examples presented here may still be useful for any other population in the species' world range.

The chapters are grouped into two general sections that relate to the two different stages required to implement conservation actions. These are as follows:

I. Identifying conservation targets, that is, evaluating the problem.
II. Implementing conservation actions, that is, solving the problem.

Although this is a broadly sequential order, all the issues raised by the guidelines should be considered together to obtain a more comprehensive picture. To enhance understanding and provide a clear roadmap for the conservation of Bonelli's eagle populations, a decision tree is provided and described in detail. Finally, a list of helpful reference sources is also included for further information.

1.2. Introducing the Bonelli's eagle

Bonelli's eagle *Aquila fasciata* was described in 1822 by the French naturalist Jean Pierre Vieillot. It was named in honour of Franco Andrea Bonelli, an Italian naturalist who first documented the species in 1819. Bonelli's eagle is a medium-sized bird of prey whose distribution ranges from western China and India through the Middle East to the western Mediterranean. The species is resident throughout its range, although juveniles will disperse up to 200 km and individuals occasionally wander further afield and pass through key migration routes (Birdlife International, 2013; Orta *et al.*, 2015) (see Figure 1).

Bonelli's eagle currently appears as a species of *Least Concern* on the IUCN Red List of Threatened Species (Birdlife International, 2013), although its global population appears to be decreasing moderately. In Europe, the Bonelli's eagle population is estimated at 1,100–1,200 pairs, of which ~80% are found in the Iberian Peninsula (Birdlife International, 2015) (see Figure 2). This eagle underwent moderately rapid population declines in Spain, which holds c.66% of the European population, during the past three generations (54 years). These declines led to the species' classification as *Endangered* in Europe (Birdlife International, 2004) and Spain (Real, 2004). More recently, its populations appear to have stabilised but the species, nevertheless, still warrants classification as *Near Threatened* within Europe (Birdlife International, 2015).

However, a regional assessment (IUCN, 2012) may lead to a higher risk category for regional or local extinction. This is the case of the Bonelli's Eagle population in Catalonia, where the species was upgraded to *Critically Endangered* (Anton *et al.*, 2013). Here, the species was relatively common in mid-20th century, but then progressively decreased until the end of the century and reached a historical minimum in 2000. After that, its population has stabilized and has even appeared to increase very slightly (see Case Study 1).

Territorial birds are found in mainly warm, sunny mountainous or rough terrain, normally with crags and cliffs, and with variable vegetation cover: normally zones with extensive growth of bushes and shrubs (e.g. maquis and garrigue) and sometimes with forests, but also barren slopes with virtually no vegetation. *Aquila fasciata fasciata* mainly occurs from sea-level to 1500 m in Europe, up to 2000 m in NW Africa and up to 3750 m in Asia; the race *renschi* occurs in moist tropical forests from sea-level to c. 2000 m in the Lesser Sundas (Orta *et al.*, 2015). Most eagles in Western Europe nest on cliffs, although in southern Portugal, most pairs nest in trees.

Like other territorial raptors, Bonelli's eagles pass through a transient nomadic phase (i.e. a dispersal period) after the post-fledging dependence period and before territorial recruitment, which mostly occurs between three and four years of age. During this dispersal period, birds perform medium- to long-distance movements and often settle for extended periods in dispersal areas. In SW Europe, at least, these areas are usually flat-to-undulating in relief, and are mainly dry farming regions that are especially rich in rabbits and red-legged partridges, the main prey items of Bonelli's eagle.

__Figure 1__: Bonelli's Eagle distribution map, with the two subspecies distinguished, Aquila fasciata fasciata *(in light green) and* Aquila fasciata renschi *(in orange). In dark green, the winter visitor distribution of* Aquila fasciata fasciata*. Source: own elaboration based on Birdlife International (2013).*

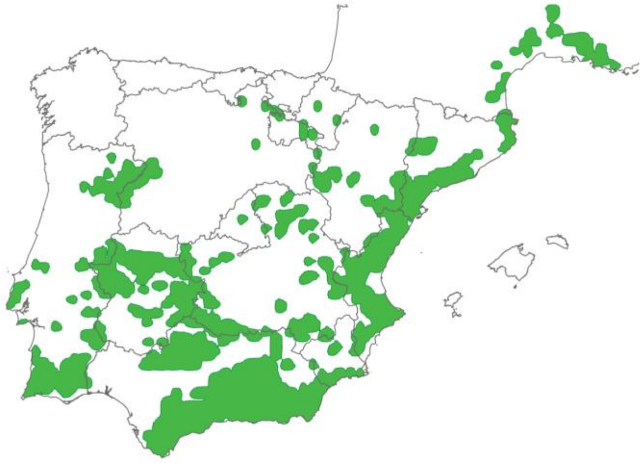


__Figure 2__: Bonelli's Eagle distribution map in Western Europe (Iberian Peninsula and France), including Catalonia in the northeast corner of the Iberian Peninsula. Source: modified from Hernández-Matías et al. (2013).

1.3. Framework

The framework inspiring these guidelines and proposed throughout the cyclical conservation process was based on two main pillars: adaptive management based on solid scientific knowledge and close interplay between key partners (see Figure 3). Specifically, monitoring is used to identify the main threats on the target population, to define proposals for conservation actions and to evaluate the effectiveness of their implementation. Monitoring and identification of conservation targets, as well as the assessment of conservation effectiveness, are based on suitable scientific and technical methods. Furthermore, conservation actions are shaped by interaction between key stakeholders, thus making such actions more realistic and achievable in the real world. In addition, the proposal of new conservation actions may require readjustments to be made to monitoring targets to allow for future assessments.

While this vision may seem rather obvious, management decisions are commonly based on either vague qualitative information or subjective appreciations of practitioners. Here, we stress the idea that conservation without well-designed strategies and not based on previous evidence is highly inefficient and often ineffective. For example, improving productivity (e.g. saving chicks in low-quality territories or releasing young eagles born in captivity) may have little effect in a declining population when high mortality is the main driver of its population dynamics. Nonetheless, managers should bear in mind that uncertainty in the effectiveness of conservation actions will increase if these actions are based on little or poor scientific evidence. In addition, it is crucial to understand management decision-making as an iterative process on which actions previously undertaken need to be evaluated and, if necessary, reoriented for future conservation actions. This process is known as **adaptive management** and requires well-designed monitoring plans, which should involve continuous monitoring of populations and, if necessary, should be modified to assess the effectiveness of the conservation actions implemented.

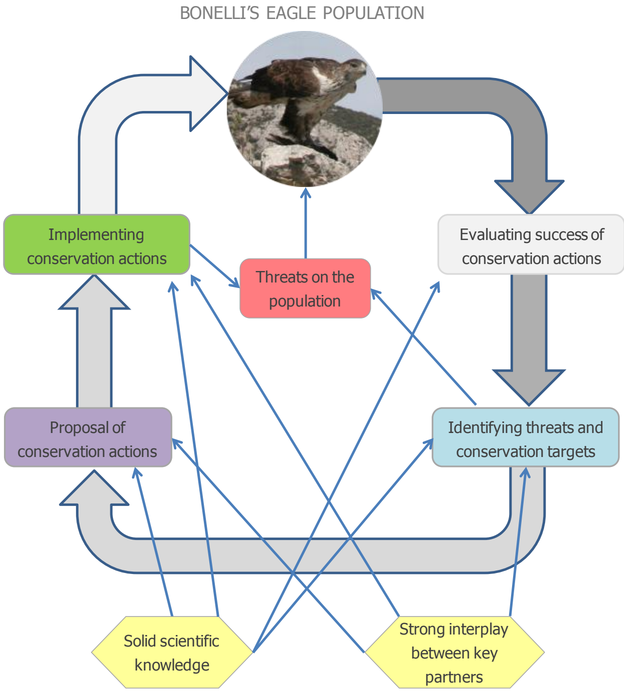


***Figure 3**: Framework for achieving the long-term viability of Bonelli's eagle populations based on solid scientific knowledge, with close interplay between key partners*.

Finally, beyond its scientific or technical complexity, the implementation of conservation measures is a difficult task because it implies actions and decisions that may affect the activities of different human groups that sometimes have opposing interests with potentially relevant economic consequences. In this sense, previous background work on local populations of Bonelli's eagle in Catalonia has demonstrated that achieving conservation targets is not possible without the direct implication of community conservation stakeholders (e.g. electric power companies, landowners, farmers and hunting societies), and that the effectiveness of conservation actions are usually proportional to the degree to which civil society embraces natural values of interest. Thus, a **close interaction between key partners** is essential for successfully achieving conservation goals. Moreover, working together with civil society allows researchers and managers a better understanding of social scenarios that may influence the implementation of the actions proposed. Local stakeholders may not only provide valuable knowledge but should also ideally be actively involved in the implementation of the conservation measures.

1.4. Conservation roadmap

As a guide to the conservation process of Bonelli's eagle populations, a **decision tree** is represented in Figure 4 as a roadmap and a visual structure. Here, by answering the set of questions in order, the reader will end up to either at:

- a 'methodological' chapter, where methods are described for identifying conservation targets or, in other words, evaluating the problem.
- a 'conservation action' chapter, where conservation actions are described to solve a particular conservation problem.

Of course, you may go straight ahead to a chapter where actions to solve specific conservation problems (e.g. how to solve electrocution in a given territory, or how to improve productivity in a territory with poor performance) are described if you have already detected a conservation problem and you need a shortcut; yet, you would risk not investing conservation efforts in the most efficient way. It is worth noting that for clarity, we represent the decision tree as a lineal process but users should bear in mind that all compartments of the tree constitute pieces plugged into compartments of the cyclical conservation process described in Figure 3. Thus, the coloured boxes in Figure 4 are a part of the coloured boxes in Figure 3 of the same colour (i.e. blue for 'Identifying threats and conservation targets', red for 'Threats' and violet for 'Proposal of conservation actions' as well as the methods used to implement this actions). The questions and brief explanation below will guide users through the process of identifying either preliminary or ultimate outcomes.

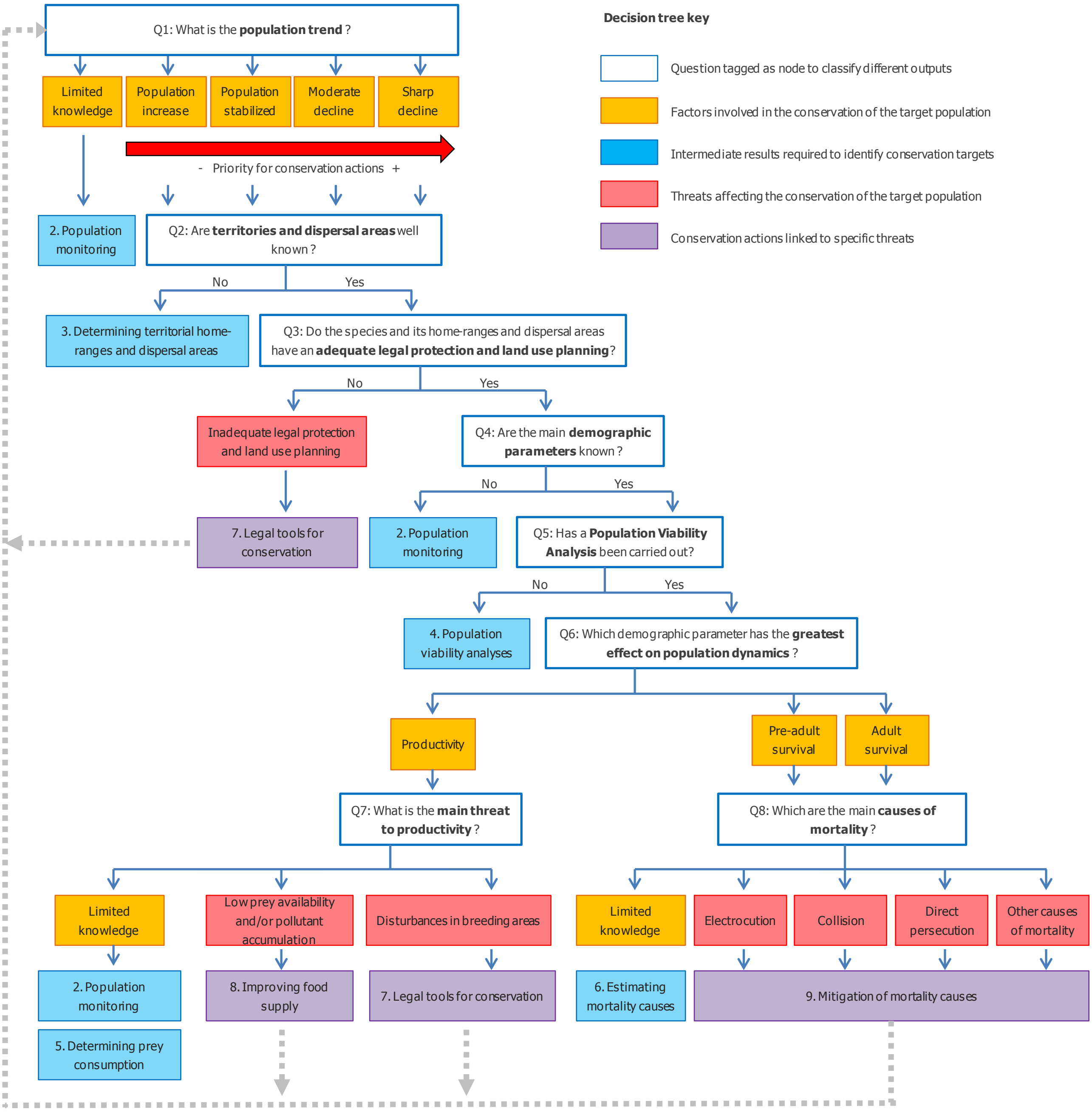


***Figure 4**: Decision tree as a roadmap and a visual structure of the conservation process in Bonelli's eagle populations. The dashed block arrows indicate the need to go back to the initial point of the conservation process to evaluate the effectiveness of the conservation actions in an adaptive management framework.*

Q1: What is the population trend?

Assessing distribution (where the species is), size (number of breeding pairs) and trends (is it increasing, stable or decreasing?) in target populations are initial steps for preserving them effectively. Although most local and regional populations in Western Europe are quite well studied, variations in size and range may occur rather quickly in time and so regular monitoring should be used to track these changes. Additionally, even such basic information may still be mostly unknown in many other populations (e.g. North Africa, India). Regarding the trend (5–10 years of annual population census may be needed to detect a neat change in population trends), a variety of situations could be ranked with less (increase) to more priority (sharp decline) for conservation actions. Although priority obviously should be put on populations undergoing sharp declines, increasing populations should not be disregarded since natural systems are highly dynamic and this situation may change in the future. Moreover, even increasing populations may have an influx of individuals from other neighbouring populations that conceal certain significant conservation threats. Proceed to the next question or go to chapter 2 (Population monitoring) if population size, range or trends are unknown.

Q2: Are territories and dispersal areas well known?

Knowledge of spatial patterns and home-ranges in Bonelli's eagle is an essential tool on which to base *in situ* conservation measures and for implementing sustainable land-use planning and regulation of human activities. Proceed to the next question or go to chapter 3 (Determining territorial home-ranges and dispersal areas) for detailed protocols and methods to obtain information of spatial use by eagles.

Q3: Do the species and its home-ranges and dispersal areas have adequate legal protection and land-use planning?

A lack of an adequate legal protection, land use planning or regulation of human activities results in an increase of some threats on the species. E.g., direct persecution might be a major threat in some countries if the species lacks a basic legal protection. Thus, the entire set of legal protection, from international laws and conventions to regional and local laws, plans and regulations, should prevent or counter various threats affecting the species conservation. Proceed to the Next question or go to chapter 7 (Legal tools for conservation) if these are lacking or are inadequate.

Q4: Are the main demographic parameters known?

Knowing the demographic parameters determining the viability of a population (productivity and adult and pre-adult survival) is essential in order to perform a Population Viability Analysis and correctly allocate conservation efforts. Proceed to the next question or go to chapter 2 (Population monitoring) to know about detailed protocols and methods on demographic parameters estimation.

Q5: Has a Population Viability Analysis been carried out?

Population viability analysis (PVA) is a basic tool in current conservation practice since it provides technical and scientific information for guiding decision-makers working with populations of target species. It is a suite of quantitative methods that can estimate the probability that a population will go extinct at a given time in the future. PVAs can be drawn from census data, though they are more realistic and useful if they incorporate the age- or stage-structure of the population (e.g. territorial and non-territorial individuals) and if they consider the values of vital rates estimated from the size of each of the groups composing the population (e.g. groups of individuals based on their age). Ideally, PVAs should incorporate all relevant aspects determining the dynamics of the population such as dispersal processes and the spatial structure of the population. Then, research and conservation actions can target factors that may have an important impact on extinction probabilities or on the rank order of management options. If a PVA has not been performed yet, go to chapter 4 (Population viability analyses) to know about detailed protocols and methods for implementing them.

Q6: Which demographic parameter has the greatest effect on population dynamics?

Sensitivity and elasticity analysis carried out during the PVA process allow us to rank demographic parameters from more to less priority for conservation actions. It is worth noting that, in general, a simple ranking of demographic parameters according to their sensitivity may not be enough, and detailed sensitivity analysis may reveal that acting on the vital rate with the highest value of sensitivity is not always the optimum decision (i.e. because the range of values that a given vital rate may take are limited). In theoretical terms adult productivity may reach values up to 2 chicks per pair, but even the healthiest populations in southern Spain show values below 1.5 chicks per pair. Similarly, real world implementation of desired measures may be unfeasible because improving pre-adult survival may be difficult for a local government, for example, if pre-adult eagles spend most of their time outside the area that can be managed. In all these cases, suitable analyses may help identify the most suitable strategy for achieving the intentioned positive impact.

Q7: What is the main threat to productivity?

When the PVA suggests undertaking conservation measures to increase the values of this demographic parameter, the causes of low productivity need to be identified. In this case, there may be a variety of threats acting simultaneously (that should all be considered at the same time) that can be classified into two main groups: low prey availability and accumulation of pollutants, and disturbances in breeding areas. If unknown, go to chapters 2 (Population monitoring) and 5 (Determining prey consumption); otherwise, go to chapters 7 (Legal tools for conservation) and 8 (Improving food supply).

Q8: Which are the main causes of mortality?

When the PVA suggests undertaking conservation measures to increase values of adult and pre-adult survival, the causes of death need to be identified. If the causes of mortality are unknown, go to chapter 6 (Estimating mortality causes); otherwise, go to chapter 9 (Mitigation of mortality causes) for detailed protocols for mitigating the impact of each threat on mortality.

IDENTIFYING CONSERVATION TARGETS

2. POPULATION MONITORING

Assessing species' distributions and population sizes (number of breeding pairs) is an initial step towards implementing measures for animal population conservation. Monitoring distribution and size of animal populations is essential for three main reasons: (1) to understand what we have in our area of interest, (2) to identify temporal variations in population size, a prerequisite to understanding what processes drive these variations, and (3) to determine the effectiveness of management actions.

In large territorial raptors such as Bonelli's eagle, population size may be estimated in absolute terms (e.g. number of territorial pairs). If all the area of scope cannot be surveyed, samplings should be designed bearing in mind that distribution of territories over regional scales may be highly heterogeneous and show aggregated patterns. Census data must be comparable between areas (countries or regions) and over time. Thus, standardized protocols for a long-term monitoring programme preclude bias due to using different census methods or an uneven sampling effort. If biases derived from sampling methods exist, suitable corrections should be applied for comparison. The basics of a long-term monitoring programme are summarized in Figure 5.

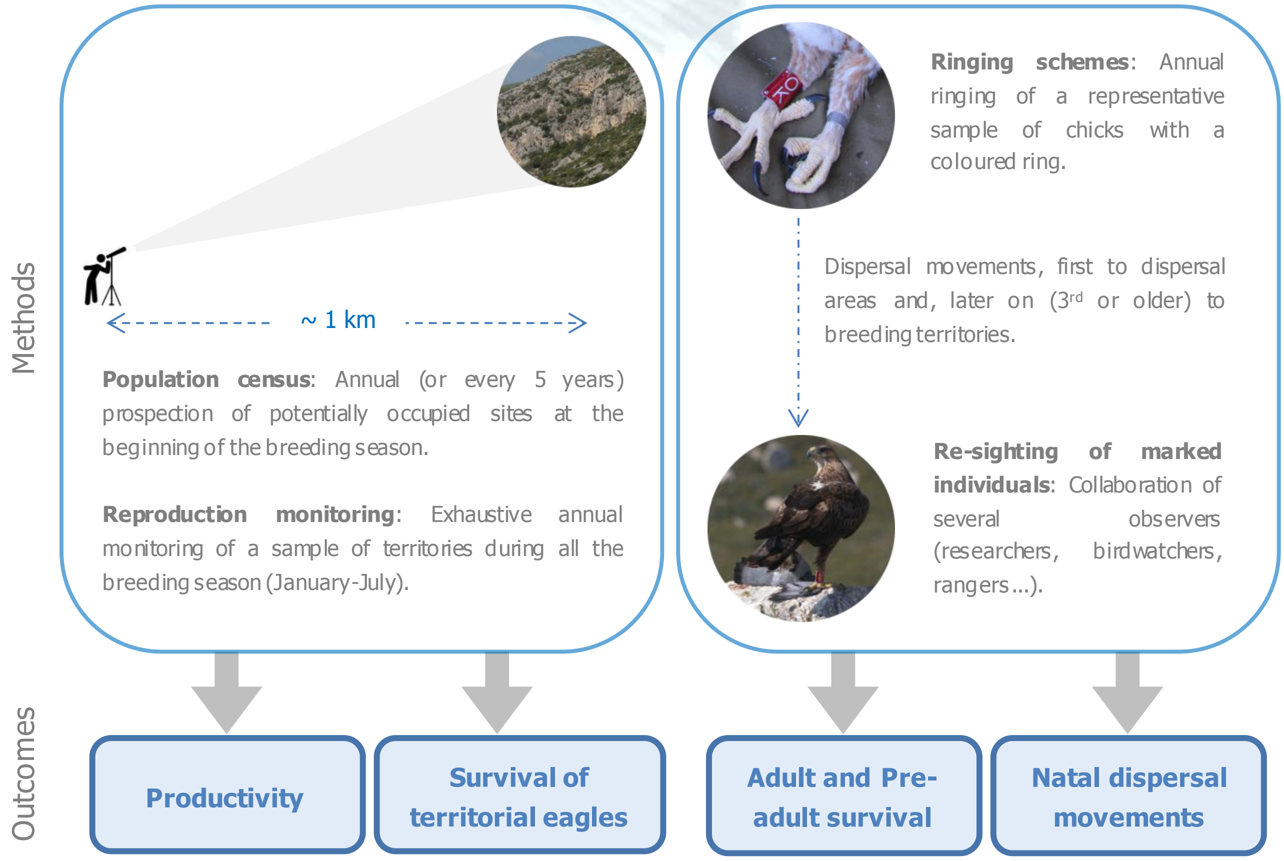


***Figure 5**: Tasks to be included in a long-term population monitoring programme. Photos: CBG-UB, except adult eagle ringed as a chick in Catalonia but observed by Alain Marmasse on a territory in France.*

The first step consists of a **population census** and the information that must be obtained is (1) number and location of occupied and unoccupied territories and (2) number of individuals present in each territory (solitary individuals may be present in declining populations), age and sex of territorial individuals according to size (females bigger than males) and plumage (Ferguson-Lees & Christie, 2006; Forsman, 2007; García *et al*., 2013). Population censuses should be conducted with a regular frequency, every year for local populations in poor conservation status or every five years for healthy local populations or in case of national surveys. Thus, there must be someone in charge of coordinating field staff who provides protocols and receives and compiles the information in the study area. All efforts must be taken to minimize disturbance. In this sense, observations to verify the occupation of a territory should be carried out from a long distance to nests (~ 1 km) and their situation should not be divulged as this could negatively affect reproduction and the occupation of the territory. Areas holding potentially occupied territories may be inferred from species distribution models. Adequate survey protocols and a good knowledge of the species' biology are necessary to locate the breeding area and to confirm occupation. A detailed standardised protocol is described in Del Moral (2006).

In addition, a representative sample of territories, or all territories in populations of less than 20 pairs, should be subject to exhaustive annual **monitoring of reproduction** performed throughout all the breeding period (from January to July). The key information to gather for each territory is whether (i) eggs are laid (inferred from incubation behaviour), (ii) chicks are born and (iii) the number of fledged chicks. To obtain such information, once occupation of a territory is confirmed, a minimum of four more visits are needed to determine whether incubation is initiated and to determine the number of up to ~10-, ~35- and ~60-day-old chicks, respectively. Thanks to this information, annual productivity for each territory can be estimated.

30–35-days-old Bonelli's eagle chicks in the nest. Author: Carles Barés (Agents Rurals, Generalitat de Catalunya).

A 60–70-days-old Bonelli's eagle fledging about to leave the nest. Author: Francesc Parés (CBG-UB).

Moreover, during fieldwork for population census or reproduction monitoring any relevant information such as interaction with potential competing species and human infrastructures and activities must be recorded, since **disturbances** during the breeding period may lead to a breeding failure and this information may help to elucidate its causes.

The main breeding parameter to be calculated annually for each territory is **productivity**, defined as the number of fledglings produced per occupied territory. A young bird is considered fledged when it reaches 60 days (8–9 weeks) of age. Then, the average and the standard deviation of this annual parameter can be calculated for the studied population.

As a general rule, capture-mark-recapture (CMR) methods are the best for estimating survival (Lebreton *et al.*, 1992). Nonetheless, it is extremely difficult to have a large sample of individually identifiable territorial individuals (on the basis of tags) in populations of large eagles. As an alternative, and possibly more sensitive to temporal variations, annual **survival rates for territorial birds** can be indirectly estimated through the turnover rate (TOR) method. To do so, studied territories of Bonelli's eagles are checked at the start of every breeding season for the presence of territorial birds, and the age of these individuals is assessed based on plumage characteristics (Ferguson-Lees & Christie, 2006; Forsman, 2007; García *et al.*, 2013). The turnover rate (opposite to survival rate) is computed for each territory as the total number of birds that either disappear from that territory from one year to the next or are replaced by a bird of another age, in relation to the total number of individuals and years considered. It is worth noting that the method assumes that breeding dispersal never occurs or, if so, it occurs between territories that are surveyed. While breeding dispersal seems to be rare in Bonelli's eagles, reported cases have occurred between neighbouring territories. Based on this method, average values for the population can be estimated from the geometric mean and variance of binomial distributions. However, since the replacement of adult birds by other adult birds is not always detected, adult survival estimates may be biased because adult–adult replacement may cause an overestimation of this parameter. To solve this problem, corrections for obtaining accurate survival estimates based on information from ringed (see estimation of pre-adult survival described below) or radio-tagged individuals can be used. Using this approach, unbiased yearly survival estimates and its corresponding confidence intervals can be estimated (see details in Hernández-Matías *et al.*, 2011a).

The most reliable and effective way of estimating **pre-adult survival** are CMR methods and a dataset from long-term ringing schemes. To achieve this information, it is necessary to annually ring a representative sample of chicks. Accessing nests requires specific training and must be done with the aid of climbers experienced in handling eagles (see box below). Chicks must be 35–45-days old. It is also very important to avoid causing any disturbance to eagles during these visits. Chicks are equipped with an alphanumerically coded, coloured riveted metal ring that permits individual identification from a distance. The re-sighting of marked individuals is the basic source of information not only for estimating the survival of non-territorial birds (Hernández-Matías *et al.*, 2011a, 2011b and 2015) but also for understanding natal dispersal movements (i.e. between the natal area and the site of first breeding) between territories and even between neighbouring populations (Hernández-Matías *et al.*, 2010 and 2013). To get a consistent amount of re-sightings, dispersal areas (prey-rich areas where young eagles may remain for several years after post-fledging dependence and before recruitment) should be intensively surveyed in a well-designed fashion. If not possible, collaboration with birdwatchers and conservation managers during the fieldwork is essential. Ideally, re-sighting efforts should be quantified in order to correct the CMR analyses for effort. Similarly, observation of territorial birds during surveys may check if birds are ringed or not. Collaboration with animal rehabilitation centres and managers is also crucial to obtain all the information from recovered birds, i.e. from birds that are found dead.

Finally, statistical CMR models can be built to estimate survival rates. These models are data-hungry and, given the low numbers and the long lifespan of the study species, we will need several years of ringing and monitoring to gather the necessary data (see case study below). It is also worth remarking that classical CMR methods assume that all individuals are equally likely to survive and be re-sighted, which may not be true. To obtain proper estimates of survival, modern multievent CMR analysis allows sources of individual heterogeneity to be taken into account (Pradel 2005, Hernández-Matías *et al*. 2015). For example, the probability of re-sighting a bird may depend on its territorial status, so non-territorial and territorial individuals should be treated as in different states. Similarly, individuals found dead by electrocution may have a different encounter probability than those dead by other causes, for example, because specific surveys to detect electrocution are performed. An extreme example is ring loss, which is common when PVC rings are used. In some cases it is possible to tackle this problem (Hernández-Matías *et al*., 2011b), but it is much more preferable to mark birds with more resistant riveted metal rings.

Important considerations when accessing to the nests for ringing chicks

Ringing requires very careful preparation since it has to be quick to avoid undesired disturbance and to ensure full security for both the people involved and the eagles. At least four people are necessary: two climbers and two biologists or fieldwork experts to ring the chicks. An additional climber may be necessary for nests of difficult access and an additional person may be necessary to guide (from a distance) climbers when descending vertically to the nest.

The features of the cliffs need to be checked previously so that climbers know all the climbing material they will need and the best way to access to the nest. Additionally, accesses to the brink or the base of the cliff need to be known. The best way to carry out the operation is for climbers to capture the chicks and then transport them to the upper or lower part of the cliff where birds can be securely processed by biologists. Chicks have to be transported separately in special bags. Biologist may also take basic security measures (e.g. use of helmets, secure with harness). Depending on its features, it may be better to handle the birds on the top or at the base of the cliff. Moreover, ringing actions should be planned for when the cliff is in shadow (particularly on hot sunny days). In case of nests placed in trees, climbers have to be trained in tree-climbing techniques.

CS1: Census and main vital rates in the Bonelli's eagle population in Catalonia during the period 1990-2014

Case study

Productivity of the Bonelli's eagle population in Catalonia

Following the protocols described in chapter 2, the productivity was estimated annually from a representative sample of territories during the period 1990-2014. In 2014, the productivity was estimated at 1.02 fledglings per territorial pair (n = 52), the same value as the mean for the period 1990-2014. However, this parameter has been declining over time, falling from 1,08 fledglings / pair (1990-2003) to 0,94 (2004-2014).

The decline observed on this reproductive parameter in recent years suggests that the Catalan population of Bonelli's eagle is experiencing a worsening of environmental conditions, such as a decrease in its main preys due to habitat changes and the increase of disturbances from leisure activities. Therefore, urgent conservation actions are required to reverse this negative trend.

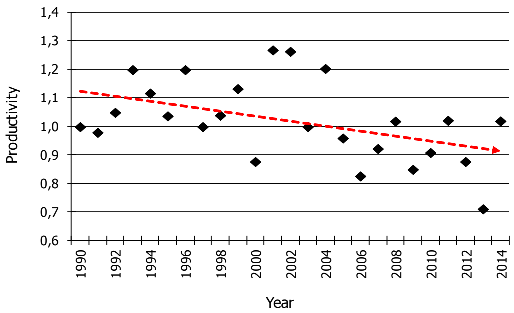


Fig. 1a: Evolution of productivity of Bonelli's eagle population in Catalonia (1990-2014)

Survival of territorial and pre-adult eagles

Using the TOR corrected method described above, survival of territorial eagles was estimated annually from a representative sample of territories during the period 1990-2014. In 2014, survival was estimated at 0.894 for all territorial eagles (n=100) and at 0.924 for adult territorial eagles (n=92). This value of adult survival is high for the Catalan population and indeed this rate have shown relatively high values in the last three years. However, average values estimated for the period 1990-2014 (0.89) are still very low for this species.

On the other hand, Pre-adult survival was estimated using multi-event capture-recapture models. Given that most territorial eagles recruit at 3 or 4 years old, the used data was the subset of ringed birds from 2008 to 2014 (n=251 chicks).

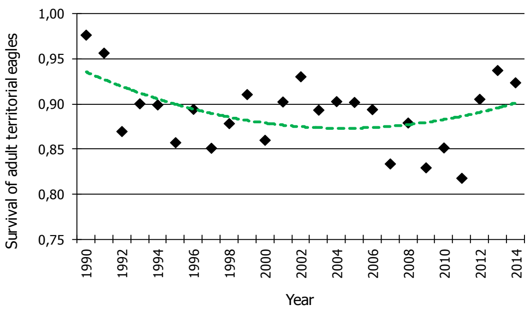


Fig. 1b: Evolution of adult survival of Bonelli's eagle population in Catalonia (1990-2014)

Of these, 71 individuals were re-contacted (28.3%) on 186 occasions. 28 out of the 34 individuals found dead or injured were electrocuted. Models show that survival increased with age, being lower during the first and second years of life (0.536; 95CI = 0.442–0.627) and higher in eagles over two-years old (0.831; 95CI = 0.702–0.911). Results indicates that conservation actions are required to increase survival of both territorial and pre-adult eagles.

Population trends

A population census of the Catalan population of Bonelli's eagle is been carried out yearly on a long-term basis. Thanks to this, it is known that it was a relatively common species in mid-20th century, having an estimated population of about 90 pairs that progressively decreased until the end of the century. The population monitoring revealed a deep decline during the 90's reaching a historical minimum in 2000 of 65 pairs. After that, population was stabilized and even appeared to be increasing very slightly (Fig. 1c) despite the low values of productivity and adult survival. This suggest that the Catalan Bonelli's eagle population might be receiving individuals from other regions.

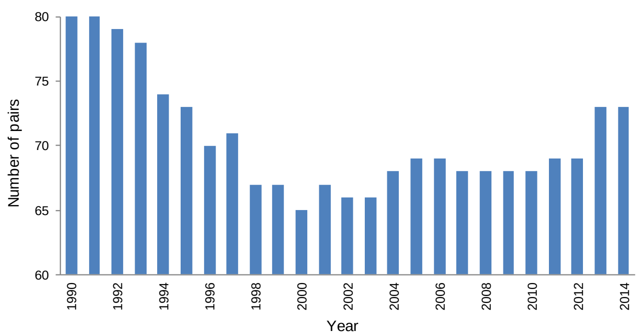


Fig. 1c: Evolution of Bonelli's eagle breeding population in Catalonia. Source: Department of Agriculture, Livestock, Fisheries and Food, Government of Catalonia.

3. DETERMINING TERRITORIAL HOME-RANGES AND DISPERSAL AREAS

Spatial use patterns by Bonelli's eagle arise from the interaction between individual (mainly age and sex) and environmental characteristics (mainly resource availability). For example, the availability of cliffs may determine the location of breeding areas, or the abundance of prey may shape the location of hunting areas. In addition, the spatial use performed by eagles determines their exposure to threats such as the risk of being persecuted, suffering a collision or being electrocuted. This means that knowledge of the spatial use by eagles is required in order to implement effective conservation actions aimed at protecting breeding areas, improving habitat quality or mitigating the main causes of mortality.

In this chapter, we briefly summarize the most common methods that either have been used or may be useful in the future to obtain information of spatial use by eagles.

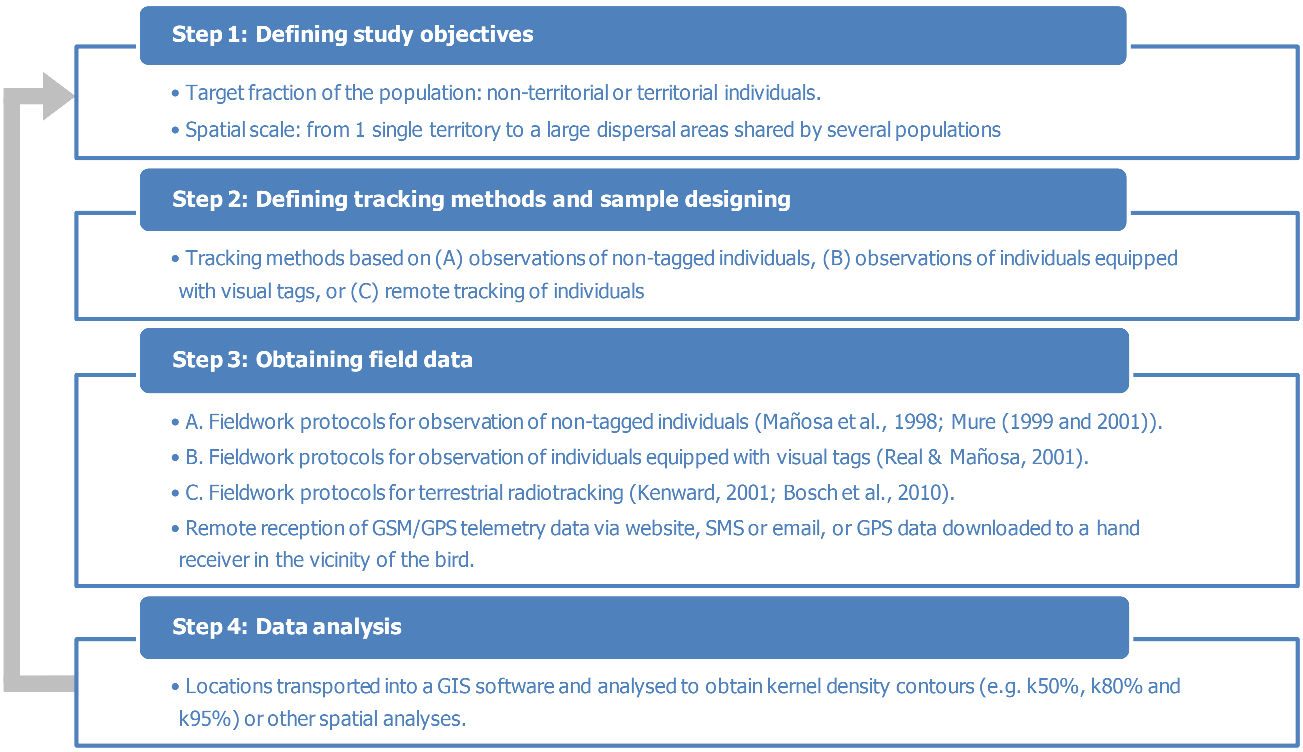


Figure 6*: Steps to be followed when determining Bonelli's eagle spatial patterns. This process should be repeated on a regular basis in order to update spatial patterns that may have been modified due to changes in habitat and/or land-use.*

3.1. Defining study objectives

Initial steps include detailed identification of the aims and scope of the study and the area of interest, and an assessment of the resources available to perform the research. Thus, a good understanding of the main biological traits of Bonelli's eagles is mandatory to correctly design the study. In this sense, a first important decision is to identify whether the study aims to identify the spatial use patterns of non-territorial or territorial individuals, since these two fractions of the population display rather different behaviour and exploit spatially separated areas.

Non-territorial individuals are birds in the period lasting from post-fledgling dispersal to territorial recruitment that usually occurs at three or four years of age (the so called 'dispersal period'). During this period, eagles do not show territorial behaviour and may perform long-distance movements of tens to hundreds or even thousands of kilometres. At this stage, individuals temporally settle in 'dispersal areas', which are usually flat undulating relief landscapes, mainly covered by scrublands or dry farming regions where food abounds (mainly rabbits and partridge in Western Europe) and located away from nesting areas (Real & Mañosa, 2001; Cadahía *et al.*, 2010, Moléon *et al.*, 2011; Orta *et al.*, 2015). The main dispersal areas known in the Iberian Peninsula are described in Real & Mañosa (2001), Real (2004), Balbontín (2005) and Cadahía *et al.* (2010), though it is also known that relatively small areas rich in prey and situated close to areas with territories may be exploited by non-territorials. Importantly, dispersal areas may be shared by individuals from different populations and, therefore, conservation actions in these areas may positively affect both nearby and distant local populations. On the other hand, it is also worth mentioning that dispersal areas may change over time due, for example, to variations in prey availability and changes in land use.

If dispersal areas have been already identified, managers may aim to finely delimitate their boundaries or identify the most intensively used patches. In this sense, it is known that non-territorial eagles tend to use more intensively dispersal areas that are close to natal populations.

Territorial individuals are those already recruited in a territory that they defend against both conspecifics and intraguild heterospecifics. Bonelli's eagle is a monogamous and sedentary species that lives in pairs on the same territory throughout the year. These territories include two kinds of sub-areas with a different functions: breeding areas and hunting areas. Breeding areas lie at the centre of the territorial activity and are usually located on cliffs or crags where nests are built and where eagles breed, feed and rest. Traditionally, conservation efforts for birds of prey have focused on breeding areas, largely because it has always been thought that breeding success can be maximized in this way. However, eagles may often use prey-rich areas distant from nest-sites (up to 14 km away) for hunting. In addition, home-ranges do not have a regular shape and size, so that extrapolating from a radius around a nest is not an accurate way of defining sensitive areas (Bosch *et al.*, 2010). It is worth underlining that breeding areas usually remain quite stable for many years (even decades), especially in high-quality territories. By contrast, hunting areas are much more dynamic and may change over the years in response to variations in habitat and prey availability. Consequently, studies addressing the identification of either dispersal areas or the home range of territorial individuals should be aware of their temporal dynamics. Studies addressing spatial use by territorial eagles have an *a priori* restricted spatial scale that may range from a single territory (e.g. in a single natural park) to a large sample of territories in a population (e.g. in a particular region).

A typical breeding area in a Bonelli's eagle territory, characterized by the presence of cliffs for nest building. Author: Francesc Parés (CBG-UB).

A typical hunting area in a Bonelli's eagle territory, characterized by a mosaic of habitats (shrublands, farmlands, small patches of pinewood, etc.). Author: Àlex Rollan (CBG-UB).

A typical dispersal area in Catalonia. Author: Àlex Rollan (CBG-UB).

Finally, sex is another important determinant of spatial use in the case of eagles. This is particularly so during reproduction because females spend much more time in the breeding area and invest more time incubating or taking care of young chicks. These behavioural differences suggest that tagging males may provide more comprehensive information on home ranges, since in all other periods of the year males and females tend to exploit the territory together and there is much overlapping between sexes in the same territory (Bosch *et al.*, 2010). In the case of non-territorials, there is no information about sex-specific use of space, although it is known that females show larger natal dispersal distances than males (Hernández-Matías *et al.*, 2010) and, therefore, it is possible that spatial use patterns are also different during the dispersal period.

Based on all this information, users of these guidelines should carefully identify the aims and scope of their study and its area of interest, and assess the resources available to perform their research.

3.2. Defining tracking methods and sample designing

A set of methods of varying complexity is available for addressing the spatial use of both non-territorial and territorial individuals (Bird & Bildstein, 2007). These can be grouped into three main types, which are described below:

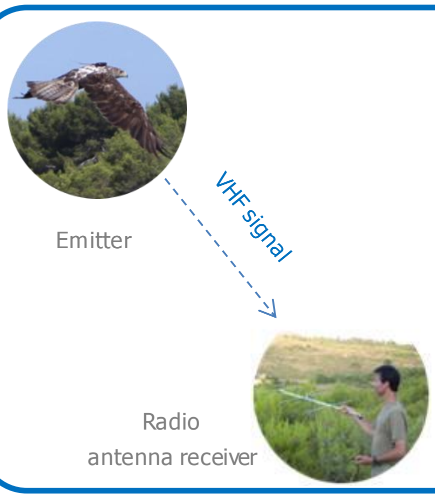
A. Methods based on the **observation of non-tagged individuals**. These are very sensitive to monitoring effort and the detectability of birds; consequently, they may provide biased results if studies are not suitably designed. However, they may be the only available method in some situations. In the case of non-territorial individuals, Mañosa *et al.* (1998), for example, compiled information for non-adult individuals provided by ornithologists over a large area of Catalonia, and then in the most important identified area performed surveys in 11 sectors selected on the basis of environmental variables known to favour the presence of eagles during August–March over three consecutive years. In Mure (1999 and 2001), a similar example is given for territorial birds, in which simultaneous surveying is used at a network of observation points on specific observation days. In all cases, efforts are required to prevent biased results, particularly in the case of areas with several neighbouring eagles where it may be difficult to assign the observation of one individual to a given breeding area. Most sophisticated methods such as spatial models parameterised on the basis of tracking data are feasible, although to our knowledge they have not yet been applied in Bonelli's eagle (see McLeod *et al*. 2002, for an example with golden eagles).

B. Methods based on the **observation of individuals equipped with visual tags**. These methods are also very sensitive to sampling effort because we cannot obtain information from areas that are not surveyed. Nonetheless, the fact that birds are identifiable ensures the correct assignation of a bird to a given area of origin or territory. For non-territorial individuals, Real & Mañosa (2001) tagged 122 fledglings in Catalonia in 1986–1993 and thereafter compiled information on re-sighted (alive) and recovered (dead) individuals until 1998 from all over the Iberian Peninsula and France. Despite the fact that the observation effort was unavoidably non-homogeneous, this study identified the most important dispersal areas for Bonelli's eagle in this large geographic range.

C. Methods based on **remote tracking of individuals**. These are the most suitable methods for understanding in detail spatial use by eagles. Basically, a transmitter is attached to an individual of interest and its position can be tracked over time. In recent times, tremendous developments have taken place in technology and some devices now provide tracking positions every few minutes and additional information such as acceleration or movement patterns. Some devices also include ground track systems to aid the location of birds that have died. Systems and technologies available for tracking wildlife movements can be grouped into three broad types summarized in Figure 7. However, advances in technology occur very quickly. Therefore, researchers may have to choose the currently available technology that best suits their research objectives. Note that both Argos Doppler and GPS emitters can be either battery- or solar-powered. Battery-powered emitters offer generally reliable performance but have the disadvantage of rather short operating lives (a few years, depending on the battery weight) and so long-term studies are not normally possible. Solar-powered emitters can provide locations for up to several years but the regularity of data depends on enough light falling on the solar panel to charge the battery (Meyburg & Fuller, 2007).

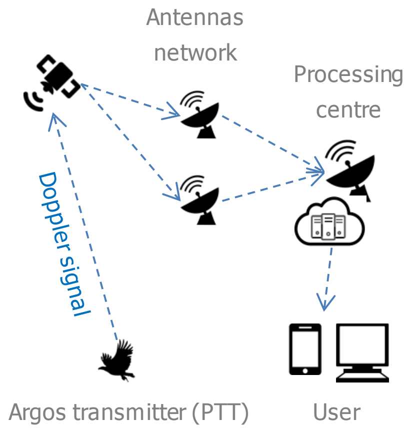
When planning fieldwork for terrestrial radio-tracking or when selecting locations from Doppler or GPS tags to determine territorial home-ranges and dispersal areas, it is important to have data that is evenly spread throughout the year in order to avoid potential biases due to differences in spatial use occurring during the year. Thus, it is better to have data from a few locations regularly distributed through the year than data from several locations concentrated in just a few months. In this sense, Bosch *et al*. (2010) estimated the home range of territorial eagles by obtaining hourly locations during a whole day for four days a month during a complete yearly cycle.

Finally, it is worth pointing out that tagging individuals with transmitters will also generate data for survival analysis (see Chapter 6) and data on natal dispersal patterns (movements between the natal area and the site of first breeding) and behaviour. However, in the latter case, readers should be aware that a relatively low proportion of individuals tagged when fledglings survive to recruitment and that, if birds are equipped with transmitters, it is unlikely that they will be working when birds recruit.



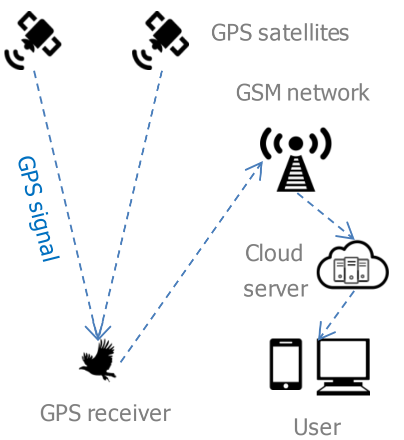
Terrestrial radiotracking: Equipment is based on VHF (Very High Frequency) and consists of a receiver tuned to a specific "station" or channel (like a radio) that matches the channel on the animal's tag. When the field researcher with the radio antenna receiver approaches the animal, the receiver beeps more loudly.

However, researchers need to be close enough and have their receiver pointed in the correct direction. Consequently, it is a highly time-consuming method and can only be used within a geographically restricted area, e.g. for tracking territorial eagles movements (Kenward, 2001; Bosch *et al.*, 2010).



Argos Doppler tags: Also known as Platform Transmitter Terminals (PTTs). Doppler effect transmitters have low power consumption but generally provide fewer high-accurate locations per day than GPS transmitters.

However Argos PTTs can also be equipped with GPS receivers and send GPS positions via Argos system (see GPS tags). Together with GPS tags, they have the advantage of being able to regularly record an individual's location worldwide for several years without any need for fieldwork carried out by an observer.



GPS tags: A GPS tag calculates the location of an animal at specific time intervals using positions estimated by a network of satellites, as in modern smart phones or handheld GPS devices used for navigation. These locations can be stored in the tag, transmitted to the user through a GSM communication network (see diagram), Argos system or ad hoc wireless downloads from the vicinity of the animal. Locations can be recorded every few minutes per day with a high accuracy (~ +/−20 m) and some tags can be remotely programmed to be active during a particular period of time (Meyburg & Fuller, 2007; Tomkiewicz *et al.*, 2010; Urbano *et al.*, 2010).

***Figure 7**: Characteristics of the main three broad systems for remote tracking wildlife movements and behaviour.*

3.3. Data analysis

Geographic Information Systems (GIS) and statistical methods to analyse spatial information have also experienced a spectacular development in recent years. Consequently, it is nowadays possible to obtain a comprehensive understanding of a wide array of topics related to spatial use such as the delimitation of home-ranges, habitat preferences or spatial activity patterns.

The simplest way to draw the boundaries of a home range from a set of location data (either from terrestrial radiotracking or GPS-Satellite telemetry) is to construct the Minimum Convex Polygon (MCP), which indicates the maximum area used including outliers. However, although this method is still widely employed, it has several biases including often overestimating the size of home ranges and not distinguishing areas with different levels of use by eagles (Burgman & Fox, 2003). On the other hand, fixed kernel density contours (Worton, 1989) allow different levels of spatial use to be assessed. In this approach, kernels are isolines that describe different probabilities of use in home-ranges. The 95%, 80% and 50% contours are the most commonly used, and they are related to low, medium and intensively used areas by eagles, respectively (see Figure 8). Choosing the appropriate smoothing parameter (or bandwidth) is an important issue in a kernel analysis (Kie *et al*. 2010). In order to develop home-range sizes through the kernel density contours (KDC) approach, all locations must be transported into a GIS software. Detailed protocols for data selection are found in Kenward (2001) and Bosch *et al*. (2010).

The KDC approach can also be used to determine dispersal areas. Since in this case the overlap level of KDC of dispersing eagles would be much higher than in territorial eagles, it would make sense to obtain these KDC from a single dataset relating to different individuals. This would allow us to assess the different levels of spatial use by the overall dispersing population. However, although some studies have already used GPS-Satellite telemetry to estimate pre-adult survival and analyse their movements (Cadahía *et al*., 2005 and 2007), the KDC approach has not yet been used to describe the most used areas by dispersing eagles.

Recent developments in tracking devices have also motivated a parallel development in methods such as movement-based kernel density estimation (Benhamou, 2011, Monsarrat *et al*., 2013), which are useful for handling a large amount of locations and obtaining very detailed information on corridors and fine-scale core areas. All this information is highly valuable for implementing conservation measures in these dispersal areas, for example for prioritizing actions to minimize Bonelli's eagle electrocution on power lines (Moleón *et al*., 2007; Tintó *et al*., 2010). However, spatial information with high detail should be used with caution, since spatial-use patterns in Bonelli's eagle arise from the interaction between individual and environmental characteristics, as pointed out at the beginning of this chapter, and these may change markedly over seasons and years.

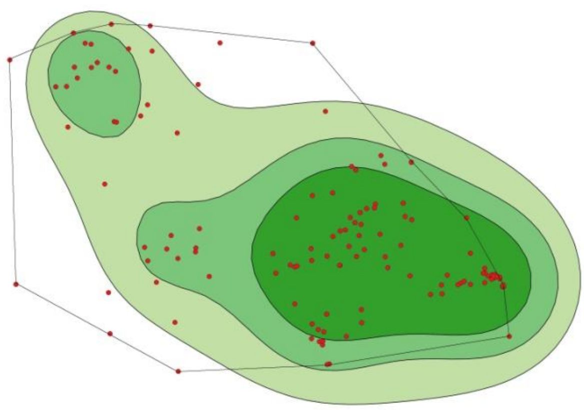


***Figure 8**: Example of 95%, 80% and 50% kernel density contours (from pale to dark green) and MCP (black polygon) built from a sample of 150 randomly selected independent hourly locations (red spots), evenly spread throughout the year for a territorial Bonelli's eagle (Bosch et al., 2010).*

4. POPULATION VIABILITY ANALYSIS

Population viability analysis (PVA) has become a basic tool in current conservation practice since they provide technical and scientific information for guiding decision makers working with populations of target species. PVAs consist of a suite of quantitative methods for predicting the likelihood that a population will increase to above a minimum size at a given future time (Morris & Doak, 2002). Although many products of PVAs are useful for management and conservation, the two main goals pursued are: (i) assess the extinction risk of a population or collection of populations; and (ii) identify key life stages or demographic processes as management targets. PVAs cover a range of data analysis and modelling methods that vary widely both in their complexity and in the type of data they require.

PVAs can be classified into two broad types according to how they handle the demographic structure of the population: count-based PVAs and demographic PVAs (see Figure 9).

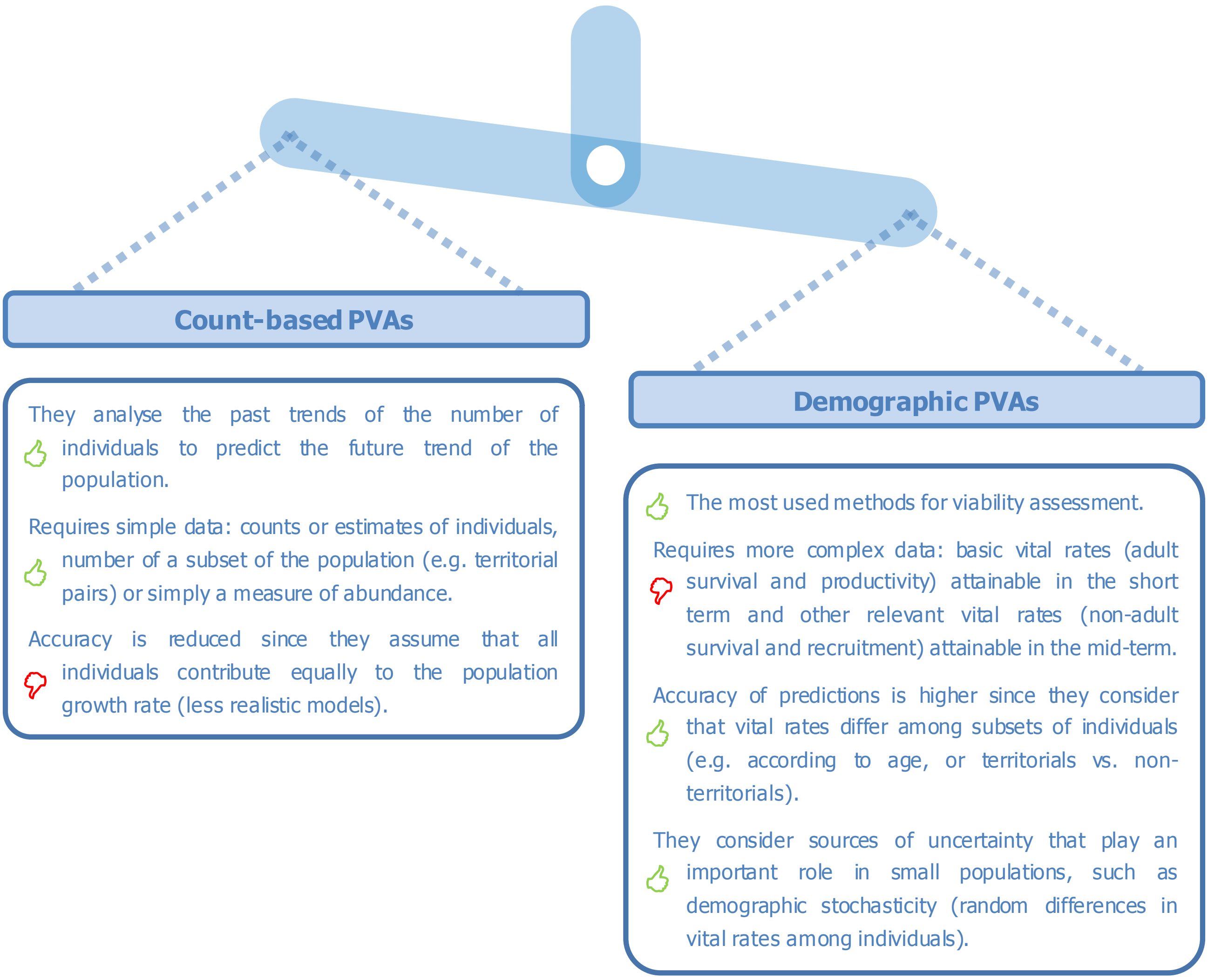


Figure 9*: Broad types of PVAs. We advocate performing demographic PVAs whenever possible since they are much more accurate. See Morris & Doak (2002) for further information.*

In the case of Bonelli's eagle, in these guidelines, we advocate performing demographic PVAs whenever possible since, despite still being an oversimplification of the real world, they are much more accurate and realistic than count-based PVAs. A sequence of the steps required to implement a demographic PVA is summarized in Figure 10. The main aims of the PVA represented here are to calculate some basic viability metrics of a population and identify management targets in terms of key life stages or demographic processes that will have a major effect on the dynamics of the study population. In this example, the model assumes a single population, structured into five age classes and two territorial stages, but does not consider the spatial structure of the population. Comprehensive guides on how to perform PVAs are available in the literature (e.g. Beissinger & Mccullough, 2002; Morris & Doak, 2002).

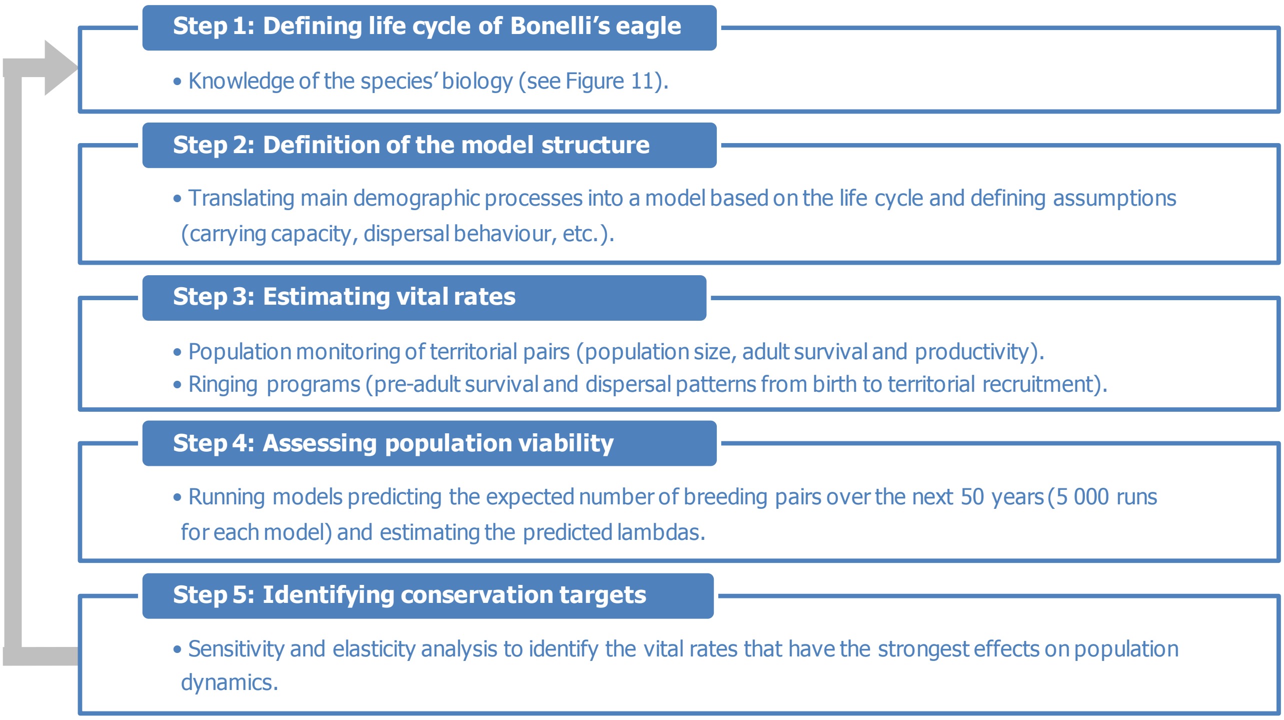


***Figure 10**: Steps to be followed in a Population Viability Analysis. See Hernández-Matías et al. (2013) for further information on each step.*

The first step consists of defining the **life cycle** of Bonelli's eagle that will become the basis of the definition of the structure of the demographic model used in the analysis. The life cycle of Bonelli's eagle is structured into five age classes strongly correlated with the main vital rates, which allows us to model appropriately the differing contribution to population growth of individuals from different classes (see Figure 11). To simplify, models may be constructed considering only post-breeding census of females in these age classes, which implies assuming a sex ratio of 1:1 and no important differences in vital rates between sexes.

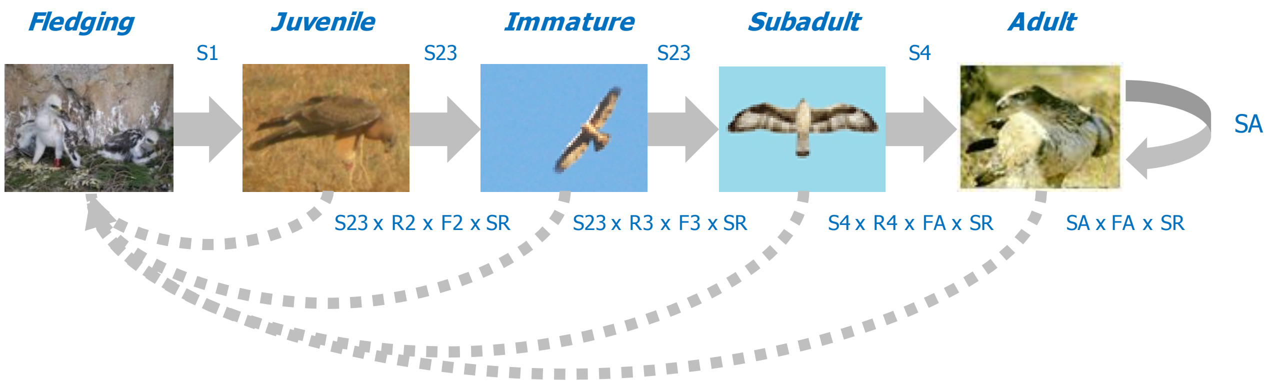


Figure 11*: Diagram of the Bonelli's Eagle life cycle (see Step 1; Figure 10). The solid lines represent the transitions between age classes, while the dashed lines represent the connection between age classes due to reproduction. SR and F represent the sex ratio and fertilities, respectively, for any given age class (F2, F3, and FA being fertility of two- and three-year olds and adults, respectively). S represents the survival rates of individuals during their first (S1), second and third (S23), fourth (S4), and fifth and subsequent (adult) years of life (SA). R represents the propensity to become territorial in immature birds (R2), subadults (R3), and first-year adults (R4) (adapted from Hernández-Matías et al., 2013).*

In the second step, the **model structure** must be defined according to main demographic processes that shape the fate of the population. In the first instance, the previously defined life cycle will establish the basis of the model. Territorial behaviour is an additional aspect that determines the contribution of individuals, since only territorial individuals reproduce. Given that not all individuals recruit at the same age, models ideally should consider age-specific probabilities of recruitment (Hernández-Matías *et al.*, 2010 and 2013). Available evidence suggests that age is a better descriptor of survival than territorial behaviour (Hernández-Matías *et al.*, 2011b and 2015). Nonetheless, if monitoring data and survival analysis of the study population reveals an effect of territorial behaviour on survival this should be considered in the models. At this stage, it is also necessary to define the spatial structure of the population. In the simplest case, the population can be modelled as one single population without spatial structure, which implies that all individuals are assumed to remain in the study population and dispersal processes are overlooked. This approach is particularly useful for determining whether the target population is self-sustaining (i.e. deaths are compensated by births), a reasonable management target. Nevertheless, in most situations populations are connected by dispersal and, therefore, to realistically estimate the viability metrics of a population it will be necessary to account for the spatial structure of the population and the dispersal processes (see Hernández-Matías *et al.*, 2013).

The models should always account for the effect of demographic and environmental stochasticity on the main vital rates. Density dependence may also play an important role in shaping vital rates and, if possible, it should be considered in the models. Nonetheless, its estimation is challenging since areas with higher densities usually show higher values in the main vital rates, that is, the opposite pattern to that expected under negative density dependence. To suitably estimate density-dependent effects it is necessary to analyse vital rates over time for an increasing population in an area with unmodified environmental characteristics. The carrying capacity of the population is another relevant component of density dependence. Given that Bonelli's eagle is territorial and has rather restricted environmental requirements, it will be very important to include a maximum threshold that the population may reach. A simple approximation to this threshold can be estimated on the basis of historical maximum population sizes and, in the case of increasing populations, as 10% above the current population size. However, more sophisticated methods based on species-distribution modelling can provide more solid information, since environmental conditions may have changed since the population achieved its maximum size. Similarly, the potential population size may be higher that the historical maximum in increasing populations.

In the third step, **vital rates** must be estimated as explained in the previous chapters. They should ideally be estimated using large sample sizes derived from long-term data sets, thereby ensuring representative information for the studied population, as well as a reduction in sampling variances around parameter estimates and a reliable awareness of the effects of environmental stochasticity (White, 2000; Morris & Doak 2002). If some vital rates are unknown, it may be possible to perform a PVA using the values of vital rates of neighbouring populations or of other populations that are thought to share similar environmental and demographic characteristics (e.g. non-territorials may share dispersal areas). Nonetheless, this should be done with extreme care, always bearing in mind that conclusions may be severely biased if the assumed vital rates are wrong.

The fourth step consists of **assessing the population viability** or, in other words, of estimating viability metrics that will be useful for determining the future fate of the population. Models are run for many replicates to predict the population size at a given time in the future (e.g. 5000 replicates to estimate the population size in 50 years). The results should allow the main viability metrics such as the population size (or of a subset of the population), the population growth rate and the quasi-extinction risk to be obtained. The **population growth rate** (lambda or λ) is a common measure of viability that quantifies the annual change in population size: values greater than 1 indicate population growth, while values less than 1 indicate decrease. Similarly, the distribution of the accumulated probability of quasi-extinction may be estimated as the proportion of population trajectories that reach the quasi-extinction threshold during the study period. This threshold should be set at a minimum size below which the population is likely to be critically and immediately imperilled (e.g. 10 territorial pairs in Catalonia). In analyses of very large populations, it will be preferable to estimate the risk of a considerable population decline (e.g. the probability of population decline to thresholds of 75%, 50%, and 20% of current population sizes), since estimating the quasi-extinction risk would only be informative in the event of catastrophe.

Finally, in order to **identify the vital rates** that have the strongest effects on population dynamics, sensitivity and elasticity analyses must be performed. The **sensitivity** of the population growth rate to a particular vital rate is calculated as the ratio of the absolute increment in the population growth rate to the absolute increment in the vital rate. In turn, the **elasticity** is the ratio of the relative increment in the population growth rate to the relative increment in the vital rate. An additional very informative measure is the absolute increment in the population growth rate resulting from a relative increment in a vital rate. We recommend calculating this measure within the range of values of the vital rates observed for the species, which will help to obtain a more realistic picture of the most suitable management targets. In this sense, it is worth to note that the lowest values of productivity observed in Europe, though this rate shows the lowest value of sensitivity and elasticity compared to survival, cause the most negative effect on the population growth rate, even worse than the lowest observed values of survival. Additionally, to suitably identify conservation targets managers should be aware that the economic cost of increasing a given vital rate as to a defined percentage (e.g. an increase of 10% of the current value) may differ substantially among vital rates.

Finally, in order to identify the target value for each vital rate to be managed (i.e. to ensure the self-sustainability of the target population), multiple projections can be carried out in which the value of the vital rate of interest are modified while the other vital rates are kept constant at current values, as illustrated in *Case study 2*. Users of these guidelines should be aware that models are oversimplification of real world, that are useful and completely necessary for evidence-based management, but that are imperfect. So, we strongly recommend that before and after performing a PVA users will identify main shortcomings that may constrain their results. Following this idea, when novel information and better understanding of the population is obtained, PVA should be refined to improve the quality of its results (see Bakker & Doak 2008).

CS2: Population Viability Analysis (PVA) of the Catalan population of Bonelli's eagle in context of Western Europe

Case study

The Catalan population under the closed population scenario

A PVA was carried out for the Catalan population of Bonelli's eagle following the stepwise process described in Figure 10. Values for the main vital rates were obtained for the period 1990-2013 using the different methods described in previous chapters. The demographic model assuming a closed population predicts an annual growth of 0.97. This means that the population would suffer a continuous decline of 3% in the number of territorial pairs (Fig. 2a). Consequently, the risk of extinction would be very high, leading the population to levels near the extinction (fixed to 10 pairs) with a probability ~30% in 50 years (Fig. 2b). Furthermore, the Catalan population should have an adult survival of approximately 0.925 (keeping all other vital rates constant) to be self-sustaining (Fig. 2c). Finally, the sensitivity and elasticity analysis indicates that adult survival is the vital rate with the greatest effect on the annual rate of population growth (Fig. 2d), having an effect about 32 times the productivity and 2.7 times the pre-adult survival (according to sensitivity values). Thus, conservation efforts should be focused on increasing this vital rate.

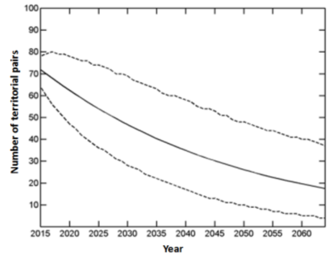


Fig. 2a: Expected population trend (±95%) of the territorial population of B.E. in Catalonia during 2015-2065, under the closed population scenario

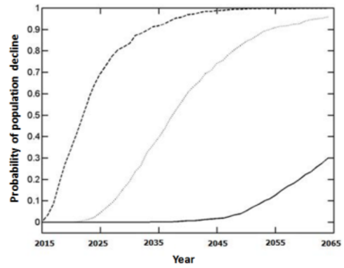


Fig. 2b: Cumulative probabilities of B.E. population in Catalonia decline to 75%, 50%, and 20% (black solid, black dashed, and gray solid lines, respectively) of current population sizes over the next 50 years, under the closed population scenario.

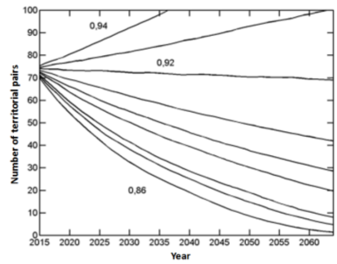


Fig. 2c: Expected population trend of the territorial population of B.E. in Catalonia during 2015-2065 under a closed population scenario and nine adult survival values, from 0.86 to 0.94 (0.01 increments).

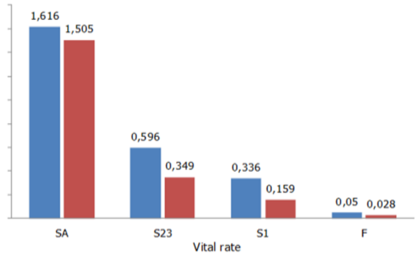


Fig. 2d: Sensitivity (blue) and elasticity (red) values for the population growth due to main vital rates considered: (A) adult (SA,) second and third year (S23) and first year survival, and fertility (F).

The Catalan population exchanging individuals with neighbouring populations

On the other hand, a PVA of the whole western European population (Hernández-Matías et al., 2013) revealed that all populations in western Europe belong to a single, spatially structured population operating as a source–sink system, whereby the populations in the south of the Iberian Peninsula act as sources and, thanks to dispersal, sustain all other ones which would otherwise decline (Fig. 2e). Authors concluded that it would be desirable to implement conservation measures aimed at preserving or restoring the suitability of territories as a means of maintaining or even improving the carrying capacity of populations.

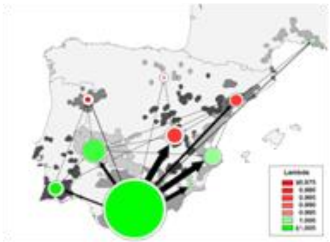


Fig. 2e: Population dynamics of B.E. in SW Europe. Red circles indicate that the local population declined in 1990–2005 (Hernández-Matías et al. 2013).

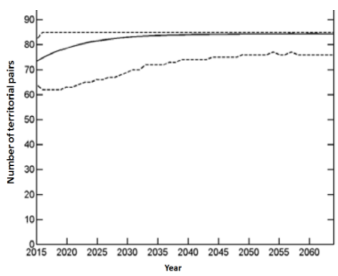


Fig. 2f: Expected population trend (±95%) of the territorial population of B.E. in Catalonia during 2015-2065, assuming exchanges of individuals with neighbouring populations.

In practice, this means allowing southern populations to produce a suitable number of dispersing eagles to sustain other populations and, in northern populations, encouraging unused territories to be reoccupied while avoiding the abandonment of currently used territories. Under this scenario, the estimated growth rate for the Catalan population would be 1,004, which would entail an annual increase of 0.4% (Fig. 2f) in the number of territorial pairs up to a maximum of 90 in a period of 50 years, which is the record of pairs known for this population.

5. DETERMINING PREY CONSUMPTION

Animal foraging ecology strongly influences individual fitness correlates such as body condition, survival and breeding success, and hence it can also explain population dynamics, prey–predator relationships and species distributions (Newton 1998, Moleón *et al.*, 2009). Consequently, knowledge of patterns of diet variation and the understanding of the processes that generate them have important **implications for conservation**:

I. The study of diet is a suitable **tool for diagnosing environmental conditions** in territories and populations, as well as changes over time. It allows us to identify those territories that have trophic problems and allows managers to prioritize resources in areas that require urgent conservation measures; efforts should be focused on improving abundances of rabbits and partridges, the optimum prey items for Bonelli's eagle in Western Europe.

II. On a long-term basis, diet may **reveal conservation problems in advance**, even before serious demographic problems occur (e.g. continued breeding failure over time), and allow managers to mitigate these conservation problems.

III. Human-caused environmental changes have modified prey abundances by diminishing the main prey of Bonelli's eagles (i.e. rabbits and partridges in Western Europe) and increasing other species favoured by human activity (i.e. feral pigeons and yellow-legged gulls in Western Europe). Therefore, monitoring the diet of Bonelli's eagle may not only **provide information for the correct conservation of the species** but also be very useful in studies of the biological indicators that help understand and evaluate variations in space and over time in Mediterranean ecosystems, and of the factors that threaten them (Resano, 2014).

On the other hand, the ingestion of contaminated prey is the main way in which pollutants are incorporated into terrestrial predators, and the accumulation of persistent contaminants in natural food webs is one of the main toxic risks for top predators (Henny & Elliot, 2007). Organochlorine compounds (OCs) and metals are the most relevant contaminants known to affect predatory raptors. OCs are liberated into the environment by many industrial activities and, given their persistence, traces of the formerly used organochlorine insecticides are still found in agricultural areas. Metals are also present in the environment at high concentrations due to human activities such as mining and groundwater extraction, but are also found in industrial effluents (e.g. copper-based fungicides) and as lead in hunting ammunition (Mateo *et al.*, 2009 and 2014). However, although pollutant accumulation is not thought to be a major threat to Bonelli's eagle, there is still a lack of information for the vast majority of this species' populations.

In this chapter, the most common methods available for determining Bonelli's eagle diet and pollutant accumulation are described, as well as known patterns of prey consumption and pollutant accumulation.

5.1. Methods for determining diet and pollutant accumulation

The main methods for determining Bonelli's eagle diet and pollutant accumulation are shown in Figure 12. Since sample collection can be conducted during certain monitoring tasks, defining study objectives is essential when planning tasks in population monitoring in order to optimize time and resources.

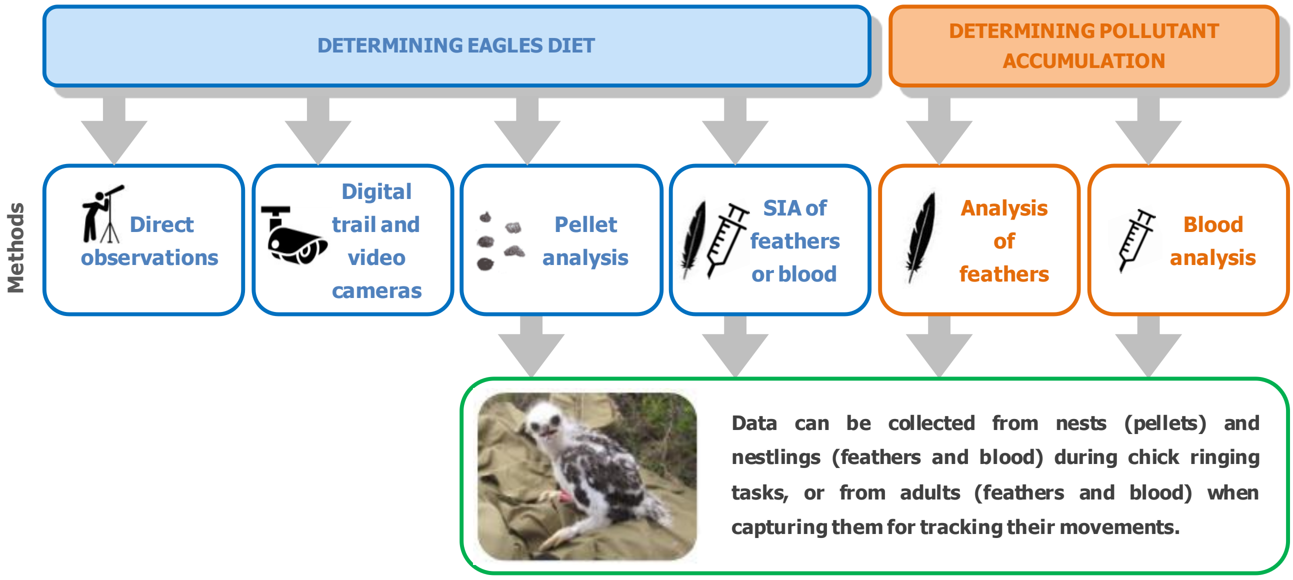


Figure 12*: Main methods for estimating Bonelli's eagle diet and pollutant accumulation. This diagram reinforces the need to incorporate feather collection during chick ringing tasks. Photo: Francesc Parés (CBG-UB).*

Direct observation of prey delivered to nestlings at nests are the simplest way of determining eagles' diets and offer reliable estimates. However, such tasks are highly time-consuming, a limitation to their implementation on a long-term basis and for a large number of territories, and field researchers must be highly experienced in prey identification in order to avoid potential biases (Real, 1996; Marti *et al.*, 2007). More recently, the use of **digital trail and video cameras** allows data to be obtained from direct observations without great fieldwork effort, although these methods still have some technical limitations that should be taken into account (Margarida *et al.*, 2006; Marti *et al.*, 2007; López-López & Urios, 2010; García-Salgado *et al.*, 2015).

The analysis of pellets, the small balls that raptors regurgitate through their beaks that contain indigestible parts of eaten animals such as feathers, hairs or bones, is the most common approach in the study of raptors' dietary habits. Similar indirect conventional methods such as prey remains or stomach content analysis are not so recommendable since they present biases linked to prey size and/or digestibility (Real, 1996; Lewis *et al.*, 2004; Marti *et al.*, 2007); nevertheless, the combined application of pellet and prey-remains analysis can enhance the identification of prey items. Pellet analysis requires access to the nest after the breeding season to collect the pellets and then to analyse the samples in the laboratory. Usually, nests are visited ca. 7–10 days after fledgling because pellets degrade rapidly and to avoid causing disturbances to eagles. If chicks are ringed and manipulated outside the nest (as is usual), the time used for processing the chicks can also be used by another person to collect pellets and prey remains from the nest, although the number of pellets and prey remains collected at this point is usually much lower than at the end of the breeding season. Pellets may also be collected from platforms in roosting and feeding areas within territorial home-ranges at any period of the year, providing complementary information to data from pellets collected at nests or at communal roosting sites in dispersal areas (Moleón *et al.*, 2009a). In order to quantify diet composition, each prey item identified in each pellet is counted as one item (Real, 1996; Resano, 2014). Pellet contents (i.e. feathers, bones, hair, nails and scales) are used to identify prey species with the help of reference collections, a magnifying glass and specialized guides (Brom, 1986; Brown *et al.,* 2003). Prey consumption in raptor diet studies is estimated for any given territory and year as the percentages of total items and total biomass (Real, 1996; Sánchez-Zapata & Calvo, 1998). More than 20 prey items in each territory and year are required to ensure reliable pellet analysis. Diet composition at population level can be estimated as the mean and the corresponding dispersion statistics of the percentages of consumption (or biomass) for each prey type in each territory and year. Pellet analysis is a useful non-invasive method and allows detailed prey identification at territory and year levels, although it cannot provide diet estimates for particular individuals, e.g. when several chicks are raised in the same nest.

On the other hand, recent studies have shown that **Stable Isotope Analysis (SIA)** (Inger & Bearhop, 2008; Hobson, 2011) is a useful tool for long-term monitoring of the diet of Bonelli's eagle, and for assessing differences between territories (Resano *et al.*, 2011; Resano-Mayor *et al.*, 2013, 2014 and 2015). To date, SIA has been used to study chicks' diets and, in this case, requires feather samples taken from chicks during the breeding season (feathers can be collected during chick ringing), which are then analysed in the laboratory. This technique can also be applied to other tissues such as blood and can be used to study adults' diet. This analysis provides isotopic ratios in bird tissues, which reflect their diet at the time of tissue synthesis in a predictable manner. The shift in isotope ratio of diet to consumer tissue can be used to quantify the relative contributions of isotopically distinct sources in the diets of individuals or populations. A major advantage of SIA is that it provides diet estimates from the sampled individuals when several chicks are raised in the same nest. Additionally, it is not constrained by insufficient sampling of pellets, so all sampled nestlings will provide isotopic values. In this sense, for 35-day-old chicks, 3–4 upper scapular feathers are enough to calculate C, N and S isotopic ratios. However, laboratory analyses are more expensive than pellet analyses and generate data about assimilated rather than ingested prey. In addition, we cannot distinguish individual prey species in predators' diet where the isotopic prey signatures are unknown. These signatures reflect nestlings' diet over the entire period of tissue development, whereas pellets may represent a shorter period if they are not collected regularly. Additionally, a comprehensive prey isotopic characterization is mandatory for transforming isotopic ratios into percentages of assimilated consumed prey. Both methods (pellet and stable isotope analyses) possess advantages and disadvantages and should be considered as **complementary methods** when monitoring dietary patterns in territorial birds (Resano-Mayor *et al.*, 2014).

Finally, an extensive set of methods and techniques are available for **pollutant analysis** in raptors (Henny & Elliott, 2007; García-Fernández *et al.,* 2008; Gómez-Ramírez *et al.*, 2014), and include the analysis of eggs, feathers, blood and other tissues (such as the internal organs of dead birds). All are applicable to Bonelli's eagle, although to date the number of studies and populations sampled are still small. **Feathers** have been shown to be useful for determining pollutant levels (mainly mercury) (DesGranges *et al.*, 1998; Palma *et al.*, 2005; Jaspers *et al.*, 2006), which underlines the need to incorporate feather collection during chick-ringing tasks in long-term ringing schemes. On the other hand, **blood analysis** collected from nestlings and adult Bonelli's eagles has already been used for assessing pollutant accumulation and its associated physiological effects on chicks (Ortiz-Santaliestra *et al.*, 2015). However, further research is still needed for a better understanding of all patterns of variation in pollutant accumulation and its consequences in terms of health and vital rates at both individual and population levels.

5.2. Patterns of prey consumption and pollutant accumulation

Bonelli's eagle diet is quite well known in Western Europe, where it predates on a wide variety of species including European rabbits *Oryctolagus cuniculus*, red-legged partridges *Alectoris rufa*, wood and domestic pigeons *Columba palumbus* and *C. livia*, corvids, red squirrels *Sciurus vulgaris*, yellow-legged gulls *Larus michaelis* and reptiles (mainly Ocellated lizard *Timon lepidus*) (Real 1996; Moleón *et al.*, 2009a and 2009b; Resano, 2014). However, there is a strong heterogeneity in diet consumption between territories within the same population and between different local populations (Resano,-Mayor *et al.*, 2015). Prey consumption depends on both the relative abundance of potential prey in the environment and the preference of Bonelli's eagle for prey species. In general, rabbits and partridges are considered 'optimal' or 'preferred' prey given that the trade-off between the effort when capturing these species and the quantity of nourishment is assumed to be very favourable. Thus, an increase in diet diversity has been reported when the consumption of these species decreases at different spatial (from territories to populations) and temporal (from inter-year variations to long-term shifts in prey abundance) scales. In recent decades, populations of these preferred prey species have decreased in many areas of Western Europe due to habitat changes (general increase of tree cover owing to the abandonment of crops), hunting overexploitation and epidemics such as the rabbit haemorrhagic disease (RHD). This decrease has led to a change in this eagle's diet, with an increase in the consumption of less favourable prey (Moleón *et al.*, 2009b and 2012). Furthermore, it has been shown that a high consumption of optimal prey (rabbits and partridges) or a moderate consumption of these species, complemented by alternative items (e.g. pigeons, doves and yellow-legged gulls), improves productivity, adult survival and nestling body condition (Resano-Mayor *et al.*, 2014 and 2015), whereas an increase in diet diversity has the opposite effect (see Figure 13). Yet, it is also noticeable that some territories in which eagles consume a large amount of alternative prey such as pigeons or gulls may also perform well, possibly because these prey species are highly abundant.

Users should bear in mind that these patterns of prey consumption and the resulting conclusions described above are valid for Western European Bonelli's eagle populations; other populations in the species' world range might have completely different dietary patterns. In these populations, dietary patterns should be determined and the main prey items identified to adequately address conservation efforts.

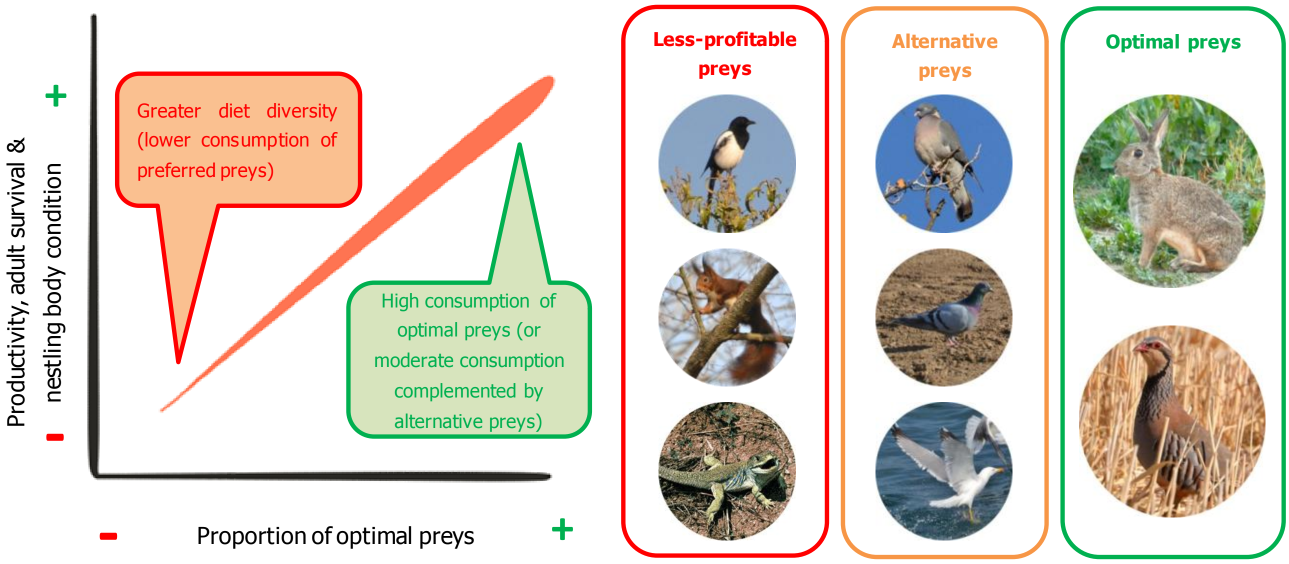


***Figure 13**: Relation between the consumption of optimal prey items by Bonelli's eagles and productivity, adult survival and nestling body condition in Western Europe. Photos: CBG-UB.*

We have still relatively little information regarding the exposure of Bonelli's eagles to persistent pollutants such as organochlorine compounds (OCs) and metals. Most detailed data refers to nestlings (Palma *et al.*, 2005; Ortiz-Santaliestra *et al.*, 2015; but see Mateo *et al.*, 2003; García-Martínez *et al.*, 2008; Van Drooge *et al.*, 2008; Figueira *et al.*, 2009) and it has been shown that nestlings in industrialized areas of Western Europe accumulate the highest concentrations of PCBs and arsenic. These compounds, together with DDTs, exert a great overall influence on nestlings' physiology (Ortiz-Santaliestra *et al.*, 2015); mercury accumulation, on the other hand, is higher in territories where preferred prey items (i.e. rabbits) are scarce, which are also the territories in which productivity is lower (Palma *et al.*, 2005).

6. ESTIMATING MORTALITY CAUSES

As seen in chapter *4. Population viability analyses*, low levels of adult and pre-adult survival are among the main conservation problems for many populations of Bonelli's eagle in Western Europe and, possibly, for other populations of this eagle. Consequently, the identification of the causes of death in target Bonelli's eagle populations is essential for implementing appropriate conservation measures. The contribution of each cause of mortality may be estimated simply as a percentage or, preferably, as a probability of being killed by any given cause. Figure 14 is a summary of the three possible scenarios for estimating causes of mortality depending on data availability (which are discussed below).

Non-tagged individuals and no ringing scheme is being conducted

- The most common situation in Bonelli's eagle populations throughout its range.
- Systematic protocols are required for gathering information from individuals found dead or injured.
- Potential bias due to different encounter probabilities for causes of mortality.

Long-term ringing scheme is being conducted

- Multi-event capture-recapture models allow unbiased estimates of the fraction of mortality due to any cause to be obtained.
- Important efforts are required to achieve reliable results.

Long-term tracking studies of a proportion of the population

- Unbiased quantitative information on the causes of mortality can be obtained.
- The chances of relocating a bird, even when it is dead, are maximized.

***Figure 14**: Possible scenarios for estimating causes of mortality in Bonelli's eagle populations depending on data availability. Photos: CBG-UB.*

In all cases, the analysis of mortality causes requires the systematic **gathering of information from individuals found dead or injured** in a target area and during a specified period. The recording of information should be protocoled and incorporated as a part of the long-term monitoring of the population. Information may come from specific research projects (tracking animal movements or intensive underline searches for power line casualties), rehabilitation centres, Wildlife Management Services and compilations of published and unpublished reports. Applying suitable protocols and data analysis methods, as well as having recorded adequate sample sizes, is crucial to reduce bias and to increase precision in estimating the impact of a given cause of death.

6.1. Estimating mortality causes from untagged individuals

The most common situation is of a target population mostly composed of non-tagged individuals, with no ringing scheme. Under this scenario, the only source of information comes from the encountering and reporting of dead individuals that, in most cases, will be untagged (Real *et al.*, 2001). Protocols should be designed to ensure that all the relevant information is gathered and that the effort in detecting mortality events is constant over time or, at least, that if the effort changes, it will be reported and taken into account when conducting the analyses.

The cause of death should be determined by necropsy performed by a specialist (e.g. veterinary in a rehabilitation centre) and should always include radiography and toxicological analysis. Shotgun pellets detected by radiography should be recorded even if they were not the cause of the death. If the bird was killed by an infrastructure (e.g. electrocution, collision), information on the technical and environmental characteristics of the infrastructure should be recorded (Tintó *et al.*, 2010).

If certain specific threats are thought to be a relevant cause of mortality, specific surveys should be performed to detect the presence of dead birds (e.g. systematic surveys on a representative sample of electric power lines) and account for potential sources of heterogeneity (e.g. stratified by habitat type).

Intensive underline searches allow Bonelli's eagles electrocuted under distribution pylons to be found. Author: CBG-UB).

Burns on eagles' claws are evident signs of electrocution. Author: CBG-UB.

The simplest measure of the magnitude of any given cause of death in a specified period can be obtained as the result of dividing the number of individuals found killed by a given cause (n_i) by the total number of individuals found dead (n). For simplicity, this number can be expressed as a percentage. It may also be considered as a raw estimate of the probability that a bird found dead was killed by that cause (P_i) during the study period. Variance of this parameter can be estimated as (P_i) * (1- P_i) / n . Nonetheless, estimates of the probability of being killed by a given cause may still be biased because the probability of encounter of an eagle killed by a given cause will differ from another cause. For example, distribution power lines are intensively monitored (Mañosa & Real, 2001; Real *et al.*, 2001) and electrocuted birds are easily detected under the distribution poles. Cases of electrocution may be overestimated compared to other causes of death such as collision (Rollan *et al.*, 2010) because birds involved in collisions are difficult to detect due to the rugged terrain with thick vegetation usually found under power lines. The only way to address this potential source of bias is by tagging birds, performing suitable sampling and implementing capture-recapture analysis, which requires a mid- or long-term time period and a considerable effort to obtain fair sample sizes and reliable estimates. In addition, individuals of different ages may present different probabilities of being killed (i.e. young individuals have lower survival rates than older birds) and the magnitude of a given cause of mortality may differ for individuals of different ages. To partly reduce this source of bias, it is desirable to split individuals found dead into two groups: non-territorial and territorial individuals, which is also helpful from a management point of view.

6.2. Estimating mortality causes from ringing data

Long-term monitoring and ringing schemes offer the opportunity to obtain an unbiased estimate of the fraction of mortality caused by any given cause, although this estimate cannot be obtained straightforwardly from models. Users may benefit from modern multievent capture-recapture analysis (Pradel, 2005). In brief, multievent capture-recapture models are a generalization of multisite recapture models. However, contrary to the multisite case, uncertainty in the assessment of state (e.g. territorial vs. non-territorial) can be incorporated into the analysis. The analysis also allows incorporating information about recoveries (i.e. individuals found dead). This type of model can be implemented with specific statistical software such as E-Surge or Mark. To implement this analysis, users should define states that may affect the probability of survival and/or the probability of encounter. An example of this analysis is found in Hernández-Matías *et al.* (2015): these authors considered six states according to whether individuals were alive or not, displayed territorial behaviour or not, and, in the event of being dead, whether they were killed by electrocution or by other causes (see Figure 15).

Models allow different survival probabilities for non-territorial and territorial birds to be estimated according to age, as well as the probabilities of encountering live and dead individuals. Nonetheless, the probability that a bird found dead was killed by a given cause is not separately estimable from the probability of encounter of an individual killed by that cause. This problem may be solved by combining information from conventional monitoring with information from untagged individuals found dead (as described in section 2.5.1), and by applying the methods described in Hernández-Matías *et al.* (2015). It is worth noting that these authors used a dataset of 251 chicks marked over a period of seven years that were monitored over eight years (28.3% of individuals were re-contacted at least once), thus highlighting the fact that the effort required to achieve reliable results is high.

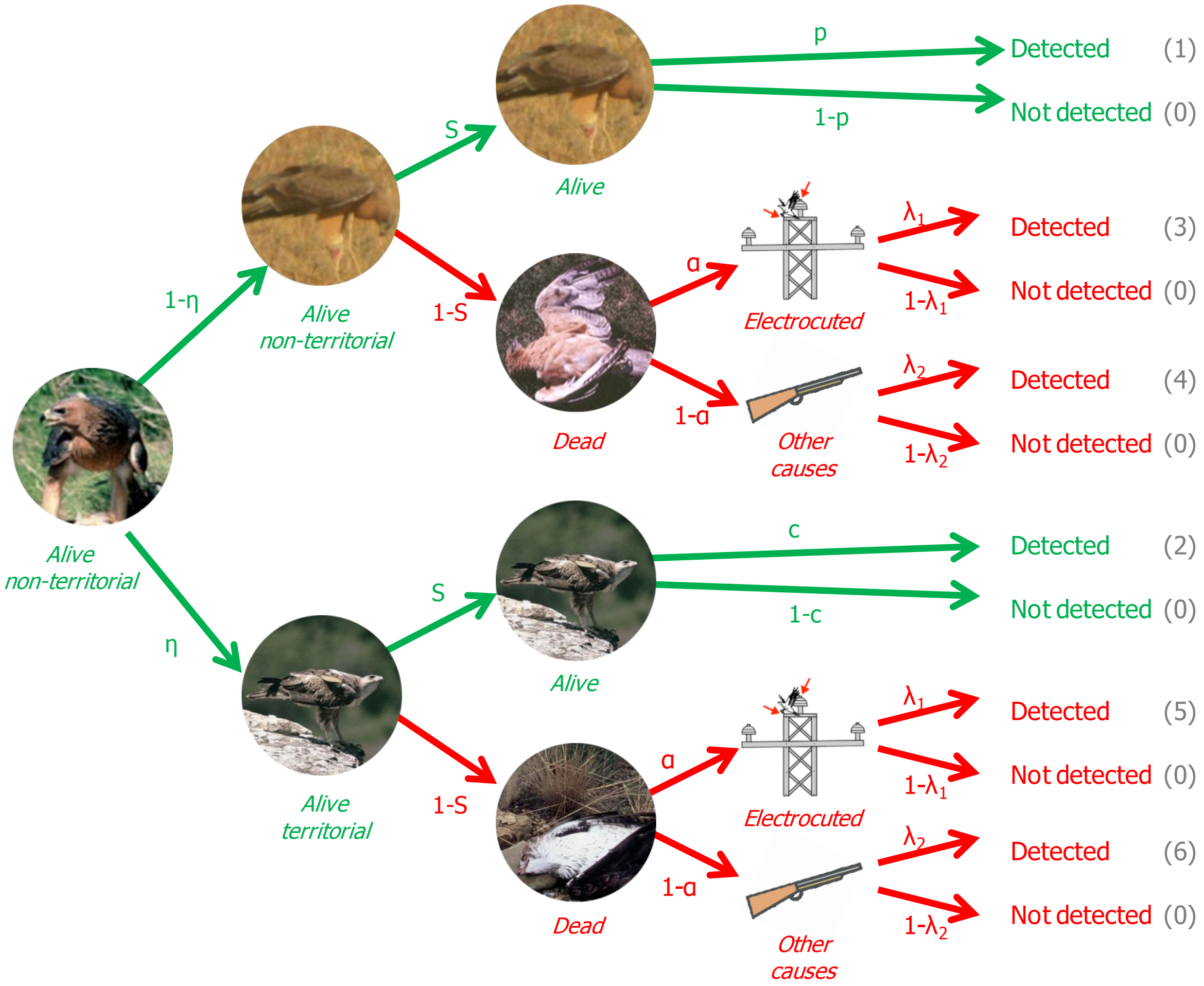


***Figure 15**: Possible events and corresponding probabilities in encounter histories. The initial event (alive non-territorial) occurs in t, while events in the next step (t+1) are described by the events in bold on the right-hand side of the figure. Numbers in brackets are the codes used for different events (possible events correspond to the states, as well as to the event 'not detected'). Adapted from Hernández-Matías et al. (2015). Photos: CBG-UB.*

6.3. Estimating mortality causes from tracking studies

Tracking studies allow us to estimate accurately the fraction of mortality caused by any given cause (Kenward, 2001). Nevertheless, it should be stressed that this parameter should not be estimated as a raw proportion of individuals killed by the cause in question in relation to all the individuals found dead while the transmitter was active. Even if the transmitter is equipped with a system that assists the location of dead birds, the probability of encountering a dead bird may be below one. Additionally, the individuals that are not found (e.g. because their battery ran out) may also provide valuable information for refining estimates of the parameters of interest. A detailed example of this analysis is shown in Tavecchia *et al.* (2012) who addressed the fraction of mortality caused by poisoning and electrocution in red kites on Mallorca. To perform such an analysis, a great effort in terms of the number of tagged individuals and frequency of surveys is required in order to know the status of the bird at relatively short intervals (e.g. once a month) throughout the study period, which should last several years to obtain good sample sizes of dead individuals. Frequent surveys are required to ensure that the state of the bird is correctly assigned (alive with working transmitter, alive without working transmitter, dead by a given cause). In addition to transmitters, individuals should be equipped with rings or wing tags to allow identification even when transmitters are not working any more. This reinforces the need to undertake long-term Bonelli's eagle tracking studies (at least a proportion of the target population), not only to identify their patterns of spatial use (Bosch *et al.*, 2010) but also to help obtain unbiased quantitative information on the causes of mortality.

CS3: Refining estimates of causes of death in the Bonelli's eagle population in Catalonia

Case study

Estimating mortality causes in Catalonia from untagged individuals

Mortality causes were determined gathering information from individuals found dead or injured in Catalonia between 1960 and 2014, as well as those who were born in Catalonia but were found killed or injured in other areas. Two periods were considered (1960-1989 and 1990-2014) to analyze the variation cause mortality over time. Results were obtained for 187 individuals during 1960-2014 (37 during 1960-1989 and 150 during 1990-2014). During 1990-2014 the main causes of death (see Fig. 3a) were electrocution (61.19%) and direct persecution (17.16%); sixteen cases of death by unknown causes were not taken into consideration. Non-territorial birds were more often electrocuted than territorial birds (69.4% vs. 50.0%) and death by persecution was similar in territorial and non-territorial birds (18.1% vs. 21.2%)

On the other hand, results show an increase of electrocution, rising from 24.32% (37 individuals; 1.23 casualties/year) during 1960-1989 to 56.72% (76 individuals; 3.42 casualties/year) during 1990-2014. In contrast, the relative importance of direct persecution by shooting, trapping, poisoning or other methods, the second cause of mortality in order of importance, decreased from 52.78% during the period 1960-1989, to 21.64% during 1990-2014 (see Fig. 3b). However, deaths from direct persecution in absolute numbers were 19 (1960-1989) and 29 (1990-2014), representing an average of 0.66 and 1.21 cases per year respectively. Therefore, it cannot be concluded that the direct persecution of this species has declined and, consequently, conservation actions are still required to mitigate this cause of mortality.

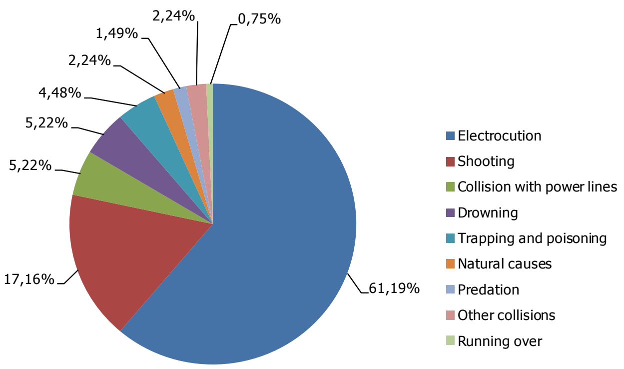


Fig. 3a: Causes of death for Bonelli's eagle in Catalonia during 1990-2014.

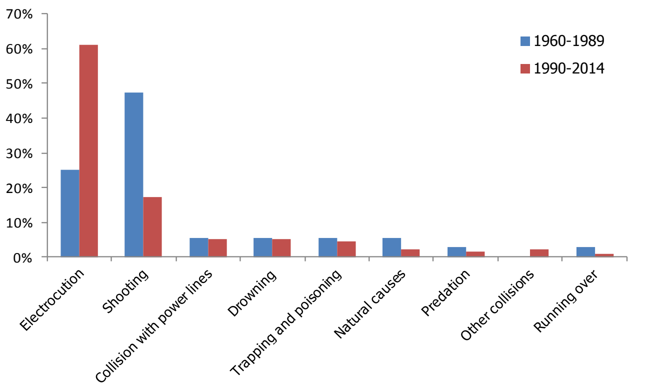


Fig. 3b: Evolution of causes of death for Bonelli's eagle in Catalonia during 1960-2014.

Obtaining unbiased estimates of mortality caused by electrocution

Ringing schemes data (period 2008-2014) was used to implement multi-event capture-recapture models (see Figure 15) and complemented with long-term monitoring information (1990-2015) for obtaining unbiased estimates of mortality caused by electrocution. During 2008-2014, 251 chicks from 43 territories were tagged. Of these, 71 individuals (28.3%) were re-contacted on 186 occasions: 31 were recruited as territorial birds (three were found dead) and 40 as non-territorial birds (31 found dead or injured). In all, 28 out of the 34 individuals (82,36%) found dead or injured were electrocuted. Re-sightings of ringed eagles was able thanks to the invaluable collaboration of a large number of observers, thus highlighting that the effort required to achieve reliable results is high. The probability of encounter of individuals killed by electrocution was estimated over three times higher than that of individuals killed by other causes and electrocution accounted for 62 and 26% of deaths in non-territorial and territorial Bonelli's eagles, respectively (Hernández-Matías *et al.* , 2015). Therefore, these results illustrate that the raw proportions of the causes of mortality derived from the number of individuals found dead may be biased (see Fig. 3c).

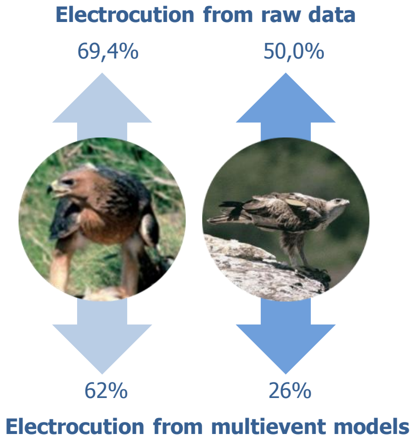


Fig. 3c: Differences in electrocution estimates among methods.

IMPLEMENTING CONSERVATION ACTIONS

7. LEGAL TOOLS FOR CONSERVATION

Legal protection, land-use planning and the regulation of human activities are essential tools for protecting biodiversity and fulfilling conservation goals such as improving the conservation status of target species such as Bonelli's eagle. These regulatory provisions should aim to counteract all those factors that negatively affect eagle conservation (see Figure 16). For their correct application the awareness and collaboration of all the different groups that use natural areas and the public and private organizations implicated in the management of the territory are essential.

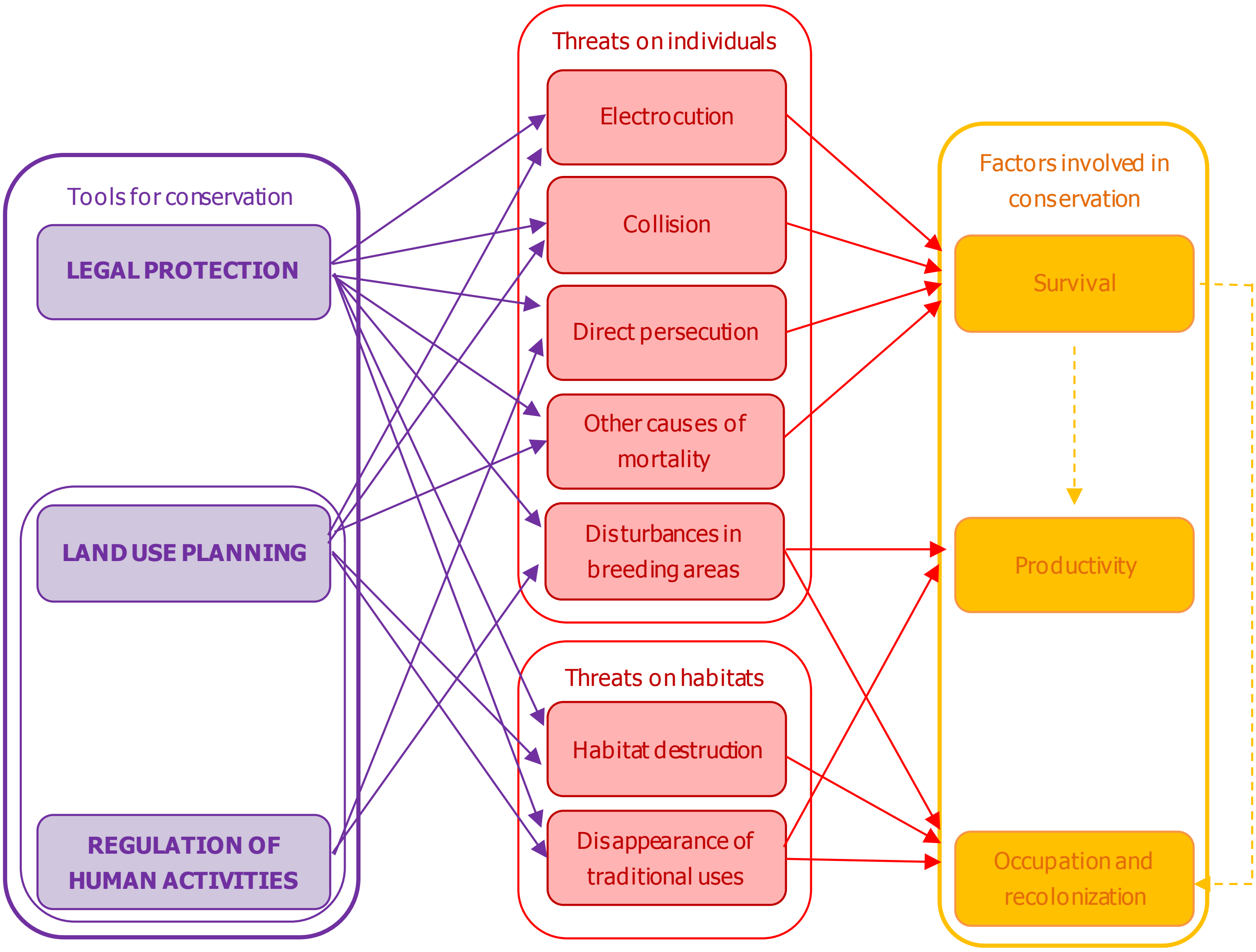


***Figure 16**: Main relationships between tools for conservation, threats to individuals and habitats of Bonelli's eagle, and some factors involved in the conservation of this eagle.*

7.1. Legal protection

Legislative provisions at international, national, regional and local level for the protection of wild animals must aim to prevent or counter threats that put the viability of target populations at risk (see Figure 16). A minimum level of protection of vulnerable species should include a **ban on its hunting** and direct persecution, as well as the designation of **protected areas** suitable for its long-term conservation. Up to six different categories of protected areas are defined by the International Union for Conservation of Nature (IUCN), three of which (categories IV, V and VI) may be suitable for Bonelli's eagle conservation (see Dudley 2008 for details).

Protected areas designed for Bonelli's eagle conservation must include at least known territorial home-ranges and dispersal areas (see Chapter 3). However, since home-ranges and dispersal areas may change over time due to a variety of environmental factors, **predictive models of the species' distribution** are also useful tools for predicting range expansions and designing protected areas (Muñoz *et al.*, 2005; López-López *et al.*, 2006; Carrascal & Seoane, 2008; Di Vittorio *et al.*, 2012; Muñoz & Real, 2013; Muñoz *et al.*, 2013 and 2015). Thus, protected areas should be large enough to allow these range changes, and encompass **buffer zones** to control the implementation of new infrastructures and prevent excessive human disturbances in core protected areas.

A good example of a conservation tool within the European Community is the **Natura 2000 network of protected sites**, derived from the **Birds Directive** and the **Habitats Directive**, which forms the backbone of the EU's internal biodiversity policy. Bonelli's eagle is included in the Annex I of the Birds Directive, for which the Member States are required to designate Special Protection Areas (SPAs). SPAs are scientifically identified areas critical for the survival of target species and are part of the Natura 2000 network. A second component of the Birds Directive **bans activities that directly threaten birds**, such as the deliberate killing or capture of birds, the destruction of their nests and taking of their eggs, and associated activities such as trading in live or dead birds. However, on some occasions, the current network of SPAs is considered insufficient for protecting Bonelli's eagle (López-López *et al.*, 2007) or areas of great biological value for the species that are not protected. Thus, the SPAs network should be revised according to updated information on eagles' spatial use and their potential suitable habitat.

Public administrations and other stakeholders involved in management of Natura 2000 sites could benefit from funds made available by the European Commission (Kettunen *et al.*, 2014a and 2014b). Thus, awareness and an understanding of these financial tools would make a huge difference in when implementing the conservation measures required in target populations and territories.

Moreover, legal provisions should also be adopted to solve other direct threats such as electrocution and collision with power lines, e.g. to prevent more dangerous power lines from being built in the most sensitive areas for birds and to find funding for urgent correction of existing power lines.

The role of **catalogues of protected species** as part of the conservation strategy of many countries should also be highlighted. After a status assessment of the population following the IUCN criteria (IUCN, 2012), the inclusion of a species on a national official list usually provides a protection regime and the automatic duty to draft an action plan. A **species action plan** is a technical document that programmes the activities needed to return the target species to a status in which it can survive on its own within the ecosystem (Machado, 1997). The research and conservation actions described for Bonelli's eagle in these guidelines must be considered and programmed for a given period of time: the performance of the recovery plan for each of the recovery actions should be evaluated and the Plan formally reviewed every 4-5 years.

Given the a variety in terminology depending on level, scale and purpose, 'action plan' seems to be the most appropriate term to be used generically (Machado, 1997). At international scale, **global programmes** or **strategic plans** set the general principles and long-term goals or aims, and are not legally binding documents. They have to be further developed by more detailed plans at national, regional or local scale. An example of these are the European Bird Species Action Plans developed for around 50 bird species listed in Annex I of the Birds Directive, and particularly the *European Union Species Action Plan for Bonelli's Eagle (Hieraaetus fasciatus)*. These plans provide information about the status, ecology, threats to each species and describe the key actions that are required to improve their conservation status in Europe.

At national, regional or local scale, **recovery plans** are much more detailed than global programmes or strategic plans and are legally binding documents. Recovery efforts (assessing, planning, implementing) must be defined, i.e. how and by whom they will be implemented. Some examples are the Endangered Species Recovery Plans in the USA or in Spain. Recovery plans are related only to species that are at risk of extinction (threatened species) and should be conceptually separated from general species conservation or management plans (Machado, 1997), the latter usually concerned with huntable species. Machado (1997), Sande *et al.* (2005), Birdlife International (2012) and NMFS and USFWS (2010) provide detailed guidance on the planning process, and the structure and contents to be included in these documents.

Recovery actions should be oriented first towards protecting and stabilising the existing population, and then, to restoring part of the historical distribution (reintroductions) and linking isolated populations (Machado, 1997). Obviously, all threats that led the population to its extirpation (local extinction) must be solved previously to any attempt to resettle the species within its historic area of distribution. In this case, the structure of **Reintroduction Plans** are very similar to other Action Plans, but have a special focus on release protocols. However, there is still little information on this issue and to date the only reintroduction experience of Bonelli's eagle is on Mallorca, where the species became extinct in around 1970 (see Pacteau, 2014; Viada *et al.*, 2014 and 2015 for further information).

7.2. Land use planning

The decline of many Bonelli's eagle populations, particularly in developed countries, is related to land use changes, affecting both territories and dispersal areas.

First, the disappearance of the traditional uses and the substitution of the agricultural soil for industrial or residential causes has led to a decrease in open hunting habitats and, consequently, to a decrease in the main prey populations and eagles' productivity.

On the other hand, the implantation of big infrastructures such as highways, roads, quarries or wind farms is related to the abandonment of breeding territories or the loss of hunting areas of either territorial or dispersing eagles (Drewitt & Langston, 2006; European Commission, 2011). The construction of new highways, roads and particularly forest/mountain tracks not only destroys suitable habitats for the eagles but also creates a barrier effect on prey populations and provides easy access to calm areas formerly hardly accessible such as the breeding areas.

Thus, the spatial use of territorial and dispersing eagles (Bosch *et al.*, 2010) should be taken into account as part of sustainable land use planning. This would also benefit other species within the ecosystems in which Bonelli's eagle live, since it can be considered as an "umbrella species". In this sense, the following criteria and goals should be considered when writing a regional land use planning:

- Programs derived from land use planning should consider **economic and financial tools** for achieving conservation goals, e.g. grants and payments to promote the extensive and sustainable activities of agricultural, cattle and forest management and improve landscape heterogeneity. Technical help is required for farmers, ranchers and forest owners.

- Including natural values and ecosystem benefits into **integrated land planning** (see Case Study 4).

- **New infrastructures should never be installed in areas of major conservation interest** for the Bonelli's eagle, including protected areas, their buffer zones and corridors connecting them. Thus, these infrastructures should be in areas or spaces of minor natural value such as next to road infrastructures, industrial estates or already existing human settlements.

- **Existing infrastructures should meet environmental criteria** (e.g. implementing corrective measures in power lines to mitigate mortality caused by bird electrocution or collision) and affect as little as possible protected species such as Bonelli's eagle.

- **Environmental impact studies** should be negotiated and arbitrated by institutions and independent from those involved in building work.

- **Collaboration between different stakeholders,** owners, administrations with competences in the territory, technical specialists and forestry defence associations is vital when carrying out habitat management.

- Information for people and groups involved in this type of activities. In this sense, **public awareness** of the importance of nature conservation is crucial in order to encourage authorities to develop sustainable land use plans.

7.3. Regulation of human activities

Like many other wild animals, Bonelli's Eagle is a shy species that does not tolerate human presence at close distance since it associates it with serious danger. Thus, human presence may imply the loss of a capture, frustrate an opportunity for hunting or disturb a moment of rest. However, during the breeding period it can motivate clutch or chick loss (negatively affecting productivity) and, if the disturbance is repeated, may even lead to the definitive abandonment of a breeding area.

Activities that cause most disturbances to Bonelli's eagles are climbing, hiking, trail running, the presence of flying devices (hang-glider, paragliding, light aircrafts, micro light planes, etc.), mountain bikes, 4-wheel vehicles, forestry management, hunting and other outdoors leisure activities in breeding areas. The attitude of a minority of naturalists or nature photographers who unconsciously or noisily approach nests too closely and too often may have serious consequences, especially during the breeding season. The impact of these activities depends fundamentally on four factors: (1) the intensity of the activity, (2) its permanence or duration, (3) its location in places sensitive for wild species (breeding areas) and (4) the season in which it is carried out (breeding season).

For these reasons, solutions involve an accurate defining of **sensitive areas** based on intensity of use by territorial eagles (Bosch *et al.*, 2010) in which different levels of **restrictions** should be applied to human activities (see Figure 17). Restrictions would also involve:

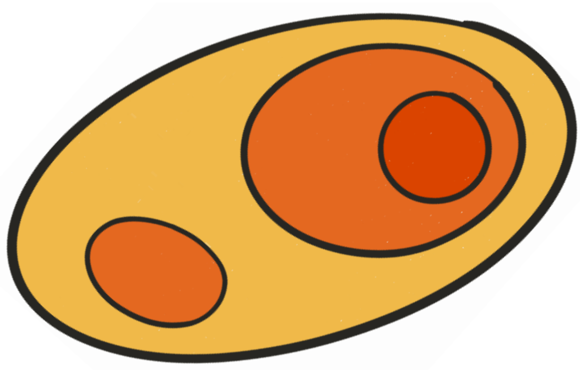
- Undertaking an **inventory of public access points** (forest/mountain tracks, foot tracks and trails) within eagles' territories and particularly in sensitive areas, and the **monitoring of human presence** to identify potential disturbances.

- Establishing a signalling system to **prevent public access to sensitive areas** and barriers to prevent illegal entry along unauthorized tracks.

- Monitoring human presence in sensitive areas to **evaluate the effectiveness of regulation actions**.

- The employment of **rangers** to ensure that current regulations are respected within the sensitive areas.

- The **raising of public awareness** and close collaboration with different stakeholders. Rather than simply banning an activity, multi-part agreements should be promoted for the self-regulation of activities that could cause disturbances in breeding areas (e.g. agreements between climbers and managers for a regulation of climbing activities).



	Low sensitive areas: Secondary hunting areas with lower prey densities.	**Medium sensitive areas**: Preferred hunting areas with higher prey abundances.	**High sensitive areas**: Breeding areas, usually located on cliffs or crags where the nests are built.
	Circulation allowed all year but restricted to main roads and forest/mountain tracks. Permanent circuits for 4WD cars not allowed (displaced to buffer zones).	Forbidden during the breeding season, except authorized vehicles (e.g. landowners, rangers…).	Forbidden all year round, except authorized vehicles (e.g. landowners, rangers…).
	Regular overflight with flying devices forbidden (e.g. airfields or heliports), but occasional overflight might be allowed.	Forbidden during the breeding season, unless exceptional circumstances (e.g. wildfire extinction).	Forbidden all year round, unless exceptional circumstances (e.g. wildfire extinction).
	Allowed all year round in solitary or in small groups.	Massified competitions and events forbidden preferably all year round (or at least during the breeding season).	Completely forbidden all year round, except authorized people on foot (e.g. landowners, rangers…).
	As a general rule, climbing should not be allowed in protected areas except in specifically authorized areas. With this approach, the areas where climbing is forbidden are not highlighted, and the publishing of sensitive areas for endangered species is avoided.		Completely forbidden all year round, except for research tasks by authorized research groups.
	Sustainable game hunting allowed on particular periods depending on the game species	Forbidden during the breeding season.	Completely forbidden all year round.
	Sustainable forestry works allowed all year round.	Forbidden during the breeding season.	Forbidden during the breeding season.

Figure 17*: Example of a sensitivity map of the intensity of use by territorial eagles and generic proposals of restrictions on human activities in these areas. Note that this is just a simplification of the reality and is provided as a guidance; the true situation and subsequent regulations may have to be much more complex.*

Case study

CS4: SITxell, a multidisciplinary tool to help with land use planning and territorial decision-making processes

Authorship: Carles Castell (Àrea de Territori i Sostenibilitat, Diputació de Barcelona)

What is SITxell ?

The Barcelona Provincial Council is a local administration at Province scale that supports policies of municipalities in many fields, which is also in charge of a network of 12 protected areas (Fig. a) and more than 100,000 hectares (parcs.diba.cat). The Area of Territory and Sustainability deals with many different environmental factors, ranging from water and air quality up to climate change and protected areas.

Based on the experience in planning and management of protected areas, the Office of Land Analysis and Planning started in 2001 a new line of work to give support to municipalities in open areas planning and management of conservation and sustainable development. The starting point was the SITxell project (www.sitxell.eu), a GIS scheme to develop land analysis from different points of view (geology, hydrology, flora, fauna, ecology, landscape, agriculture…) to be applied in local and regional land planning. Nowadays, the information included in the SITxell project is used in our daily work of land analysis and planning, and it is applied at different scales, from urban to protected areas and regional planning.


Fig. 4a

Incorporating Bonelli's eagle spatial use information to the SITxell system


Fig. 4b

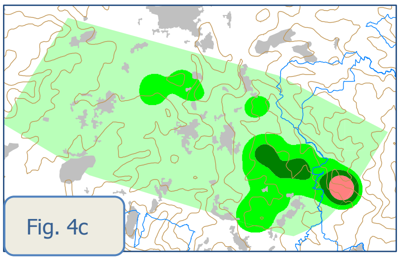


Fig. 4c

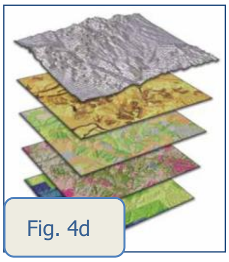


Fig. 4d

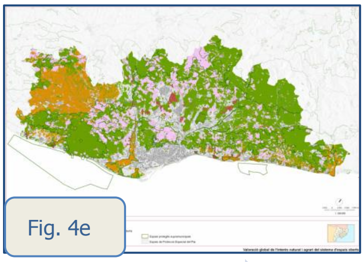


Fig. 4e

Step 1

Radiotracking of 11 individuals in the Barcelona province, carried out by the CBG-UB (Fig. 4b).

Step 2

Obtaining home-ranges for all Bonelli's eagle territories in the Barcelona province (Fig. 4c).

Step 3

Combining this information with other indicators of SITxell project (Fig. 4d).

Step 4

Transferring this information to land analysis for urban, protected area and regional planning (Fig. 4e).

What are the main uses of SITxell ?


Fig. 4f

Since implemented, information of SITxell project (including Bonelli's eagle home-ranges and other associated indicators) has been used for:

✓ Urban planning of 41 municipalities, based on natural and socio-economical values of natural and rural areas, following SITxell report and recommendations.

✓ Protected areas planning: Foix Natural Park and Montseny Natural Park.

✓ Regional Plan for the Metropolitan Region of Barcelona. More than 70% of total land specially protected because of natural or agricultural interest (Fig. 4f).

✓ Evaluation of several projects for new developments (wind farms, transport infrastructures, urban settlements) finally rejected or strongly modified because of natural values.

CS5: Management measures applied to public use in Bonelli's eagle sensitive breeding areas in Catalonia

Case study

Authorship: Servei de Biodiversitat i Protecció dels Animals, Generalitat de Catalunya

Negative impacts of human activities

The Bonelli's eagle is very sensitive to human presence. Consequently, many human activities happening in breeding areas (Fig. 5a) during the breeding period have a negative impact on the species population, causing the breeding failure or even the definitive abandonment of a breeding area (affecting territory occupancy). For this reason, the Catalan Government implements a set of regulations and management measures in sensitive areas in order to minimize the impact of the public use of natural areas on the conservation of this and other endangered species .

Fig. 5a

Approach to solve the problem: identifying sensitive areas

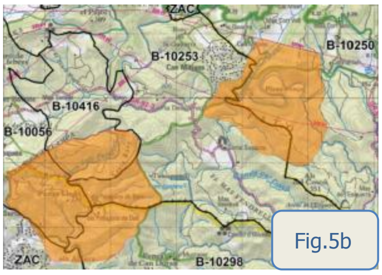


Fig.5b

The Catalan Government has identified the sensitive areas (Fig. 5b) of the Bonelli's eagle breeding in Catalonia and thus, providing a detailed mapping of areas where human activities may be causing major disturbances. This information is the basis for any decision-making referring to the regulation of activities that may cause disturbances to the eagles and transferred to collectives and stakeholders that develop professional or leisure activities in the eagle's breeding areas (hunters, sport associations, municipalities, etc.).

Application: regulation of public use in sensitive areas

- Limiting game hunting, climbing (Fig. 5c) and other sport and leisure activities, as well as forestry works in sensitive areas during the breeding season.
- Closing paths and trails leading to sensitive areas (Fig. 5d) and pointing out alternative routes.
- Limiting access to sensitive areas during the breeding season (Fig. 5e).
- Identification of disturbances, enforcement of the regulatory provisions, providing *in situ* information and raise awareness among visitors by the Rural Ranger Corps (Fig. 5f).

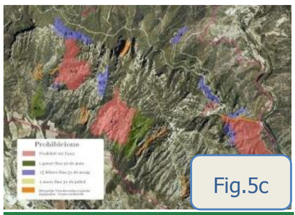


Fig.5c

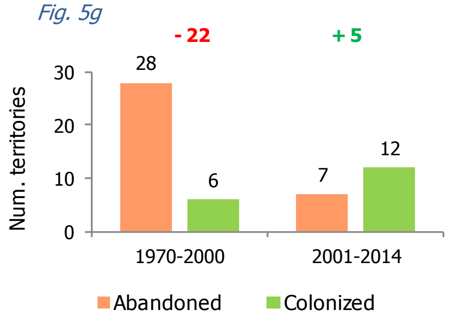
Fig.5d

Fig.5e

Fig.5f

Result: improving territory occupancy

Fig. 5g



As a result of the management measures undertaken in sensitive breeding areas, the number of territories abandoned is being reduced, and recently a colonisation of new territories has been noted (Fig. 5g). These, together with conservation actions aimed at mitigating mortality causes, have led the Catalan population of Bonelli's eagle to a slight recovery since 2001. However, productivity is still decreasing despite the regulation actions in breeding areas, probably due to an increase of new leisure activities, and other factors such as habitat changes leading to a decrease of Bonelli's eagle preys.

8. IMPROVING FOOD SUPPLY

The scarcity of trophic resources is considered one of the factors that contributed to the decline that the European population of Bonelli's eagle suffered from the 1970s to the early 1990s (Ontiveros *et al.*, 2004; Real, 2004). Decrease of key prey populations in Western Europe was caused by habitat changes (general increase of tree cover owing to the abandonment of crops and traditional uses), hunting overexploitation and epidemics such as the rabbit haemorrhagic disease (RHD).

As previously discussed, productivity increases in those pairs with a high consumption of key prey items (rabbit and red-legged partridge in Western Europe). Thus, increasing prey availability in breeding territories is necessary for the recovery and conservation of those Bonelli's eagle populations where prey scarcity is limiting breeding success (Ontiveros *et al.*, 2004). In addition, actions to improve prey populations may also be required in dispersal areas, if low prey densities in these areas are identified as a conservation threat. In both cases (breeding territories and dispersal areas), we advocate improving local wild populations of the key prey species that are already present. The main actions for favouring prey populations are habitat and sustainable hunting management, which must be considered complementary to each other. Efforts in habitat management are of little use if then there is excessive hunting pressure; on the other hand, reducing or even removing hunting pressure may not have much effect on game species if it is not complemented by habitat management.

In order to properly address efforts aimed at improving prey availability in breeding territories and to maximize their effectiveness at population level, we suggest following the steps summarized in Figure 18.

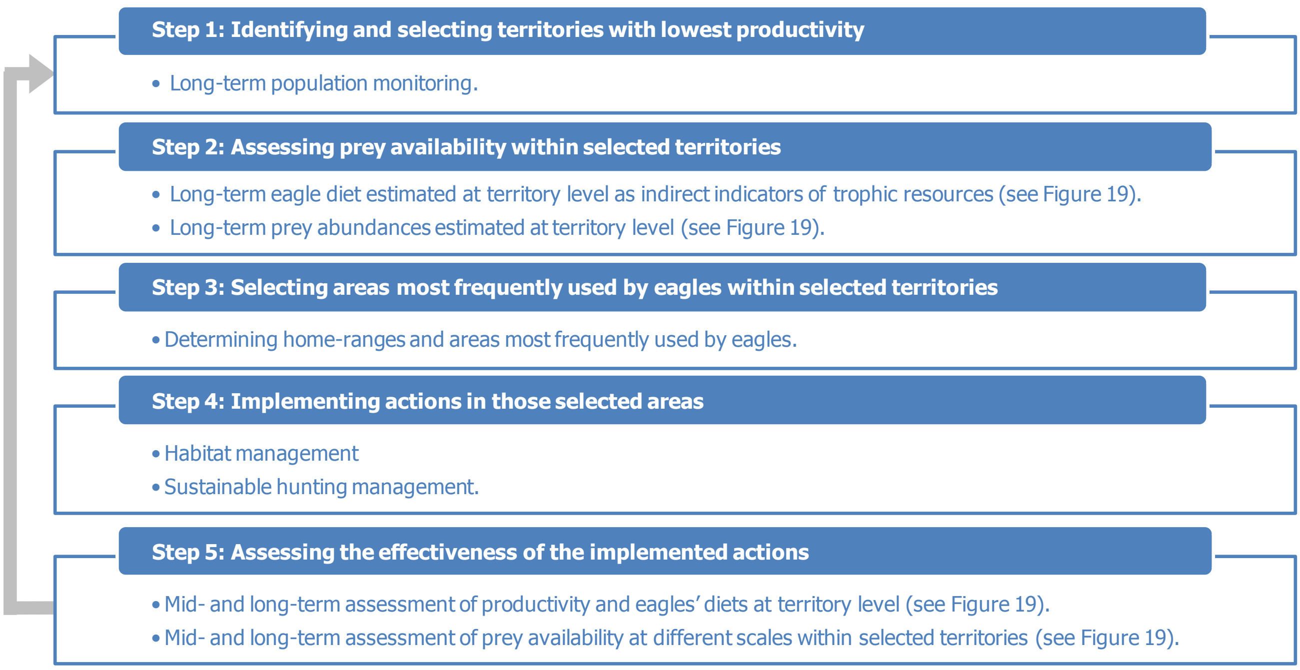


***Figure 18**: Steps to be followed when implementing actions aimed at improving prey availability in breeding territories and to maximize their effectiveness at population level.*

In some extreme scenarios and when a local population is at a high risk due to environmental deterioration, it may be possible to implement conservation actions to provide supplementary feeding to territorial eagles. Nevertheless, these measures should be considered temporary and should not be maintained in the long term. Increasing trophic resources in unoccupied territories to favour their occupation might be considered as well if the right conditions are present (e.g. large population of floating individuals deduced from, for example, the observation of a quick replacement of disappeared territorial eagles and a high proportion of adult eagles at the time of territorial recruitment).

8.1. Assessing prey availability and the effectiveness of actions

Identifying breeding territories where actions to improve prey availability is required is a crucial step in properly addressing conservation efforts and maximizing their effectiveness at population level. The identification and selection of these target territories should be carried out with a long-term view at three complementary levels: productivity, eagles' diet and prey abundance (see Figure 19). This multi-level approach would offer a global understanding on the availability of prey and its output in terms of eagles' performance, and even it may enable the detection of conservation threats that might remain unnoticed, e.g. territories where the breeding failures may not be due to a lack of food resources but to repeated human disturbances.

In the same way, the effectiveness of actions to improve prey populations should also be assessed at these same three levels (see Figure 19). These indicators must be used to compare values obtained before and after the implementation of conservation measures. To control for large scale environmental changes other territories or areas where measures are not implemented should be also studied at the same time. In any case, users of these guidelines should be aware that assessment conducted in the short term may unreliable, e.g. some actions may be highly efficient in the long term but not in the short term, or exactly the opposite (i.e. efficient in the short term but not in the long term). In this sense, the use of the 'three levels' approach (productivity, eagles' diet and prey abundances) to assess territorial prey availability and the effectiveness of implemented actions may help to prevent a wrong interpretation of the results. An example of this may be a habitat management action implemented in just a small patch that has no impact at all on the territorial eagles' diet or productivity levels, despite the fact that the managed patch has high prey densities and is actively used by eagles for hunting.

In the case of dispersal areas, the assessment of territorial prey availability and the effectiveness of implemented actions may have to be restricted to two levels: eagles' diet and estimates of prey abundance levels.

The right method for estimating prey abundance should be selected depending on the scale and the purpose of the survey (see Figure 19). Basic principles of survey sampling, that is, replication, randomization and control of variation should be always considered for designing a proper survey sampling and further getting reliable abundance estimates (Williams *et al.*, 2002).

When estimating rabbit abundances, the best way to optimize efforts is by yearly monitoring during early summer coinciding with the annual peak in rabbit abundance. For partridges, abundance estimates may be related to annual maximum abundance, i.e. after the breeding season and before the hunting season. In the case of populations outside Western Europe where key prey items are different, methods adapted to the relevant prey species should be defined.

When long-term information on prey abundances through direct or indirect counts is not available,

hunting statistics may be an alternative for the determination of temporal dynamics and trends in game species (Virgós *et al.*, 2007).

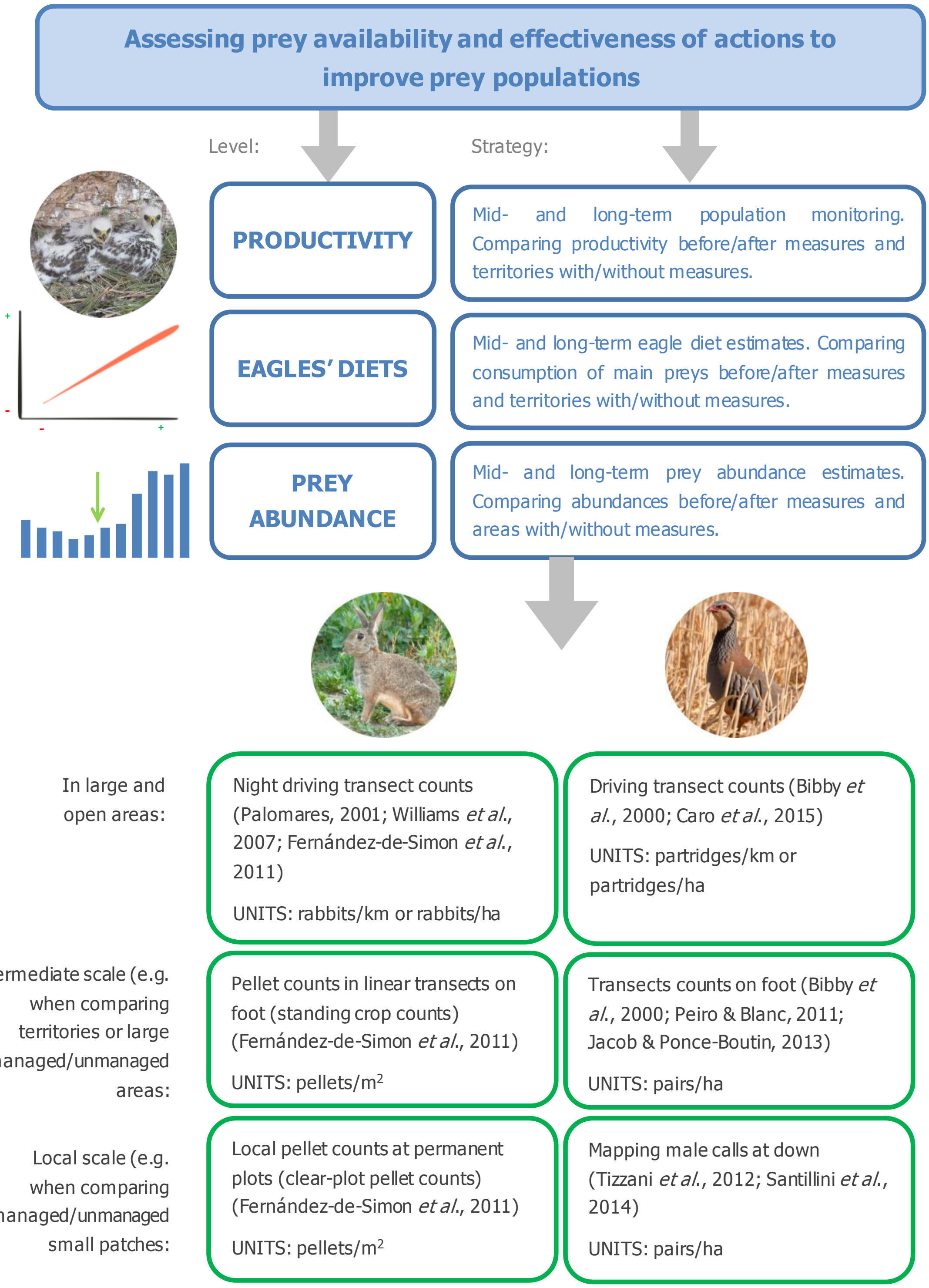


***Figure 19**: Complementary levels of evaluation assessment of prey availability and effectiveness of actions to improve prey populations. In the case of populations outside Western Europe where key prey items are different, methods adapted to the relevant prey species should be defined.*

8.2. Habitat management

One of the main factors involved in the decline of rabbit and partridge populations in Western Europe is the loss of suitable habitats due to the abandonment of traditional non-intensive agricultural, grazing and forestry activities. This has led to an homogenization of the landscape and an increase in the vegetation cover, which are unfavourable for these prey species. Hence, habitat management should be aimed at creating a mosaic of open habitats such as clearings in scrublands, open woodlands, natural pastures and cultivated fields.

Although these actions could also be implemented on a private estate at a relatively small scale (see Case Study 6), in order to have a clear impact on the food availability of the target territory, these clearings should preferably be applied to a larger area. However, there is a lack of empirical data on how much surface area needs to be managed in eagles' territories to improve breeding success. The size probably depends on the densities of prey obtained after the management actions, the use of the managed area by eagles (e.g. due to accessibility from the breeding area) and the environmental quality of the surrounding territory. Nonetheless, the surface area corresponding to the most used areas for hunting (e.g. the 80% Kernel area excluding the breeding area), might be used as a guidance on how much surface area needs to be managed in case of lack of finer information.

Small clearings in areas of dense and continuous scrubland: The aim of these clearings and patches of open areas is to provide high-quality food for rabbits and partridges (e.g. spontaneous growth of grass). These patches must be small (< 1 ha) and preferably elongated in order to increase the edge-effect, thereby shaping a balance between food availability and avoiding an excessive exposure to predation (Figure 20; 1). Techniques for scrub clearance include prescribed burning, hand clearance by volunteers or contractors using manual saws or chainsaws, and the use of flail cutters, circular saws or heavy machinery (Moreno & Villafuerte, 1995; Lasanta *et al.*, 2009; Rollan *et al.*, 2009; Real *et al.*, 2011).

Dry cropland patches in open areas created by scrub clearance or in old patches: A variety of crops are seeded to offer food of high nutritional value to rabbits and partridges. Crop species must be selected according to local soil and climate. The species most commonly used are cereals such as wheat (*Triticum* sp.), oats (*Avena sativa*), barley (*Hordeum murinum*) or rye (*Secale cereale*), or legumes such as lupins (*Lupinus luteus*) or sainfoins (*Onobrychis* sp.) (González & San Miguel, 2004; Guil, 2009). These must be organically grown (i.e. without using herbicides and pesticides) since organic farming produces clear benefits for biodiversity over conventional farming (Pfiffner & Balmer, 2011).

Thinning treatments in oak forests: The aim of these thinning (i.e. the selective removal of trees or stems) treatments is to reduce tree cover, thereby allowing the appearance of spontaneous grasses (which favours rabbits and partridges) and increasing acorn production in the long-term (Espelta *et al.*, 2011 and 2013) (which favours wood pigeons). Thinning treatments may be moderate and leave around three stems per tree (Figure 20; 2) or more intense and leave a low density (< 100 trees/ha) of scattered trees as in wood pastures in Spain (*dehesas)* and Portugal (*montados*) (Pérez Soba *et al.*, 2007).

Thinning treatments in fire regenerated pine forests: The aim of thinning treatments conducted in younger stands (10-yr-old and densities around 60,000–100,000 stands/ha) that leave less than 1000 stands/ha is to reduce fire occurrence and increasing cone production in the long term (Verkaik &

Espelta, 2006; De las Heras *et al.*, 2012), thereby favouring Red Squirrels among other species.

Promoting extensive livestock: Extensive livestock is the most effective and sustainable option to create and maintain open habitat patches (Figure 20; 3). It also creates local employment associated with nature conservation. In this sense, multi-part agreements should be promoted between managers, landowners and shepherds, for instance. Locally adapted livestock types are the most recommended.

Installation of water troughs and creation or recovery of water ponds: The lack of water might be a factor limiting wildlife in Mediterranean areas, particularly in summer (González & San Miguel, 2004; Guil, 2009). Thus, the water supply is a common approach to increasing densities of small game species. Water ponds can be designed for harvesting rainwater (Figure 20; 4) and complemented by a ~200-litres water tanks to ensure water availability. On the other hand, concrete water troughs should be allocated close to shrub cover to ensure water supplies during the summer (Armenteros *et al.*, 2015).

Maintenance and creation of field margins: Field margins are increasingly being considered as a vital habitat for biodiversity in agricultural landscapes. Their loss and the simplification of agricultural landscapes has led to a biodiversity decline. In semiarid agricultural landscapes, crops provide the main food for rabbits and partridges while natural vegetation and field margins provide refuge and breeding sites, as well as providing corridors that connect natural or semi-natural habitat patches. In this sense, a more complex structure with longer ecotones, smaller extensions of crops, and more edges between alternate cereal crops (Figure 20; 5) would benefit rabbit and partridge populations, as well as a huge variety of other animal species (Calvete *et al.*, 2004; Hackett & Lawrence, 2014).

Creation of artificial warrens in large open areas with low coverage or in hard soils inadequate for burrows. There are three main types of artificial warrens: stone, tube and pallet warrens (Fernández-Olalla *et al.*, 2010). Pallet warrens are the simplest and consist on several layers of pallets covered with stones, trunks and earth to make the structure strong enough to prevent access by predators; tubes are provided to allow rabbits to enter the structure (Figure 20; 6 & 7). Detailed information is provided in González & San Miguel (2004) and Guil (2009).

The actions described above benefit rabbits, partridges and pigeons, and also reduce the risk of wildfires affecting extensive areas (Lasanta *et al.*, 2009). It is known that early stages of post-fire successional development, which are dominated by herbaceous plants, are favourable to animal species typical of open habitats, and so that **wildfires** could be considered as an opportunity for improving the habitat of Bonelli's eagle prey species. However, one of the most generalised post-fire forest treatments consists of the clear cutting and removal of burnt trees, followed by the leaving of branches on the ground (Rollan & Real, 2010). Instead, branches should be removed at the same time as burnt trees as soil covered by burnt branches appears to have a negative effect on rabbit abundance and colonisation. In areas where burnt branches cannot be totally removed or where there is little vegetation to provide cover for breeding, refuges for rabbits could be built with burnt branches (Figure 20; 8), which could also be used to build bench terraces to prevent soil erosion (Figure 20; 9).

***Figure 20**: Main habitat management actions favouring prey abundances that could be implemented in Bonelli's eagle territories in Western Europe. See the text for description. Photos: Àlex Rollan (1, 2, 3, 5, 8 & 9) and Francesc Parés (4, 6 & 7) (CBG-UB).*

8.3. Sustainable hunting management

Sustainable hunting management must be based on the implication of hunting managers and all the hunting community in the protection of the natural values present in the hunting estate. A collaborative and multilateral approach between hunting managers, landowners, public and private conservation agencies and conservation biologists will create positive synergies that will allow populations of game species and endangered predators to be improved; this is the most adequate strategy for preserving hunting interests and conserving biodiversity (see Case Study 6; Rollan *et al.*, 2009; Real *et al.*, 2011).

In fact, the best way to understand the dynamics of prey species and to set levels of sustainable harvesting that are compatible with eagles' requirements is the use of population models (Williams *et al.*, 2002), which in the case of rabbits should ideally account for the complex epidemiology of this species (Calvete, 2006). In all cases, long-term estimates of prey abundance must be conducted with a solid scientific basis in order to allow managers to establish **adequate harvesting thresholds** (Caro *et al.*, 2015). However, raw data from **hunting statistics** recorded by hunters may be subject to strong biases and, therefore, it is mandatory to ensure that recorded hunting statistics are realistic. Additionally, to obtain fine estimates of prey abundance, the numbers of hunted prey items should be corrected for hunting effort (e.g. number of hours by area and year) and species huntability (Skalski *et al.*, 2010).

Finally, although rabbit restocking and red-legged partridges releases are frequent actions in hunting estates, they can put local populations at risk since released animals may carry diseases and genetically impoverish local populations (Guerrero-Casado *et al.*, 2013). Thus, these should be the final intervention options to be considered and only implemented when all management actions aimed at the natural recuperation of local populations have already been applied. They must be restricted to Bonelli's eagle territories with the lowest productivity – for example, those in which eagles are suffering starvation – and where urgent measures are required. In this case, all possible cautions must be taken to avoid sanitary and genetic contamination of local populations; habitat management and sustainable hunting pressure is essential as well.

8.4. Supplementary feeding

Supplementary feeding has been used fairly often as a conservation action in several endangered raptor species, including Bonelli's eagle (Real, 1989; González *et al.*, 2006). Although some controversy exists on when these measures should be implemented, we advocate using them exclusively in extreme situations of food scarcity and when the continuity of a territory or a population are highly endangered. Indeed, the main constraint for implementing these measures is that they require great effort and are not self-sustaining in the long-term, which implies thus that if they are not complemented with other sustainable measures the territory or population will become completely dependent on the continuing of these actions. The only population of Bonelli's eagles where supplementary feeding actions have been widely implemented is that in Castilla y León (Fernández *et al.*, 1998). There, most territories have been continuously supplemented for years and, indeed, these measures have improved productivity.

Several methods have been used to provide supplementary feeding. The simplest is to systematically **provide prey at a fixed location** that eagles already exploit and at regular periods of time (e.g. once or twice a week), particularly during the breeding season (January to June) to ensure that pairs fledge at least one chick. A better method is to construct an **enclosure containing prey** (e.g. 10x10 meters), well protected against the entrance of terrestrial predators and the escape of the prey, thereby allowing eagles to use the resource as much as they need. Managers should control the health of the prey animals and ensure that they live in correct conditions. The enclosure should be located in an area accessible to eagles, ideally close to other foraging areas and, obviously, outside the breeding area. The best prey species are hens, rabbits or disabled pigeons weighing 1 kg or less to ensure that eagles can carry them to their nests. **Dovecotes**, whose maintenance requires less effort, have also been used as an alternative feeding method. Nevertheless, managers should be aware that the main problem associated with dovecotes is the high prevalence of *Trichomonas gallinae* in pigeon populations that may cause chick mortality in some territories and/or populations (Real *et al.*, 2000). The recovery of formerly used dovecotes and agreements with local farmers may enhance the application of this conservation measure.

CS6: A land stewardship experience for reconciling game management and Bonelli's eagle conservation

Case study

Background and parts involved in the initiative

Cingles de Bertí is a protected area situated in the Catalan Pre-Littoral Range and included in the Natura 2000 Network due to the presence of a Bonelli's eagle breeding pair as well as other endangered species. After suffering a wildfire in 1994, the open habitats gradually disappeared and the landscape homogenized, dominated by a dense Mediterranean scrublands and post-fire oak forests, with a high risk of further devastating fires. As a consequence, small game species (rabbit, hares and red-legged partridges) decreased sharply and presented very low densities and the Bonelli's eagle pair had a worrying low productivity (0.57 young per year during 2000-2007).

To reverse this negative trend, a multi-part agreement was signed in 2007 for a period of 4 years. The parts involved were: (1) the **landowner** of small private estate (112 ha) selected because it was within the traditional hunting area of the eagles, (2) the **game hunting society** (Societat de Caçadors de Sant Quirze Safaja) where the private state was included, in charge of implementing the measures, (3) two **project funders** (Fundació Catalunya-La Pedrera and Diputació de Barcelona) and (4) the **CBG-UB** who wrote a Management Plan where all particular actions where detailed, and directed the implementation of the measures. To allow the recovery of prey populations during the agreement, hunting was not allowed.

Conservation measures implemented

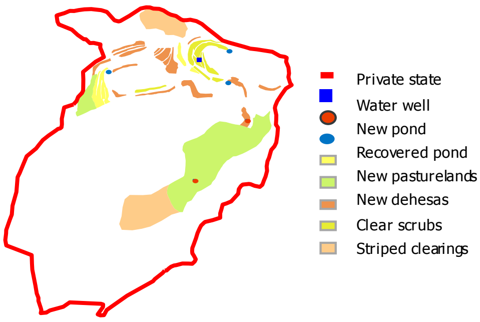


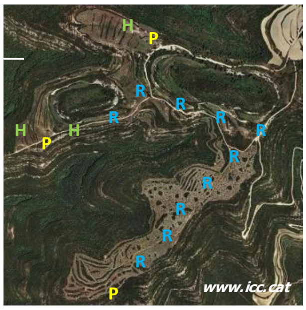


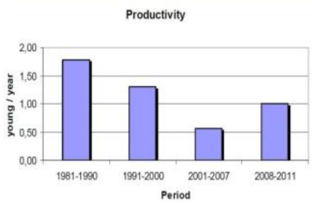
The conservation measures were aimed at creating a mosaic of habitats favouring small game species. They consisted on: a) creation of "dehesas" by selecting thinning oak stems; b) creation of open areas by scrubland clearing; c) creation of new pasturelands with a mixture of oats and esparcet; d) recovery of old dry crop fields; e) recovery of old water ponds and creation of new ones; f) grazing with sheep to maintain open areas. In addition, since the area suffered from human disturbances, the circulation with motor vehicles in mountain tracks was regulated. Photos: Francesc Parés (CBG-UB).

Highlighted results

Rabbits, almost extinct before the actions, colonized new created "dehesas" and open scrubland areas. The red-legged partridge presence increased from 1 (before the actions) to 3 pairs/100 ha and the presence of hares was consolidated. Thanks to this, Bonelli's eagles foraged regularly in the property and increased their breeding success (1 nestling per pair and year during 2008-2011). The hunters took a major role in the experience, since they were not only in charge of implementing the measures, but also incorporated sustainable hunting practices, becoming a key partner in nature conservation.







Top left: Management Plan map. Top right: Aerial view of the area and presence of hare (H), red-legged partridge (P) and rabbit (R) after the implementation of measures in 2009. Bottom right: Evolution of the productivity of Bonelli's eagle pair in Cingles de Bertí.

9. MITIGATION OF MORTALITY CAUSES

The main causes of mortality of Bonelli's eagles are of human origin: electrocution on electrical pylons, collision with power lines and direct persecution. The mortality of both non-territorial and territorial individuals has a strong negative effect on population dynamics and it is thought to be the main cause of the population decline in European populations (Real, 2004; Hernández-Matías *et al.*, 2015). Mortality of non-territorial individuals (usually non-adults) reduces the fraction of the population able to re-colonize abandoned territories or replace deceased territorial individuals. In the case of adults, mortality is the chief demographic parameter shaping population dynamics (Hernández-Matías *et al.*, 2013) and, additionally, the death of an animal during the breeding season entails the reproductive failure of the pair in that breeding season and usually in the next. If this occurs repeatedly in a same territory, it may end up causing it to be abandoned. Therefore, the application of measures to mitigate human impact is crucial for Bonelli's eagle conservation.

The use of rigorous protocols is a highly valuable tool to maximize the effects of conservation actions, which allows them to be applied preventively rather than just when and where eagle deaths are reported. A **protocol for mitigating Bonelli's eagle electrocution** is presented in Figure 22. Although this protocol was developed to mitigate electrocution in Bonelli's eagle territories, it could be adapted to dispersal areas or to mitigate other causes of mortality that, like electrocution, have an aggregated distribution of casualties such as collision with power lines, collision with fences or drowning in ponds.

9.1. Electrocution

The electrocution affects principally to big or medium size birds, such as raptors, crows or storks, that use the electrical pylons as a perch, and it occurs mostly on 15-66 kV distribution lines. In certain supports, the bird may touch very easily two conductive wires (a) or do mass between the tower and one of the wires (b), so that it falls down victim of an electrical discharge usually causing the death of the bird (see Figure 21).

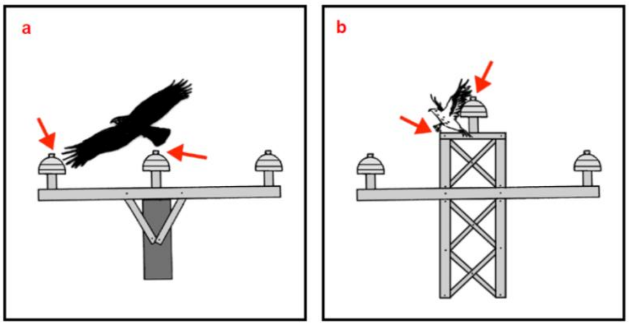


***Figure 21**: Electrocution occurs on certain supports on which birds can easily touch two conducting wires (a) or touch the pylon and one of the wires (b), thereby receiving a fatal electrical discharge. Modified from Janss & Ferrer (1999).*

To ensure the strongest demographic impact of electrocution mitigation, a multi-scale approach is proposed for correction prioritization. This **protocol to optimize electrocution mitigation** in territorial eagles is summarized in Figure 22 and involves different steps that range from wider to more local scales. This protocol may be a useful tool for managers and practitioners at any scale, from those in charge of deciding priorities in large geographic areas to those in charge of local populations or protected areas with just one or a few Bonelli's eagle territories. In addition, since Bonelli's eagle is considered as an 'umbrella species', conservation efforts focused on correcting dangerous power lines for this species help avoid the risk of electrocution for many other birds of prey (Moleón *et al.*, 2007).

Step 1: Selecting local populations acting as 'sinks' over large geographic areas

- Population Viability Assessment to identify populations with lower lambda or lower probability of self-sustainability (Hernández-Matías *et al.*, 2013).

Step 2: Selecting territories acting as 'sinks' within target local populations

- Long-term monitoring to identify territories with lower survival rates within populations.

Step 3: Selecting areas intensively used by individuals in target territories

- Determining areas most frequently used by eagles within home ranges.

Step 4: Selecting dangerous pylons in the most used areas

- Use of predictive models (Tintó *et al.*, 2010) to classify pylons present in the most used areas.
- Selecting those pylons (~20%) with a higher risk to give an expected reduction in electrocutions by up to 80%.

Step 5: Implementing corrective measures in dangerous pylons

- Permanent or long-term durable correction measures, such as substitution of dangerous pylons for safer ones.

Step 6: Assessment of the effectiveness of corrections

- Comparing mortality rates in corrected and control pylons both before and after corrections.
- Comparing survival of the focal territories between the periods before and after corrections .

***Figure 22**: Protocol to optimize electrocution mitigation in Bonelli's eagle breeding territories with a multi-scale approach to achieve the strongest demographic impact.*

The highest level of this strategy (Step 1; Figure 22) implies a deep knowledge of population dynamics at a metapopulation scale over a large geographic area. In this case, it is known that some local populations with low productivity and survival rates act as 'sinks', whereas other populations with high productivity and survival rates act as 'sources' of individuals (Hernández-Matías *et al.*, 2013). In the same way, some territories act as sinks within local populations (Step 2; Figure 22). Therefore, sink populations and sink territories within target populations should have the highest priority for electrocution mitigation.

Within a selected territory, the areas more frequently used by eagles must be determined (Step 3; Figure 22) since the risk of electrocution on a particular pylon will be much higher in areas intensively used than in poorly used ones. It is known that the risk of electrocution on a particular pylon is highly variable and will depend on its design and location. Pylons with the highest risk of electrocution are made of conductive materials such as metal or reinforced concrete, and even wood or concrete-earthed pylons. In addition, some technical elements such as connector wires, pin-type insulators or exposed jumpers are also related to the electrocution risk: vault, flat, cross and perpendicular configurations are particularly dangerous (Mañosa, 2001; Tintó *et al.*, 2010; Guil *et al.*, 2011) (see Figure 23). Pylons in dominant positions in the landscape, especially those placed on hilltops and surrounded by low vegetation cover (scrubland), pose a higher electrocution risk (Tintó *et al.*, 2010). As a result, **predictive models** can be developed to determine the risk of electrocution according to pylon design and location (Step 4; Figure 22). Hence, if we apply these predictive models we can correct power lines more effectively without having to apply measures to huge numbers of pylons. In this sense, applying correction measures to only 20% of the most dangerous pylons could reduce bird mortality by up to 80% (Tintó *et al.*, 2010). Information on eagles found electrocuted under a particular pylon can complement pylon selection by predictive models. However, it is not the only way since there could be a bias due to easier access to certain pylons where casualties have been reported. The use of the protocol to mitigate Bonelli's eagle electrocution also allows managers and practitioners to act preventively instead of waiting until an eagle is found dead.

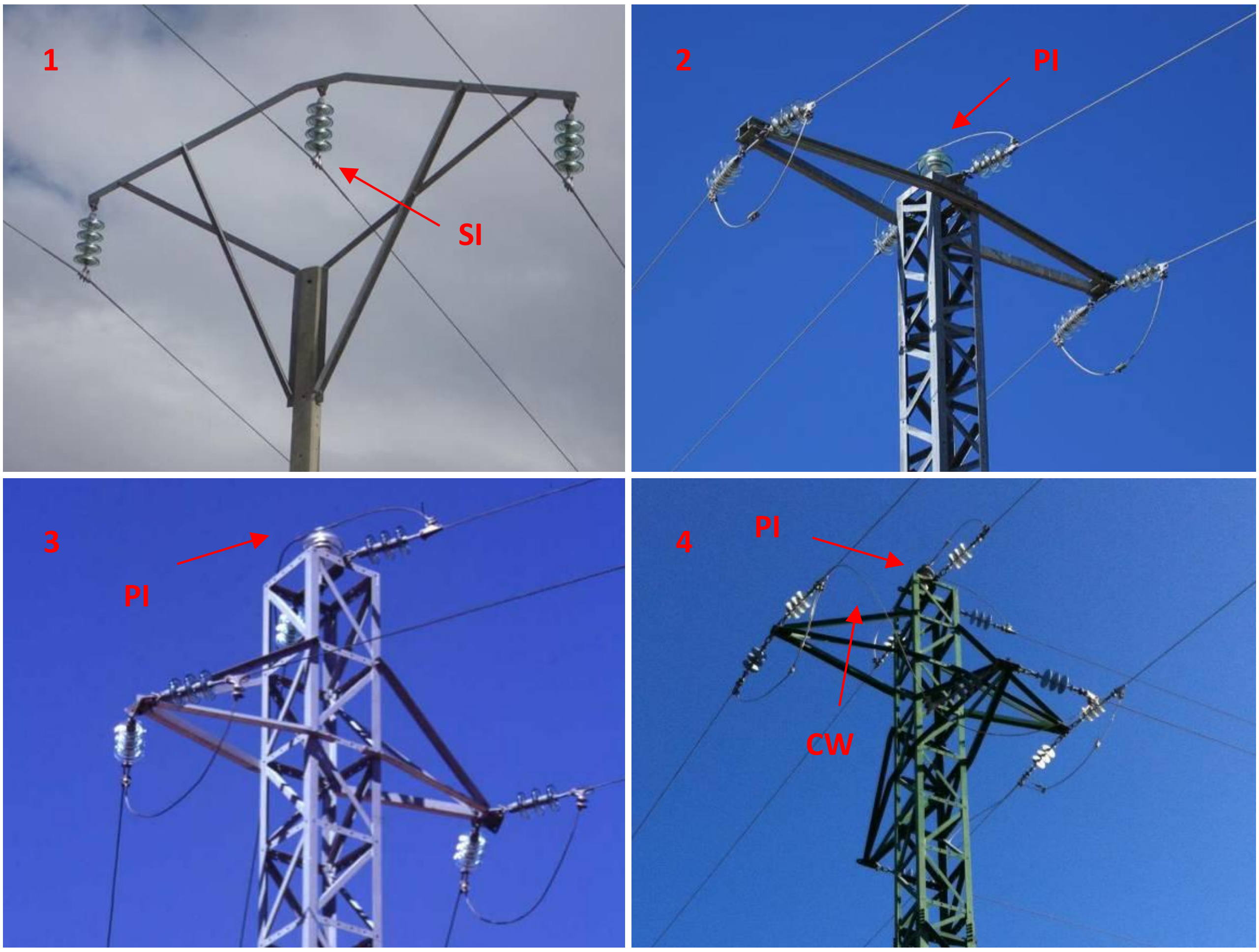


Figure 23*: Different types of pylons with a high risk of bird electrocution: vault (1), flat (2), cross (3) and perpendicular (4) configurations. Technical elements related to the risk of electrocution are also indicated: suspended insulator (SI), pin-type insulator and exposed jumper (PI), and connector wires (CW). Photos: Albert Tintó (CBG-UB).*

Therefore, dangerous pylons such those with vault, flat, cross or perpendicular configurations should be avoided in new power lines and corrective measures should be applied to pylons of this type that already exist in Bonelli's eagles territories and dispersal areas (Step 5; Figure 22). Correction measures must be permanent or at least long term and durable (see Figure 24). Substitution of dangerous pylons or cross-arm designs by safer ones may be preferable to insulation, which is not permanent and needs regular monitoring and repair (Tintó *et al.*, 2010; Guil *et al.*, 2011). Since Bonelli's eagle is highly sensitive to human presence, corrective measures must not be applied during the breeding period and especially in the breeding area (i.e. near the nest cliff) in order to avoid disturbances that may negatively affect its reproduction.

Finally, an **assessment of the effectiveness of corrections** must be carried out (Step 6; Figure 22) at two levels: (1) comparing mortality rates (rate of bird deaths by pylon) in corrected and control pylons both before and after corrections using suitable study designs (e.g. Tintó *et al.*, 2010) and (2) comparing the survival of the focal territories between the periods before and after corrections (Real *et al.*, 2015). Complementarily, the self-sustainability of the target population can be assessed by using the demographic parameters obtained after corrections to check that the corrections have improved the viability of the population (Hernández-Matías *et al.*, 2015).

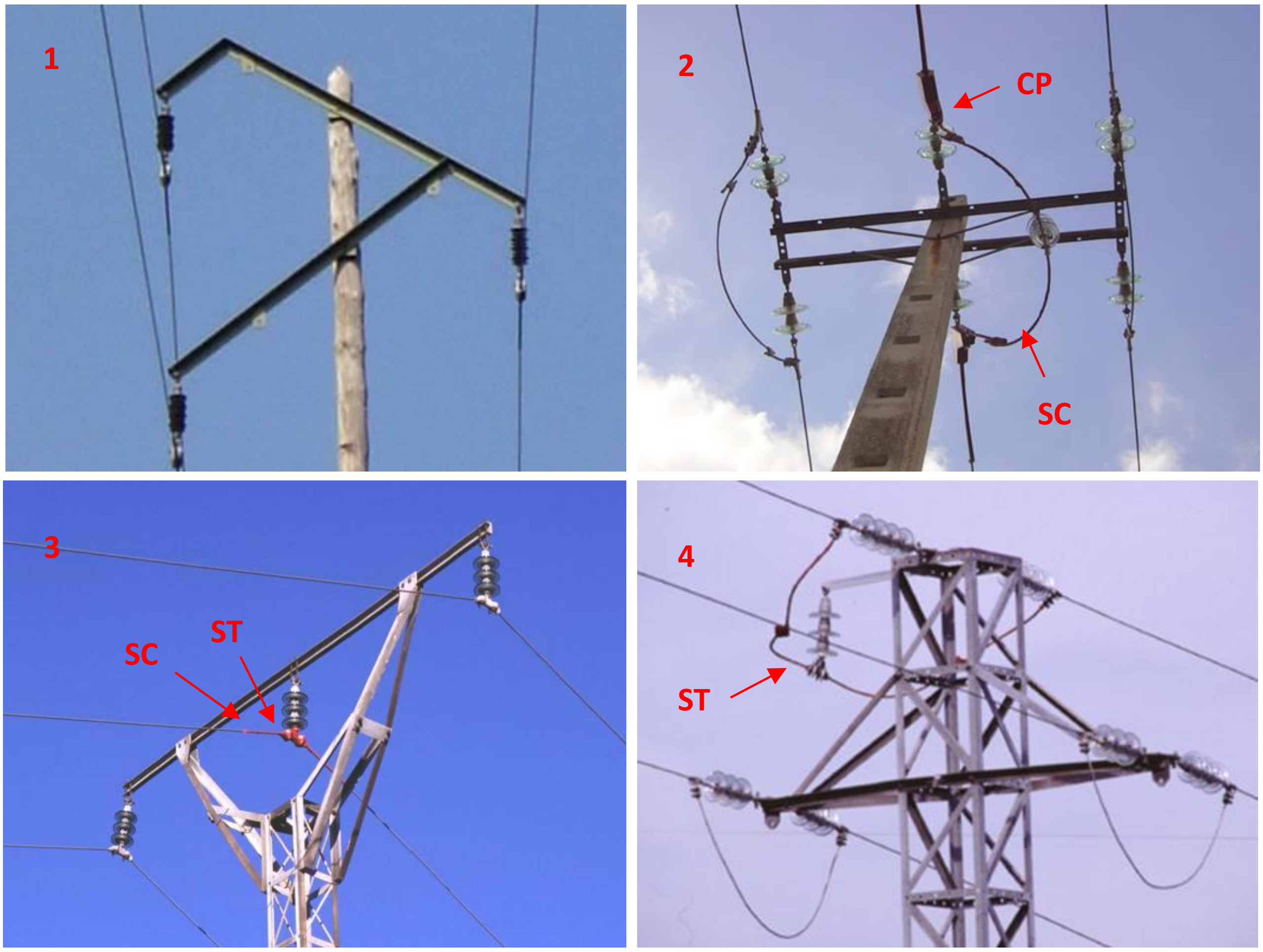


Figure 24*: Examples of adequate corrective measures: (1) A 'safe' pylon with an alternate cross-arm configuration; (2) a concrete pylon with a flat configuration in which the pin-type insulator and the central exposed jumper have been substituted for one suspended insulator and jumper; the metal hook-end of the two central strained insulators has been covered using Raychem BCIC cover packs (CP); (3) vault pylon in which the central conductor wire has been isolated with 3M silicone covers (SC) and the metal hook-end of the suspended insulator has been isolated using 3M silicone insulating tape (ST); (4) metal pylon with a cross configuration in which the pin-type insulator and the central exposed jumper have been substituted with a suspended insulator. Photos: Albert Tintó (CBG-UB).*

9.2. Collision with power lines and wind turbines

Bird collisions mostly occur with **transmission lines** carrying tensions ≥110 kV, probably due to the greater number of conductors, the presence of undetectable earth wires, higher tower heights and larger distances between towers. A significant positive correlation was found in Bonelli's eagle between territorial turnover rates and the risk ascribed to transmission lines with earth wires. Moreover, this correlation had a higher significance for the 50% kernel area when transmission without earth wires and double circuit distribution lines were added, whereas no correlations were encountered for distribution lines (Rollan *et al.*, 2010). This suggests that collisions might be underestimated compared to electrocutions, since distribution lines are intensively monitored (Mañosa & Real, 2001; Real *et al.*, 2001) and electrocuted birds are easily detected under distribution poles, whereas birds involved in collisions are difficult to detect, due to the rugged terrain with thick vegetation usually found under the spans.

Most transport power lines (≥110 kV) have earth wires on their highest points that intercept lightning; these wires are normally the thinnest and therefore the least visible, and so collision risks increase. Author: Àlex Rollan (CBG-UB).

Moreover, bird mortality due to collisions with **wind turbines** is one of the major ecological concerns associated with wind farms, along with habitat loss and displacement due to disturbance. However, the magnitude of this cause of death is still not well known, although even low rates of this additional mortality may have adverse impacts on population viability of long-lived species such as Bonelli's eagle (Drewitt & Langston, 2008; Martínez *et al.*, 2010; European Commission, 2011).

Thus, the main recommendations for mitigating the impact of these collisions in Bonelli's eagle populations are as follows:

The design and implementation of a **protocol for optimizing collision mitigation** in Bonelli's eagle territories or dispersal areas aimed at achieving the greatest possible demographic impact, analogous to that proposed for electrocution mitigation (Figure 22). In the same way, territories acting as 'sinks' within target local populations should have a higher priority for actions aimed at mitigating collisions.

The development of **predictive models** in order to identify dangerous spans and/or wind turbines in the most used areas (Step 4; Figure 22), which may be used not only for careful route planning or strategic planning (Marques *et al.*, 2014) and deciding upon the most effective way to minimise collisions, but also for implementing measures – especially on transmission lines with earth wires – aimed at mitigating the risk of collisions. Telemetry techniques can be used to obtain not only kernel areas (Step 3; Figure 22), which correspond to flight frequencies (and consequently to the risk of collision), but also eagle flight patterns inferred from joining consecutive continuous locations, which provide more exhaustive information for selecting dangerous spans (Step 4; Figure 22). Thus, the telemetry technique used must provide high accuracy locations (including altitude) with high frequencies.

Generally, the most dangerous spans for Bonelli's eagles are situated in the areas most frequently used by eagles, that is, breeding and roosting areas (cliffs) and open hunting habitats (scrubland, farmland and grassland) far away from the human disturbance of urban areas, and along the flight paths between foraging and breeding or roosting areas (Rollan *et al.*, 2010), which would also be valid for wind turbines location (Marques *et al.*, 2014)

👍 Implementing the most adequate **corrective measures** to mitigate collision with **power lines** (Step 5; Figure 22) that include the suppression of obsolete spans and cross zones with a high risk of collision for the birds. Wire marking with anti-collision devices might be an alternative corrective measure, although studies of the effectiveness of such devices have yielded contradictory results (Barrientos *et al.*, 2011) and there is still little information for territorial raptors. In any case, since Bonelli's eagle is highly sensitive to human presence, corrective measures must not be applied during the breeding period and especially in the breeding area (near the nest cliff) in order to avoid disturbances that may negatively affect reproduction.

👍 Implementing the most adequate **corrective measures** to mitigate collision with **wind turbines** (Step 5; Figure 22) that include turbine shutdown on demand, restrict turbine operation, habitat management for creation of alternative feeding areas and increasing turbine visibility, among others (see Marques *et al.*, 2014 for details).

👍 **Assessing the success of implemented measures** (Step 6; Figure 22) by comparing the territorial turnover rates before and after implementation or by comparing turnover rates of territories with and without implemented measures. Telemetry can also enable corpses to be recovered for an unbiased estimate of the overall importance of collision as a cause of death (Margalida *et al.*, 2008).

👍 Finally, in order to succeed in implementing a protocol to mitigate the impact of collision with power lines, close collaboration is necessary between stakeholders, researchers, the administrations that manage the territory, and electricity companies.

9.3. Direct persecution

Direct persecution by man is one of the problems that from ancient times up to the present day has affected the populations of many predators, among them Bonelli's eagle. Up to the beginning of the 1970s laws existed in Spain that promoted and stimulated the elimination of these animals. The most commonly used methods were shooting, poisoning and trapping, or the robbery of eggs and chicks in the nest.

Although the frequency of direct persecution in relation to electrocution has diminished in some areas, the absolute number of eagles killed by this cause is similar (or even higher) to the numbers from decades ago (see Case Study 3) and is still a major cause of mortality, both in non-territorial and territorial Bonelli's eagles. This resurgence of illegal practices that are very harmful to the fauna and the ecosystems (poisons, systematic persecution of predators) can probably be attributed to the decrease in hunting yields caused by the appearance of new diseases in game species, inappropriate repopulations, the degradation of habitats and untenable hunting pressure that blames predators. In other cases, it may be simply a question of shooting indiscriminately any animal or of killing and trade in a protected species. Sustainable hunting activity that respects the environment and favours biodiversity can be perfectly compatible with the conservation of eagle species. Thus, the main recommendations for eradicating or minimizing the number of eagles killed by direct persecution are:

Raise public awareness on the importance of Bonelli's eagle conservation (and predators in general) and its benefits to the public, since raptors play important roles in ecosystems and are valued by society in several ways (see Caskey & Chutter, 2013). Educational campaigns should be addressed to conservation bodies, estate owners, hunters, game-keepers, the general public and especially school students in areas where the species is present.

Close collaboration with the hunting community to raise their awareness of the importance of Bonelli's eagle conservation and the sustainable management of the hunting. Multi-part agreements should be promoted to involve hunters in sustainable habitat management and nature protection.

Creation of non-hunting areas, that is, spaces in which hunting is not allowed (natural reserves or refuges for wild fauna), located in the principal nuclei of the breeding territories and dispersal areas of juvenile Bonelli's eagles.

Adequate legislation and its rigorous application when penalizing poaching and other offences against the protected fauna; however, such legislation should also provide technical support and help for game reserves where sustainable hunting management is practiced.

Creation of gamekeeper jobs aimed at ensuring that the current legislation is respected inside hunting areas.

9.4. Drowning in water ponds

Water ponds for irrigation or water tanks for fire prevention can be mortal traps for Bonelli's eagles and a wide variety of species including other raptors, mammals and amphibians. However, the magnitude of this cause of death and the factors involved are still not well understood. Even so, it is considered to be the fourth most important cause of Bonelli's eagle mortality in Catalonia based on the records of birds found dead (Hernández-Matías *et al.*, 2015).

Bonelli's eagles use fluvial courses and dams to capture prey such as aquatic birds. In addition, they also bathe regularly. Deep tanks with vertical walls or ponds with a sliding base do not have structures that facilitate the entrance or exit of animals. For this reason, the main recommendations for mitigating the impact of drowning in Bonelli's eagle territories or dispersal areas are as follows:

The design and implementation of a **protocol to optimize drowning mitigation** in Bonelli's eagle territories or dispersal areas that will ensure the greatest possible demographic impact of drowning mitigation, analogous to that proposed for electrocution mitigation (Figure 22). In the same way, territories acting as 'sinks' within target local populations would be given greater priority when implementing actions to mitigate drowning.

Installing mechanisms that allow the exit of the animals from existing ponds and tanks without affecting their functionality, such as concrete ramps or 'Numagrid' meshes that are always attached to the ground (see Figure 25). However, there is still a lack of knowledge of the effectiveness of this type of corrections, as well as other alternatives, which should be tested on a long-term basis.

New water tanks constructed or installed for fire prevention should be **covered to prevent wildlife from drowning**.

Specific scientific research to improve knowledge of this cause of mortality, its magnitude and the best practices to mitigate it should be carried out Marking individuals with emitters would facilitate the recovery of dead animals and an adequate understanding of the magnitude of this cause of death.

Raise public awareness and collaborate closely with relevant stakeholders such as landowners (in case of irrigation ponds) and administrations that manage the territory.

Figure 25*: (1) Adult Bonelli's eagle found drowned in a fire prevention water tank; Photo: Francesc Parés (CBG-UB); (2, 3 & 4) Some corrections implemented in Catalonia to avoid wildlife drowning. However, the effectiveness of these corrections, as well as other alternatives, still need to be tested on a long-term basis; Photos: Servei de Biodiversitat i Protecció dels Animals. Generalitat de Catalunya.*

9.5. Other causes of death

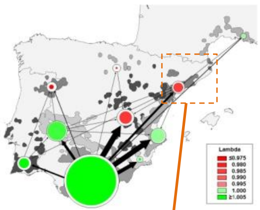
Collisions with game fences, vineyard wires and cars, as well as a wide variety of other causes, are occasionally responsible for Bonelli's eagle casualties. Bonelli's eagles are prone to impacts with game fences and vineyard wires when flying low after their prey, as also occurs in eagle owls (Martínez *et al.*, 2006). However, there is a huge lack of knowledge of the factors involved in these casualties, so further research is required to properly address this issue. A **protocol to mitigate these causes of death,** analogous to that for optimizing electrocution mitigation (Figure 22), is needed to identify these potentially mortal traps and to implement corrective measures such as the suppression of fences that are obsolete, or their substitution with more visible 'safe' fences made of wood.

Case study

CS7: Using multi-scale prioritization criteria to optimize electrocution mitigation: an example for the endangered Bonelli's eagle in Catalonia

Step 1: Selecting populations acting as 'sinks' over large geographic areas

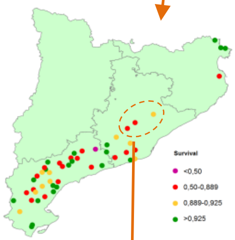
To achieve the strongest demographic impact correction prioritization should be carried out in local populations with lower lambda or lower probability of self-sustainability, like the one in Catalonia.



Population dynamics of Bonelli's eagles in SW Europe. Red circles indicate that the local population declined in 1990–2005 (Hernández-Matías et al. 2013).

Step 2: Selecting territories acting as 'sinks' within target populations

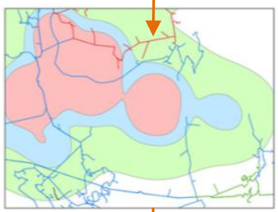
A pilot area of 1,056 km2 (10,970 pylons) including 3 eagle's territories with low survival was selected.



Territories in Catalonia (dots). Colours indicates yearly survival of territorial birds on the basis of a >10 year period. Green dots correspond to territories with healthy survival values. Dashed line indicates pilot area.

Step 3: Selecting areas intensively used by individuals in target territories

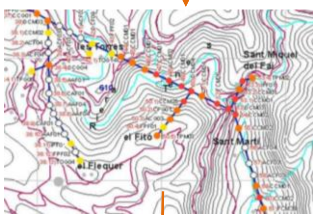
Seven territorial individuals from 3 focal territories were tagged (2002-2006) to determine their home ranges (Bosch *et al.*, 2010).



Intensity of use of the home range in one territory (most used areas represented in red). Coloured lines represent power lines.

Step 4: Selecting dangerous pylons in the most used areas

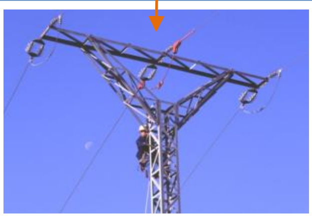
A predictive model (Tintó *et al.*, 2010) was applied to select the most dangerous pylons. Within 3 focal territories, 977 out of 3,258 (~30%) pylons were considered to be priority pylons for correction, according to the model.



Route of a power line on a map. Red and orange dots correspond to dangerous pylons according to the predictive model.

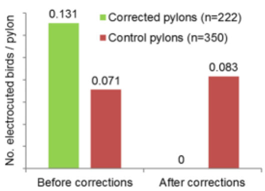
Step 5: Implementing corrective measures in dangerous pylons

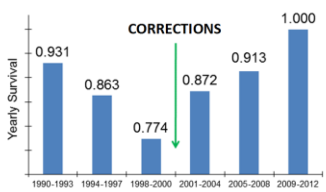
Within 3 focal territories, 308 were corrected (31.5% of priority pylons). Different stakeholders were involved throughout the stepwise protocol: researchers of the CBG-UB, managers (Diputació de Barcelona), sponsors (Fundació Miquel Torres, Ministerio de Educación, Ministerio de Ciencia e Innovación) and power companies (Endesa, Electra Caldense and Estebanell y Pahisa Energía).



Step 6: Assessment of the effectiveness of corrections

Corrected pylons showed significant differences in the number of electrocuted birds per pylon before and after corrections while no differences were found in control pylons (left). On the other hand, survival of the focal territories markedly increased after corrections (right).





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