European Raptor Biomonitoring Facility
Advice Hub

How to monitor raptors

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European Raptor Biomonitoring Facility

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Recommended citation: European Raptor Biomonitoring Facility Advice Hub Team, 2022.
How to monitor raptors. ERBF Advice Hub. EU COST Action 16224 (European Cooperation in Science and Technology). European Raptor Biomonitoring Facility: https://erbfacility.eu/

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This publication is based on work done under COST Action 16224 European Raptor Biomonitoring Facility supported by COST.

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April 2022

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HOW TO MONITOR RAPTORS

BACKGROUND TO THIS GUIDANCE – MONITORING RAPTOR POPULATIONS AND RELATIONSHIP TO MONITORING CONTAMINANTS

In the ERBFacility network we consider that pan-European ecotoxicological studies of raptors will benefit greatly from the availability of a range of what we term 'contextual data'. Contextual data are defined as a range of parameters (Table 1), ideally about the specific raptor populations from which samples for contaminant analysis are derived. In this section, we have attempted to give a concise guide to monitoring a range of these contextual parameters in raptors, with a focus on those that are (a) most useful for interpretation of pan-European contaminant studies and (b) most feasible to record by many researchers across Europe. Our hope is not to repeat information that is already available elsewhere, but rather to provide a brief overview of some of the main considerations and then sign-post readers to accessible sources where more detail can be found. Although the content is designed for those who may wish to get involved with contaminant studies on raptors and pan-European monitoring of contaminants, we hope the information will also be useful for anyone thinking about setting up raptor monitoring activities.

We consider that the availability of such population-specific contextual data will improve contaminant studies in two ways:

1. Some contextual parameters can help us to explain the exposure profiles of the populations from which the sampled individuals are derived. For example, knowledge of the breeding and wintering ranges of the population helps to define the geographical areas across which exposure could have taken place through the lifetime of an individual bird. Dietary composition, and variation in this between populations, may help to explain geographical variation in exposure, or should be taken into account when inferring other reasons for spatial variation in exposure levels.
2. Other contextual parameters can be important to monitor in raptor populations because they have the potential to provide early warning of threats to populations, including threats from the toxic effects of contaminants. For example, declining breeding numbers, reduced clutch size, reduced nesting success and reduced survival rates of different age classes could all be potential indicators of threats from contaminant exposure.

TABLE 1 – A range of contextual data parameters from studied raptor populations that are of use for interpretation of ecotoxicological studies and/or act as early warning indicators of contaminant threats to raptors, with suggested levels of priority based on both value for contaminants work but also feasibility of collecting the information from a specific study population.

Priority	extremely valuable information for contaminant studies based on samples from the specific population, and also feasible to survey/monitor in many studies across Europe
Valuable	extremely valuable information for contaminant studies based on samples from the specific population but more difficult to survey/monitor for a specific study population (due to time/specialist skills/technology required)
Difficult	also valuable for contaminant studies based on samples from the specific population but very challenging to survey/monitor and therefore unlikely to be carried out by many studies across Europe (due to time/specialist skills/technology required)
Minimum recommended parameters to include in any new breeding season monitoring scheme (particularly to benefit interpretation and monitoring of contaminants) are highlighted in yellow. A separate Advice Hub document is available that explains these suggested priorities in more detail.	

CONTEXTUAL DATA PARAMETER	DESCRIPTION	VALUE FOR CONTAMINANT STUDIES	SUGGESTED LEVEL OF PRIORITY FOR CONTAMINANT STUDIES *(justification based on value but also feasibility)*
Relating to a breeding population (sampled for contaminants)			
Extent of study area(s)	Village, municipality, district, country, coordinates	Basic information for spatial ID (linking) of monitoring and contaminant data	Priority (essential)
Methodologies used within study area(s)	A description of the methods used for each of the parameters collected	Basic information for ensuring appropriate quality control of contextual data	Priority (essential)
Wintering range and	For the breeding population being	Important descriptive data to define potential	Priority – from literature or, ideally, from studies

CONTEXTUAL DATA PARAMETER	DESCRIPTION	VALUE FOR CONTAMINANT STUDIES	SUGGESTED LEVEL OF PRIORITY FOR CONTAMINANT STUDIES *(justification based on value but also feasibility)*
migration routes	studied. It will generally only be possible to infer these areas from existing literature unless the population itself is ringed/tracked.	contamination source area(s).	of marked birds from the population under study
Range/range change	Distribution of breeding population in the country/changes in breeding range	Important for assessing whether study area(s) are representative of the wider population. Range contraction may indicate threats.	Valuable – but may require survey effort outside of study area(s)
Population density	Numbers (pairs) breeding per km^2	Spatial variation may be linked to spatial variation in population health/environmental quality.	Valuable – but requires very intensive survey methods (compared to measuring trends in numbers)
Population trend	Changes in numbers (pairs) through time (or indices of change)	Basic data to assess contamination population effects and population vulnerability	Priority – recommended as part of any new monitoring scheme.
Nesting frequency/proportion of population breeding/trend	The proportion of years in which breeding occurs within a territory or the proportion of territorial pairs that breed each year	Lower proportions breeding may indicate increasing threat (e.g., from contaminants)	Valuable – but demands relatively intensive survey intensity (numbers if visits to territories) to distinguish non-breeding from early failures

CONTEXTUAL DATA PARAMETER	DESCRIPTION	VALUE FOR CONTAMINANT STUDIES	SUGGESTED LEVEL OF PRIORITY FOR CONTAMINANT STUDIES *(justification based on value but also feasibility)*
Timing of breeding/trends	Phenology of breeding (timing of laying), usually back-calculated from egg density/known hatching date or chicks of approximate known age and growth patterns.	Assessment of the most critical period for breeding for evaluation of different environmental effects including contamination. Changes in phenology could be linked to adverse effects within the population (e.g., low female body condition).	Valuable – but requires relatively intensive survey and/or disturbance to access eggs/young for back-calculation of laying dates
Clutch size/trend	Number of eggs per nest (average and variability)	Population breeding fertility assessment	Valuable – but requires disturbance at nest to assess clutch size
Egg shell thickness	Average annual egg shell measurements	Annual measurements of egg shells in the nest might indicate contamination effects at population level (e.g., DDT)	Valuable – but depends on accessing samples of egg shells (may require nest disturbance)
Clutch failure rate/Hatching success/trend	% nests that fail before hatching/% nests that hatch successfully	Egg abandonment/loss as a possible indicator of contamination effects	Priority
Causes of clutch failure/trend	% of clutches attributable to each cause of failure	Ratio between known nest failure causes (e.g., predation, stress, nest destruction) and unknown nest failure causes might indicate hidden contamination problems in the population	Valuable – but requires regular visits to detect objective evidence of reasons for failure
Brood failure rate/Fledging success/trend	% nests that fail during brood rearing/% nests fledging at least one young	Brood failure as a possible indicator of contaminant effects	Priority

CONTEXTUAL DATA PARAMETER	DESCRIPTION	VALUE FOR CONTAMINANT STUDIES	SUGGESTED LEVEL OF PRIORITY FOR CONTAMINANT STUDIES *(justification based on value but also feasibility)*
Causes of brood failure	% of broods attributable to each cause of failure	Ratio between known nest failure causes (e.g. predation, stress, nest destruction) and unknown nest failure causes might indicate hidden contamination problems in the population	Valuable – but requires regular visits to detect objective evidence of reasons for failure
Productivity per territory/trend	The total number of fledged (large) young produced related to the total number of occupied territories	Population breeding productivity assessment – poor or declining productivity could be linked to contamination effects	Valuable – but requires accurate knowledge of overall number of pairs
Productivity per active nest/trend	The total number of fledged (large) young produced related to the number of active nests (i.e., nests in which eggs were laid)	Population breeding productivity assessment – poor or declining productivity could be linked to contamination effects	Priority – recommended as part of any new monitoring scheme.
Productivity per successful nest/trend	The total number of fledged (large) young produced related to the number of successful nests (i.e. nests in which at least one large young was produced)	Population breeding productivity assessment – poor or declining productivity could be linked to contamination effects	Priority and often quite feasible.
Survival of young/trend	% of young birds surviving to the next year	Assessment of post-breeding mortality of young birds (contaminants may affect survival rates)	Difficult for a specific study population – requires individual marking and work away from study area(s)

CONTEXTUAL DATA PARAMETER	DESCRIPTION	VALUE FOR CONTAMINANT STUDIES	SUGGESTED LEVEL OF PRIORITY FOR CONTAMINANT STUDIES *(justification based on value but also feasibility)*
Survival of adult age classes/trend	% of adult birds surviving from one year to the next	Assessment of mortality of breeding population (contaminants may affect survival rates)	Valuable – requires individual marking and work away from study area(s) to measure survival rather than just return rates
Post-breeding dispersal	Non-migrating post-breeding movements of young and adults (distances). It will generally only be possible to infer this from existing literature unless the population itself is ringed/tracked.	Assessment of effective contamination area	Difficult for a specific study population – requires individual marking/specialist techniques and/or work away from study area(s)
Natal dispersal	Distance of movement between natal and first breeding site. It will generally only be possible to infer this from existing literature unless the population itself is ringed/tracked.	Assessment of effective contamination area	Difficult for a specific study population – requires individual marking/specialist techniques and/or work away from study area(s)
Breeding dispersal	Distance of movement between first breeding and subsequent breeding sites. It will generally only be possible to infer this from existing literature unless the population itself is ringed/tracked.	Assessment of effective contamination area	Difficult for a specific study population – requires individual marking/specialist techniques and/or work away from study area(s)
Diet	Composition of diet at population/local level	A principal information source for defining main contamination and biomagnification pathways	Priority - recommended as part of any new monitoring scheme.

CONTEXTUAL DATA PARAMETER	DESCRIPTION	VALUE FOR CONTAMINANT STUDIES	SUGGESTED LEVEL OF PRIORITY FOR CONTAMINANT STUDIES *(justification based on value but also feasibility)*
Causes of death	% of birds found dead for each specific cause of death	Ratio between known death causes (e.g. roadkill, electrocution, predation, collisions) and unknown death causes might indicate hidden contamination problems in the population	Valuable – but few carcasses may be found and establishing cause of death objectively can be problematic. Separate Advice Hub document is available.
Relating to a wintering population (sampled for contaminants)			
Breeding origins	For the wintering population being studied.	Important descriptive data to define potential contamination source area(s).	Valuable – from literature or, ideally, from studies of marked birds from the population under study
Wintering density	Absolute numbers wintering		Difficult without very intensive survey methods and repeated counts (as wintering numbers may be mobile).
Trends in wintering numbers	Changes in wintering numbers through time (or indices of change)	Basic data to assess contamination population effects and population vulnerability, particularly for populations that are hard to monitor on the breeding grounds	Valuable and often feasible to monitor.
Diet	Composition of diet at population/local level in winter	A principal information source for defining main contamination and biomagnification pathways	Difficult for many species.

CONTEXTUAL DATA PARAMETER	DESCRIPTION	VALUE FOR CONTAMINANT STUDIES	SUGGESTED LEVEL OF PRIORITY FOR CONTAMINANT STUDIES *(justification based on value but also feasibility)*
Relating to migrating populations (sampled for contaminants)			
Breeding origins and wintering areas	For the migratory population(s) being studied. It will generally only be possible to infer these areas from existing literature unless the population itself is ringed/tracked.	Important descriptive data to define potential contamination source area(s).	Valuable – from literature or, ideally, from studies of marked birds from the population under study
Numbers migrating/trends	Changes in migrating numbers through time (or indices of change)	Basic data to assess contamination population effects and population vulnerability, particularly for populations that are hard to monitor on the breeding grounds	Difficult for many species.
Diet	Composition of diet at population/local level	A principal information source for defining main contamination and biomagnification pathways	Difficult for many species.
Other parameters (can relate to any population)			
Causes of death	% of birds found dead for each specific cause of death	Ratio between known death causes (e.g. roadkill, electrocution, predation, collisions) and unknown death causes might indicate hidden contamination problems in the population	Valuable – but few carcasses may be found and establishing cause of death objectively can be problematic. A separate Advice Hub document is available.
Threats (including persecution)	Quantitative or semi-quantitative information on threats (and	Important for placing any impacts of contaminants on	Difficult without other intensive related research. A separate

CONTEXTUAL DATA PARAMETER	DESCRIPTION	VALUE FOR CONTAMINANT STUDIES	SUGGESTED LEVEL OF PRIORITY FOR CONTAMINANT STUDIES *(justification based on value but also feasibility)*
	changes in these threats) to study populations	populations into the context of other negative influences.	Advice Hub document is available.
Morph variability	% of colour morphs in polymorphic species	Colour morphs are usually related to different physiological traits, which might affect the level of contamination through physiological or behavioural patterns	Priority and often quite feasible.
Genetic variation	Level of genetic heterogeneity in the population	Populations with low genetic variability are usually more susceptible to different environmental changes, diseases and contamination.	Valuable. A separate Advice Hub document is available.
Age structure	% of population (breeding/non-breeding) by age class	Basic data that can indicate age-specific mortality in the population	Valuable and often quite feasible.
Sex structure	% of population (breeding/non-breeding) according to the sex	Basic data that can indicate sex-specific mortality in the population	Valuable and often feasible (particularly where the species is sexually dimorphic).
Diseases	Veterinary control of dead or alive birds for different known diseases and parasites (% of infected and dead individuals)	Infection rate in the population might indicate higher susceptibility to contamination (as a stress factor) or might cause additional mortality and breeding success decrease besides contamination	Difficult – requires sufficient carcasses and/or specific samples from live birds.

IMPORTANT CHARACTERISTICS OF RAPTORS THAT INFLUENCE CHOICE OF MONITORING TECHNIQUES

MANY RAPTORS BREED AT LOW DENSITY COMPARED TO OTHER BIRD GROUPS, WITH IMPLICATIONS FOR MONITORING APPROACHES

With the exception of colonial or semi-colonial species (such as Lesser Kestrel and Red-Footed Falcon), **most raptors** breed at low densities and forage across extensive areas, characteristics which influence the survey methods that are most effective for raptor monitoring. Survey methods designed for monitoring breeding songbirds, like transect methods, may not work so well because the encounter rate with breeding raptors will be low (so that the power to detect changes will also be low), and observations made of raptors along transects will not necessarily be of breeding individuals and/or can be difficult to interpret in relation to the true number of breeding territories present. Whilst such methods can sometimes be used to provide indices of breeding raptor numbers, in general more intensive survey methods that rely on identifying occupied breeding territories and active nests are beneficial for monitoring purposes.

SOME BEHAVIOURAL PATTERNS SHOWN BY RAPTORS THAT CAN ASSIST WITH MONITORING

There are however some characteristics of raptors that are more helpful for monitoring purposes. Many raptors have **periods of territorial display above their territories and close to their nest sites at predictable times of the year**, which can help with identifying occupied territories. Some can also be **vocal at certain times of the year**, or if predators/competitors/humans approach their nest site. Others, however, are much less vocal and can be very secretive (including some forest species) and the nest sites of these species can be much harder to locate. Some species (such as Short-eared Owls) are extremely difficult to locate even when actively breeding, and may only be located reliably when they have (noisy) dependent young.

RAPTORS OFTEN LEAVE SIGNS THAT CAN ASSIST WITH MONITORING

Many raptors also leave signs that can be helpful in locating active territories or nest sites. These can include prey remains (e.g., feather pluckings from avian prey), moulted feathers, pellets (regurgitated fur, feathers and bones from prey animals) and faeces (usually white splashes for raptors).

RAPTORS CAN BE VERY VISIBLE AND WELL KNOWN TO PEOPLE

Raptors are large and charismatic birds that are often liked and respected by the public. People that work in the countryside (foresters, farmers, gamekeepers, rangers) are often aware of their presence and also may know where active nests are located. Conversely, in some situations, where they are perceived to threaten human interests, raptors are disliked and may suffer illegal killing. However, in situations where this sensitivity does not exist, **people living and working in the countryside can be a useful source of information to help to locate the presence of a species in an area or active nests.**

CHOICE OF PARAMETERS TO MONITOR AND CHOICE OF STUDY AREAS

WHICH PARAMETERS ARE MOST VALUABLE / WHICH ARE MOST FEASIBLE?

There are many parameters that would theoretically be possible to monitor that would be valuable for interpretation of contaminant studies, or for helping to identify contaminant threats to populations (through early warning signs of negative changes). These parameters differ widely in how feasible they may be to measure generally (due to the skills and resources required) and this feasibility may differ in different parts of Europe. Therefore, we have tried to suggest parameters in priority groups – focusing on those that may be both practical to measure but also of high value for contaminant studies. Below we provide some general guidance on monitoring raptors and also some recommended literature for further reading.

MONITORING CHANGES VERSUS MONITORING ABSOLUTE POPULATION PARAMETERS (PROS AND CONS)

In general, measuring the absolute value of population parameters (for example, the density of breeding raptor pairs, clutch size or numbers of fledged young) is more difficult and demands more intensive survey effort that measuring trends (changes over time) in these parameters (or parameters that change in direct proportion to the absolute parameters of interest). For example, measuring the absolute number of raptor pairs breeding in a large study area (such as an area of forest) each year can be extremely time consuming but it may be possible to use a less intensive survey method (such as transect counts) to measure an 'index' of the size of the breeding population and, if done using a standardized method, this can be used to effectively monitor trend in breeding numbers through time. Similarly, because of the behavior of some young raptors post-fledging, it can be hard to establish the absolute number of young that leave the nest, and often a minimum number is recorded, as it is acknowledged that not all young may be found. Instead, often raptor researchers use the number of large young recorded in the nest (for example at the time of ringing them) as a surrogate measure of breeding success, and use this measure to monitor trends in productivity through time.

GENERAL CONSIDERATIONS FOR SELECTING STUDY AREAS (SIZE, REPRESENTATIVENESS, NUMBER OF SAMPLES ETC)

In order for the results of monitoring to be scientifically rigorous, **sample study areas need to be representative of the population to which the collected data will relate**. The ideal would be to have a random sample of study plots selected from within the range of the population being monitored, taking into account the range of habitats used by the species and the abundance of the species in the different habitats. Some other species characteristics may need to be considered – for example if some individuals of a species breed in trees and some breed on cliffs, then ideally both types of nest site should be included in the sample to be monitored (in case these differ, for example in frequency of breeding or reproductive success). It may not always be practical to choose a completely random sample of study areas (perhaps because of access limitations or the availability of volunteers to carry out monitoring) but every attempt should be made to choose study plots that are as representative as possible.

The **choice of study area size and number of samples** will be dependent on the focal species and habitat but also on the overall objectives of the study, and on the resources available (who will do the monitoring work and how much time do they have). As a general rule, assuming that resources for monitoring are finite, it is often better to spend effort monitoring a larger number of smaller study plots than a smaller number (or a single) large study plot. A study based on a larger number of smaller study plots is more likely to be representative of a wider population, and is also more likely to allow some quantification of variation within the population for the parameters that are being monitored. Where population monitoring has been set up with the explicit aim of producing regional, national or supra-national, study areas are generally based on a formal sampling design, involving an element of random selection plus often some form of stratified sampling relevant to spatial variation in abundance and habitat use of the species under consideration. In other cases, more intensive research studies may have other priority objectives (alongside monitoring) and these may then be less likely to follow such a formal design and may cover one (larger) area, or a small number of larger study areas. In the latter case, useful information can still be obtained but it is very important to consider to what extent the parameters measured in the intensive study are truly representative of the species population over a wider area (and this is equally true for relating population contextual information to contaminant results, if the two types of information do not derive from exactly the same study population).

The most appropriate **size of study plot** necessarily depends on the abundance of the species (density of breeding territories per km2) and how much time is available to cover the area (availability of people). One person carrying out breeding season monitoring of one or more widespread and abundant raptor species might perhaps cover an area equivalent to a 2 x 2 km square (e.g. recommended by the Raptor Patch initiative in Scotland), whilst a team of people might be able to cover larger study areas (e.g. a 5 x 5 km or 10 x 10 km square). Larger raptors that breed at low density will require coverage of larger areas, and colonial species require a different approach (based on selection of a number of colonies, generally of differing sizes if possible).

CHOICE OF SEASON & PARAMETERS TO MONITOR TO AID CONTAMINANT STUDIES

Most population monitoring work for producing trends in birds is focused on the breeding season. This is the time when monitoring of numbers is most straightforward because breeding birds are linked to breeding territories (making duplicate counting less of an issue), and also because of the value in monitoring a range of reproductive parameters as well as numbers. Outside of the breeding season, raptors are not tied to breeding sites and can be much more mobile, making counting and assessment of population trends more problematic. For the purposes of studies of contaminants in the many raptor populations that are not sedentary throughout the year, it may often be important to understand where individual birds from a particular breeding population spend the winter, and the route(s) taken on migration, so that geographical contaminant exposure pathways can be assessed (usually requiring some form of individual ringing/tracking, genetic or isotopic analyses). However, population numbers and trends are usually best assessed on the breeding grounds. The exception is for populations breeding in areas that are difficult to access or to survey in a representative way because of their remoteness (for example large parts of Russia). So, for the European breeding populations of some species, counts made during migration and/or in wintering areas can be the only practical way of monitoring populations. Due to the value for contaminant studies of measuring and monitoring a range of breeding parameters as well as breeding population size and trend, we have focused our advice on monitoring during the breeding season but also included short sections to sign-post to guidance on migration and winter monitoring as well.

MONITORING PARAMETERS RELATING TO A SPECIFIC RAPTOR BREEDING POPULATION

In all cases, the ideal situation for a study of contaminants in raptors will be to have breeding population parameters measured and monitored from the same population (or ideally study area) from which tissue samples are obtained for analysis, as this allows the most powerful interpretation of the contaminant results in relation to the other population parameters. The most rigorous inferences are likely to be possible from raptor populations that are sedentary throughout the year (non-migratory), or from breeding populations of migratory species for which there is also rigorous knowledge of wintering areas and migration routes and timings.

BREEDING AND WINTERING DISTRIBUTION (RANGE) AND CHANGES

Changes in the breeding distribution (range) of a species may be indicative of threats (including those posed by contaminants). It is also important to understand the range of a species, and any changes in range, to assess whether study areas selected for monitoring are representative of the population as a whole. The distribution of raptor species is most often assessed through ‘atlassing’ approaches - that are designed to record the presence of a broad range of species. They usually consist of a walk-over methodology designed to detect the majority of species in every spatial unit (e.g., 10x10 km square) covered, or a sample of such units, and they may contain a timed recording element, to provide some measure of spatial variation in relative abundance. They generally do not measure absolute population size. Most atlassing work has focused on breeding populations but similar approaches can be used to assess wintering ranges. The latter may require more complex design however, because of the increased mobility of birds outside the breeding season. Atlassing methods have the advantage of being able to cover large areas and a broad range of species. However, if a more detailed understanding of the range of a species is required and/or knowledge of the absolute numbers of breeding pairs, then a survey designed specifically for that particular species will be required (see below). Such species-specific surveys must be carefully designed however if they are to identify changes in range. Often such surveys use previous knowledge of breeding range to establish the design (often based on some kind of stratified random sampling). If such surveys aim to assess range changes (particularly range expansion), it is important that areas not thought to be occupied by the species previously are included in the sample of areas to be surveyed.

BREEDING NUMBERS AND CHANGES IN BREEDING NUMBERS

Many raptor species breed at low density over extensive areas, so survey and monitoring techniques must be selected with these characteristics in mind. By far the most reliable method of assessing absolute breeding numbers of raptors and monitoring change is territory mapping. The sightings of raptors from consecutive visits in any given study area are plotted on a map and their home ranges as well as their territory boundaries are delineated. The number of areas could be set as an index of abundance although if the study area is covered several times per month and simultaneous observations of adjacent birds are made territory occupancy and the number of territorial pairs in the study area can be adequately assessed. Information on home ranges, territory occupancy and nest site selection are essential in order to: 1) assess important nesting, feeding, wintering and roosting areas, 2) monitor population trends and productivity and 3) evaluate detrimental human activities and monitor environmental health status.

If the aim of a study is to provide only a measure (index) of breeding population change through time, then a lower intensity survey technique demanding less survey time may be suitable, such as some form of transect or point count/vantage point methodology. However, to measure the absolute number of breeding raptors, and to be certain of accurately monitoring change, surveys based on detecting all occupied home ranges/active nests in an appropriately representative sample of study areas are generally required - and these can be combined effectively with survey work through the breeding season to allow measurement and monitoring of a range of breeding parameters from a representative sample of active nests (see below). For species that are relatively rare or relatively easy to locate during breeding, such surveys may be able to cover the whole breeding population but, in most cases, selection of a representative sample of study plots of suitable size for each to be covered comprehensively will be required. The latter approach also has the benefit of allowing statistical confidence in population estimates to be calculated, which is not possible if attempt is made to survey the entire population. Such survey programs may be designed/optimized for a single raptor species or they may be designed to monitor a range of species, such in the Finnish Raptor Grid program, Estonian raptor monitoring program or Scottish Raptor Patch initiative.

SUGGESTED SCHEDULE OF VISITS THROUGH THE BREEDING SEASON

Reproductive rates (i.e., hatching, fledgling and breeding success; productivity) are important components of avian population dynamics as they can be valuable in assessing the status of raptors populations and factors that influence the various stages of their breeding cycles. However, increasing concerns focus on their monitoring (e.g. due to risks of disturbance) and there can be important sources of bias depending on the survey protocol used and fieldwork timing. The optimal time for surveying depends on both the methods used and nesting habitat because the relative importance of the potential biases will differ. Two main approaches on the timing of surveys were initially formulated and are still often followed namely: (i) surveys carried out during incubation so as to locate non-breeding territorial pairs; and (ii) surveys made only after the eggs have hatched in order to avoid nest failures caused by fieldworker disturbance. However, as the timing of nest surveys is critical for rigour of monitoring certain parameters, visits should initiate during the first half of the species breeding cycle and, if possible, during the early courtship and display flights of the territorial birds, and caution should always be applied when approaching nests during the sensitive incubation period.

For establishing whether an individual breeding territory is occupied, it is preferable to make two (or more) visits early in the breeding season. If only a single visit is made prior to laying and incubation, it can be difficult if a pair of birds or only a single bird is present but sightings of a bird or two birds ‘on territory’ on more than one occasion early in the season provide stronger evidence of occupancy. If a study aims to monitor both occupancy (numbers of territorial pairs) and breeding performance, then a minimum of four visits are recommended to every part of the study area/to every home range:

VISIT 1 to establish occupancy of a home range/nesting territory/nest site;

VISIT 2 to check for breeding by locating active nests and/or to follow up sites not found to be occupied during Visit 1;

VISIT 3 to check for successful hatching (young active in nests); and

VISIT 4 to measure breeding success (ideally by counting fledged young if feasible; or to count large young).

Hardey et al. (2013) give information on the timing of these visits for all species breeding regularly in the UK, and also suggest some variations, for example to take account of the ease (or otherwise) with which the information can be obtained for each species, and any times when visits should be avoided due to particular sensitivities over disturbance. If a study aims only to monitor the productivity of active breeding pairs (not occupancy), then a minimum of two visits is required (Visit 2 and Visit 4) but a four-visit program of visits is still highly recommended.

HOW TO FIND ACTIVE PAIRS AND ACTIVE NESTS

Occupied breeding territories are generally located through one or more of: watching for evidence of breeding behavior by adult birds, often from vantage points (e.g., sky-dancing displays over breeding territories); looking for signs of active occupancy (evidence of kills, plucking posts, regular roosts with faeces or pellets); and locating active nests (such as nests that have fresh vegetation added at the start of the breeding season). For some habitats (such as broad-leaved woodland), checks may also be useful during the winter months (when leaves are absent from trees) to locate nests from the previous breeding season that can later be checked for breeding season activity.

Fieldworkers prior to fieldwork should: 1) collect and consult references on the nesting requirements of the focal raptor species; 2) determine the potential nesting sites by examining maps and aerial photographs; and 3) plan ground survey routes to cover all suitable raptor nesting habitat. When they actually conduct a survey, they should: 1) utilize the best access routes and visit all the potential breeding areas; 2) examine nests from a safe distance (600-900m) depending on the tolerance of species and keep disturbance to the minimum; 3) map and geo-reference all old or abandoned nests as they may serve as alternative nests in subsequent years; and 4) take photos of the nest sites (cliffs, trees, cavities) as well as of the surrounding area. Local knowledge from people that work in the countryside in the area may also be useful in locating active territories.

REPRODUCTIVE PARAMETERS TO MEASURE AND MONITOR

Estimates of reproductive parameters, and trends in these, should be based on an adequate sample that is representative of the population under consideration. An appropriate sample size for measuring changes through time will depend on the scale of change that it is desirable to detect and the natural variation in each parameter (known or assumed) within the population (which will influence statistical power to detect change).

The best indicators for assessing habitat quality (and the impacts of contaminants) are likely to be estimates of productivity and/or survival. However, estimating age-specific survival rates demands the monitoring of marked or radio tagged individuals for the time they fledge to adulthood over large spatial scales. On the other hand, monitoring the species population and assessing its breeding success rates and productivity can be quite indicative of the relative habitat quality and environmental health. Raptor populations comprise a sector of territorial breeders and a sector of nonbreeding individuals or "floaters". These latter individuals may be located in suboptimal habitats but preferentially in close proximity with territory holders. Non-breeders may represent more than 50% of the total population and the survival of the entire population is strongly dependent on the number of floaters available to replace lost breeders and abandoned settlement areas.

A territorial pair should be defined as 'breeding' if it is known to lay at least one egg. However, unless very regular checks are made in the territory in the time leading up to laying, it can be difficult to distinguish between those pairs that lay but fail soon after laying and those that do not lay at all. This is why it is important: (a) to be clear when defining breeding parameters whether they are expressed as, for example, 'percentage of pairs **known to lay** which fledge at least one young' or 'percentage of **occupied territories** which fledge at least one young' (the latter measure not requiring laying to be confirmed).

PROPORTION OF BREEDERS (SEXUALLY MATURE BIRDS) MAKING A BREEDING ATTEMPT

Occupancy of a territory by potential breeders is confirmed by the presence of birds of potential breeding age (first age of breeding varies for different species). A breeding attempt is confirmed by observing incubating adults or a nest with eggs and/or young. As mentioned above however, unless very frequent visits are made to the territory, it can be difficult to separate pairs that lay and fail early from those that do not lay at all (and so the proportion of pairs making an attempt will often be under-estimated). However, if a consistent programme of (for example, four) visits is made to territories every year, then there is the possibility of at least detecting changes through time in the proportion of pairs that attempt to breed. Care must be taken, however, to also consider the implications of changes in the timing of breeding (e.g. as a result of climate variation) for the ongoing annual visit schedule within a study.

PRODUCTIVITY & BREEDING SUCCESS (CLUTCH SIZE, HATCHING SUCCESS, BROOD SIZE, FLEDGING SUCCESS, NUMBER FLEDGED PER BREEDING ATTEMPT, NUMBER FLEDGED PER OCCUPIED TERRITORY)

Clutch size is defined as the total number of eggs laid per nesting attempt. The general trend is for clutch size to be disproportionate to the size of the species concerned. The larger species such as vultures lay 1-2 eggs, while small falcons lay up to 4 eggs per clutch. There are many extrinsic and intrinsic factors that influence clutch size, such as the latitude, the altitude, the weather conditions (with temperature being the most critical) and food abundance, as well as the status of the female (e.g., age, body mass) and population density. Clutch size is known to have an influence on the overall breeding performance of many raptors. In several species, individuals produce submaximal clutches in an effort to have better survival prospects and increase their lifetime breeding performance compared to maximal breeders. Other species follow a different strategy to optimize lifetime fitness, namely they adapt their clutch size on an annual basis in relation to food quality and abundance and the population fluctuations of their prey species. For instance, small falcons that eat rodents tend to lay larger clutches than bird-eating falcons in the same area, and these in turn have larger clutches than insect eaters.

For assessing the reproductive outcome of breeding raptors, at least two visits are needed, one at the start of the nesting cycle close to the time of egg-laying/ incubation and a second one before the fledging of the young. The objective of the first check is to count the number of egg-laying pairs while the second one is to count the number of successful pairs. However, in order to maximize the information on reproductive parameters that can be obtained, survey schedules based on at least four visits through the breeding season are recommended (see above).

A breeding attempt should be regarded as successful if at least one young is known to fledge. However, determining whether successful fledgling has occurred can be difficult in many species without very frequent nest visits because the young are difficult to locate once they leave the immediate vicinity of the nest and frequent visiting may not be desirable due to disturbance risk. Therefore, a rule of thumb is often used to define a breeding attempt as successful if at least one young reaches 80% of the average age when most young normally fledge. It is also often not possible to measure the actual number fledged because once raptors actually leave the nest it can be difficult to ensure that all young are found during a survey visit, and often it is only then possible to record a minimum estimate of the number that actually fledge. Owls present a special problem in this respect because the young of many species leave the nest before they are able to fly (termed ‘branching’), so the true number of fledglings can be underestimated.

MOST COMMONLY USED TERMS RELEVANT TO THE MEASUREMENT OF BREEDING PARAMETERS INCLUDE:

NESTING TERRITORY. An area that contains, or historically contained, one or more alternative nests within the home range of a mated pair.

TERRITORY OCCUPANCY. Observation of paired birds engaged in territorial defense, copulation, nest building, or performing undulating flights (“sky-dances”).

BREEDERS. Mated birds (of potential breeding age) that occupy nesting territories.

FLOATERS. Unmated birds in sub-adult or adult plumage that do not reproduce due to lack of vacant territories.

NON-BREEDERS. Floaters and territorial pairs that do not lay eggs.

BREEDING SEASON. The period from the start of nest building to the independence of young.

PRE-INCUBATION PERIOD. The time between laying of the first egg and onset of incubation.

INCUBATION PERIOD. The time between egg-laying and egg-hatching when eggs are brooded by the parent birds.

NESTLING PERIOD. The chick-rearing period, namely the time between egg-hatching and fledging of the young.

NESTING PERIOD. The time from laying of the first egg to the time when the last young fledge.

POST-FLEDGING PERIOD. The time between fledging and independence of parental care.

CLUTCH SIZE. The number of eggs laid in a nest.

HATCHING SUCCESS. The number of eggs hatched to the number of eggs laid. [An extra visit during the hatching period is needed except for multi-egg clutches in inaccessible nests that are impossible to assess]

FLEDGING SUCCESS. The number of fledglings to the number of eggs hatched.

BREEDING (OR NESTING) SUCCESS. The proportion of egg-laying pairs that produce at least one fledgling.

SUCCESSFUL PAIR. A pair that produces at least one fledgling.

BROOD SIZE AT FLEDGING. The number of fledglings produced per successful pair.

PRODUCTIVITY. The number of fledglings produced per territorial pair or per occupied territory per year. (An extra visit is needed during the pre-breeding season to assess territory occupancy)

APPARENT NEST SUCCESS. The ratio of the number of successful pairs to the total number of territorial pairs.

Ideally, surveys to measure breeding parameters should begin early in the nesting season and analysis should be restricted to pairs found prior to egg-laying. However, frequently, nesting success is estimated as the raw proportion of pairs that raise young successfully. Such simple ratios of successful pairs to the total number of nesting attempts detected (i.e., apparent nesting success) can be biased upwards if active nests found late in the breeding season are included in the analysis. Nesting attempts discovered during the later stages of the breeding cycle are more likely to survive as they have less time to fail before the end of the breeding season. One strategy to avoid this upward bias caused by unequal nest detection probabilities is to apply the apparent estimator only to the nesting attempts found at the onset of the breeding season. This approach is restricted by small sample sizes but may be suitable for assessing long-term trends if the bias is predictable and consistent over time.

Overall, three methods have been used to calculate an unbiased estimate of success rates per pair for long-lived raptor species:

3. Calculation of the percentage of successful pairs from a preselected sample of territorial pairs. This approach involves minimal disturbance to the birds and has the advantage that fieldworkers do not have to distinguish non-breeders from failed breeders. Its disadvantage is the sample size, since only pairs identified in earlier years can be used in the analysis.
4. Multiplying the percentage of breeding pairs out of a sample of preselected territorial pairs, by the percent of successful breeding attempts, based on the preselected territorial pairs plus those breeding pairs that are found early in the breeding season. This approach increases the sample size and at the same time avoids bias. The sample of preselected territorial pairs is usually small but it is used only to calculate the proportion of territorial pairs that actually breed. Meanwhile the percentage of successful breeding attempts can be calculated from a larger sample that adds the breeding pairs found during incubation. This method has the disadvantage that researchers must distinguish nonbreeders from failed breeders but is suitable for the early detection of raptors that rebuild large conspicuous nests almost every year.
5. The ‘Mayfield method’ - namely calculate a daily nest survival rate from all breeding attempts checked twice or more during the nesting season. This method can be applied when it is not possible to find all pairs before egg laying. In that case, nest survival models can be used in order to estimate the success of laying pairs, as long as the status of the nest is determined on at least two separate dates within the nesting period. Mayfield (1961, 1975) proposed this alternative method based on "exposure days" that would be appropriate for all situations.

NEST SURVIVAL RATES

When it is not possible to find all pairs before laying, nest survival models can be used in order to estimate the success of laying pairs, as long as the status of the nest is determined on at least two separate dates within the nesting period. The “Mayfield” method incorporates data from nests found at various stages of the nesting cycle and calculates daily nest survival during the time that a nest is under observation. The method estimates the probability that all nests will survive over an entire nesting period assuming a constant daily survival rate for all nests. Considering the length of the laying, the incubation and the chick rearing period to the average fledging age, nest checks should be relatively spread over the entire nesting cycle and the status of the nests during three dates should be available i.e., date nest found, last date the nest was checked and date the nest was last known to be active if it had failed by the last check. Newer models implemented in relevant software e.g., Program MARK may incorporate categorical and continuous covariates, while model selection is achieved via likelihood-based information-theoretic methods. However, nest survival models should only be used to estimate nesting success of egg-laying pairs while productivity per territorial pair is estimated in combination with an independent estimate of the percentage of egg-laying pairs.

The Mayfield approach has the advantage of larger sample sizes because pairs found late in the breeding season can be included in the analysis. The disadvantages are that nest status must be confirmed at least twice during the breeding season, the approximate hatch dates must be known for most nests and reproduction might be underestimated if most nests found in a survey are unsuccessful. The technique may be suitable for raptor surveys due to its flexibility in using nests found after hatching but it does not address the problem of nonbreeding territorial pairs.

BREEDING PHENOLOGY (HOW TO ESTABLISH LAYING DATES)

Laying dates are useful because they often correlate with nest success and are also required for some modelling of nest survival (failure rates). Evidence of egg laying is usually based on observations of incubating adults, eggs, chicks or fresh eggshell fragments. Laying date is usually calculated indirectly, however, by backdating from some later stage in the breeding cycle, taking into account the intervals between laying of successive eggs (two days in most raptor species), the incubation period (from bibliographic references on the species), and, in the case of nests found during the nestling period, from the age of the young. Ages of nestlings can be estimated from weights or measurements or by the aid of photographic aging keys. Repeated checks during the pre-breeding and expected laying period can facilitate the estimation of the date of onset of incubation but this can be very intensive work. Investigators often assume that egg laying, egg-hatching, fledging of the young or nest failures occur midway between successive nest checks, with the latter check being the one in which the event was discovered. The possibility to get exact dates depends on the frequency of visits and the number of days that elapse between consecutive visits.

USEFUL LINKS & REFERENCES FOR GENERAL RAPTOR MONITORING GUIDANCE AND MONITORING BREEDING POPULATIONS

Hardey, J., Crick, H., Wernham, C., Riley, H., Etheridge, B. & Thompson, D. (2013) Raptors – A Field Guide for Surveys and Monitoring. 3rd Edition. The Stationary Office Ltd. All chapters available at: https://raptormonitoring.org/need-advice-on-monitoring [Very comprehensive guidance on all aspects of raptor monitoring; guide to identifying raptor feathers; guide to chick growth; the hard copy also contains a CD of raptor calls]

Bird, D.M. & Bildstein, K.L. Eds (2007) Raptor Research and Management Techniques. 2nd Edition. Hancock House Publishers. [Very comprehensive guidance on all aspects of raptor monitoring]

Bird Study EURAPMON Special Issue (2018) Volume 65. [Examples of good practice monitoring schemes]

Acrocephalus Special Issue on a preliminary Inventory of Monitoring for Raptors in Europe (2012) Volume 33 (154/155). (More examples of existing monitoring schemes from across Europe)

Xeno-canto (https://xeno-canto.org/) [Extensive library of raptor calls]

Mayfield, H.F. (1961) Nesting success calculated from exposure. Wilson Bulletin, 73, 255-261. [Calculation of nesting success]

Mayfield, H.F. (1975) Suggestions for calculating nesting success. Wilson Bulletin, 87, 456-466. [Calculation of nesting success]

MONITORING RAPTOR POPULATIONS IN WINTER

Raptor populations are generally less studied outside their breeding season e.g., wintering period, although winter represents almost half of a raptor's annual life cycle. Currently little information exists on raptor winter status as this season is generally underrepresented in the literature even though winter mortality rates of raptors are often similar to those of the breeding season. Winter raptor populations usually comprise local breeders of an area and an influx of long-distance migrants and young birds in dispersal which both become temporary residents. A well-designed monitoring scheme for wintering raptors should include: a) concrete survey objectives, b) cost-effective fieldwork techniques and c) appropriate analytical methods for data handling, analysis and storage.

SURVEY OBJECTIVES

The objectives of winter raptor surveys need to be clearly set but most of the times they include: 1) Information on raptor distribution, 2) estimates of relative abundance within areas and across large geographical scales, 3) assessment of population trends at local and regional level, 4) identification and delineation of winter "hot spots", 5) assessment of barriers and threats along the flyway from breeding to wintering areas 6) evaluation of landscape and habitat associations at multiple scales and 7) assessment of basic biological traits such as age and sex differences between breeding and wintering grounds. However, in most of the times survey objectives focus on species distribution and abundance and on identifying shifts in winter distributions in response to environmental change. Ideally, a baseline database for assessing winter raptor population should start by building a proper sampling strategy within the study area i.e., a survey design that should consider the sample unit, the appropriate sample size, and the spatiotemporal survey scale that needs to be conducted. In several occasions a combination of techniques might be used depending on the terrain that has to be surveyed, the target species involved and the manpower available (Table 10).

SAMPLING PROCEDURE

A stable network of study plots (of at least 25 km2 in extent) with suitable habitat for diurnal or nocturnal raptors should be selected within a large geographical area (e.g., 100-120 km2). The census area would require many days of monitoring; thus a few-days of fieldwork will allow researchers to monitor only a fraction of the raptor winter population. Regardless of the fieldwork effort some basic factors for the selection of sampling plots are: 1) the total extent of coverage, 2) the weather conditions during the census period, 3) the habitat types and 4) the prey abundance occurring in the census area. In all cases the raptor monitoring could be conducted by covering a large geographical region or by sampling a representative portion of it and extrapolate species density over its winter distribution range.

ENVIRONMENTAL CONDITIONS

Surveys should be conducted under favourable conditions avoiding days with fog, rain and wind speeds >20 km per hour (more than Beaufort 3). Temperatures should be close to the average for the season and efforts should be made to avoid extremely cold temperatures. Data on weather conditions should be recorded at the beginning and end of each survey, and preferably at every sampling plot, so that weather variables can be used as covariates to reduce variance in count indices, or so that data from selected plots can be excluded from certain types of analyses if conditions exceed the thresholds.

SURVEYS DATE & TIMING

Surveys are conducted in December, January and February. If performed only once in a season, a January survey is preferred. If more than one survey is conducted per season, they are held at least 20 days apart. Surveys along a given route are of greatest value when they are held close to the same date every year, for example always in January. By mid-afternoon on calm days, raptors are often soaring at high altitudes, making them more difficult to detect. Suggested start time is no earlier than 30 minutes after local sunrise, and the suggested latest finish time is 30 minutes before local sunset. Most surveys are usually conducted two hours after sunrise and end one hour before sunset. Stops are mainly to complete data entry for observations, and to scan at designated locations along the route that are consistent between surveys. For owls the best time to run a survey route is between half an hour after sunset and midnight.

FIELDWORK

The survey techniques should address factors that affect raptor detectability (e.g., time of the day), species-specific life-cycle and behavioral patterns, and experience of the observers. In all cases the ultimate aim is to acquire data that will be meaningful from a statistical point of view. This means that sampling plots are representative of the region being surveyed and will generate valid statistical inferences about raptor populations in the region. Furthermore, at large spatial scales some useful facts about raptor biology should be taken into account in order to detect birds. For instance, most raptors do not occupy strict feeding territories during winter but are often concentrated in suitable habitat patches with high prey density. Furthermore, birds are frequently sighted soaring at mid-day during sunny weather and they might spend considerable time on hunting posts along roads or prominent outcrops and trees in open habitats. Overall surveying raptors in winter can be conducted from the ground from a vehicle along roads, or from a boat along shorelines, the air and rarely through remote sensing (e.g., radar).

ROAD SURVEYS

In the majority of the cases monitoring comprises of large scale transects followed by motor vehicles. Road surveys are most appropriate for surveying large conspicuous raptors by traversing specified routes along roads over pre-determined sampling plots. They have the advantage of covering large areas and are recommended for monitoring raptors dwelling in open habitats. However, although road surveys are the commonest tool for monitoring winter raptor populations as roads can be followed consistently over the years, they are not distributed randomly within the sampling plots. Considering that the greater the element of randomization, the greater the statistical credibility of the survey, the only way to ensure that routes are representative is to select them at random from within the survey area using a stratified sampling scheme. A further condition should be that some routes go through potentially suitable habitat. Effective routes should be between 50-100 km long. They can contain stops for extended looks if the stops are done consistently. The fieldwork period should preferentially coincide with the period or time of maximum detectability of the birds or at least the season that this is relatively constant. By this way repeated counts over the years or at different spatial scales will be reliable and appropriate for constructing population indexes based on changes in raptor abundance. The field team usually comprises of at least two persons i.e., a driver who drives at slow speed (20-40 km/hr) and an observer who keeps notes of all birds of prey recorded in a known distance travelled over a recorded time. Censuses are conducted throughout the day and the direction and order of transects driven varies so to minimize time and directional biases. Whenever a perched or flying raptor is seen with unaided eye, a brief stop is made so to allow species identification by the use of binoculars (10x40 or 8x42) and data are recorded on standardized protocols. The perpendicular distance from the transect (m), and coordinates (GPS fixes) of observation point along transects should be also recorded. Optical range finders, compasses and clinometers can be used in order to measure the radial distance between the raptor and the observer and its angle on the horizon and calculate trigonometrically the ground projection of the observed bird and its perpendicular distance to the observer.

TRANSECT SURVEYS ON FOOT

These surveys generally produce a lower encounter rate of raptors compared to road surveys, but have the advantage of accessing remote plots with suitable habitat in roadless areas. Fieldworkers should walk along randomly selected routes of predetermined length. The position of the birds i.e., its approximate distance and direction from the transect line and the time taken to cover the route should all be recorded. Some routes are "circular", where the route ends at the beginning point, and some are more linear. They can be any shape i.e., straight or zig-zag line, square, circle. Shape and distance are in large part determined by the topography of an area and where the raptors occur. To avoid double counting close parallel lines should be avoided.

VANTAGE POINT SURVEYS

In rugged terrain the survey technique may be modified to stand-watches which may be more effective, namely views of fixed duration from vantage points. Fieldworkers should position themselves on appropriately selected prominent sites with good visibility over the surrounding area and record all raptors observed. Vantage point surveys are also recommended for counting numbers of individual raptors entering or leaving a given location such as a communal roost and for monitoring the abundance and flight lines of foraging raptors in an area. Vantage point surveys can be combined with transect surveys to provide a combined means of monitoring changes in raptor numbers over time. The modified technique involves repeated counts at regular intervals at fixed locations for a given time period. The primary advantages of stand watched that the relative abundance of many species that can be determined over broad areas at a moderately low cost and the species-habitat relations that can be evaluated effectively compared to other methods. Fieldworkers should estimate the approximate direction and distance to the first position where they detect each owl and even plot proximate locations on maps provided. The location may help to determine whether the same owls are being detected at different stations along the route. More precise habitat modeling can be conducted, provided that the stations themselves are georeferenced. Distance information can be used to adjust for some of the variation in detection rates, especially observer variation, using distance sampling methods.

CALL PLAYBACKS

The basic survey method is to broadcast conspecific calls in order to elicit responses along a predetermined route consisting of a minimum number of 10 stations, distributed along the route at equal intervals of 1.6 km within the survey area. The observer should broadcast an amplified call and then, using a compass, plot the direction of calls made in response. Such surveys should be conducted between half an hour after sunset and midnight and always be repeated more than once at any given location starting from the smallest owl species. Within a species, response rate can be influenced by age and sex, time of year and lunar cycle. If the aim of such surveys is to produce an estimate of absolute population size, then validation work to assess the proportion of birds which respond, and variation in the response rate, should be carried out. Each random route should be separated by at least 5 km from any other route, to minimize the risk of the same species being heard on more than one route. The survey window should be relatively broad (e.g., 4 weeks) to maximize the number of surveys that can be conducted, and to include any annual variation in phenology. Fieldworkers should estimate the approximate direction and distance to the first position where they detect each owl group distances into categories (i.e., 0-100 m, 100-300m, >300m). The location may help to determine whether the same owls are being detected at different stations along the route. More precise habitat modeling can be conducted, provided that the stations themselves are georeferenced. Distance information can be used to adjust for some of the variation in detection rates, especially between observers.

BOAT SURVEYS

Surveys from the water involve the use of vessels where the population size or the relative density of raptors are estimated along the shorelines of rivers and lakes where wintering birds forage communally on aquatic prey (e.g., osprey, white-tailed eagle?). Boat surveys usually take place in mid-winter and fieldworkers complete each survey route at least once between December and February, with a preference for January if surveying only once. Each boat survey involves at least three participants i.e., a boat operator, a lead observer, and a data recorder who follow predefined routes ensuring full coverage of the study area and filling standardized protocols. The boat travels at a speed not exceeding 24 km/hr approximately 50–200m offshore.

AERIAL SURVEYS

Such surveys cover extensive areas, and have been used effectively for some of the larger raptors. The technique involves the use of light airplanes or helicopters and more recently drones where raptor aggregations (e.g., communal roosts) are located in their foraging grounds. The observers fly along sets of transects (or grids), the optimal spacing of which depends on the spatial dispersion of the species and record observations of the target species. Surveys should be carried out at ca. 200 m above ground level, at a speed of 30–130 km per hour. When suitable habitats are identified, slow (80 kph) passes at lateral distances of about 50m are conducted. However, as individual birds can be difficult to detect from the air and because they often are widely dispersed and might be easily disturbed, aerial surveys have not been extensively used for monitoring wintering raptors.

SURVEY EQUIPMENT

Fieldworkers should carry notebooks, or worksheets, clipboard and writing utensils, binoculars, spotting scopes, window mounts (for vehicle surveys), optical range finders, compasses, clinometers, GPS (Global Positioning System) units and Bird Identification Guides. For playback calls, digital technology is recommended (CD-ROM) with enough power so volume can be heard at ca. 400m.

SURVEY PROTOCOL

The data recorded when censusing wintering raptors include: 1) date, 2) fieldwork period (i.e. start and ending time), 3) name of the observers, 4) coordinates of the starting and ending location, 5) specific information on weather conditions at the start and end times of the survey (i.e., temperature, sky, wind conditions), 6) mileage covered during the road, foot or boat survey, 7) time and precise location of each raptor encountered, 8) species and additional individual characteristics such as age, sex, color morphs, 9) behavior or activity (roosting, flying, soaring, hunting, feeding, injured/dead), 10) perch type (if roosted) and prey item (if feeding), 11) intra-specific or inter-specific interactions and 12) habitat type where each individual is initially observed.

DATA ENTRY

All spatial data along with the raptor observation should be georeferenced during a winter raptor survey. The location of the starting point of the routes and stations, should be recorded as precisely as possible, either using a GPS device (or through reading the coordinates from an accurate and detailed map, or with the aid of relevant applications of a smart phone). The GPS device is turned on and set to record the track and mark as "way points" the route location raptor sightings take place. In addition, the waypoint number is noted on the field protocol along with other data (e.g., species, age, sex, activity etc.). At the end of the route the "current track" is saved. Relevant waypoint numbers and the associated coordinates are then uploaded to a computer or the data are copied and pasted into a database.

DATA HANDLING

A data handler should name and enter the route into a spreadsheet or even better in a database (e.g., Microsoft Access). Routes can be saved as GPX files in the GPS unit (i.e., track logs) that marks routes, points and stations and the waypoints with the coordinates of the raptor observations. The files can be then uploaded, viewed and saved as kml/kmz files on Google Earth and subsequently converted into shapefiles by the use of a GIS (Geographical Information System) software. Alternatively in conjunction with GIS habitat maps, accurate locations would allow analysis of broad scale habitat associations with raptor presence by plotting their precise locations on the maps. In case of vantage point and playback call surveys the knowledge of station locations is required, in combination with accurate habitat maps to enable post-hoc stratification and to "weight" stations in relation to the amount of each habitat in the region.

DATA ANALYSIS

For all kind of survey method, data can be analyzed by the widely used "Distance sampling" software which calculates species density or extrapolates to population size for the entire study area. "Distance sampling" models the probability of detection a species as a function of its distance from the observer. By pooling all observations for each species, a detection curve (with adjustment terms) is established and density per year estimates with 80% confidence intervals can be generated by fitting the best model according to the Akaike's information criterion. A visual inspection of the histogram of observation distances, may reveal break points suggesting data truncation. To assess the influences of climate and habitat on raptor numbers, the survey data can be further combined by the aid of relevant software. For instance, the maximum-entropy modeling is quite robust and excessively adopted by using only presence data namely individual species observations. Predictor variables (e.g., topographic, climatic and habitat parameters) can be produced or acquired by appropriate digital elevation models in a GIS software or bioclimatic and land cover classification types databases (e.g., WorldClim; https://www.worldclim.org/, CorineLandCover; https://land.copernicus.eu/pan-european/corine-land-cover).

TABLE 2 – Advantages and disadvantages of the main survey techniques for monitoring wintering raptors.

TECHNIQUE	PROS	CONS
Road Surveys	Suitable for large, conspicuous raptors	Surveys must coincide with the period of maximum detectability of raptors
	Suitable for common and widespread species	Raptor detectability depends greatly on weather conditions
	Suitable for open landscapes and habitat types	Accuracy is greatly affected by raptor detectability
	Large areas can be covered in relatively short time period	Inappropriate for cryptical species
	Good for assessing the wintering distribution of raptors over large geographical areas	Inappropriate on busy roads
	Allow easily replicable raptor counts (e.g., on prominent roost sites along roads)	Existing road network might not cross representative habitat types of the study area
	Most suitable technique for estimating relative abundance and densities of wintering raptors	Needs great familiarity of the observer with the study area
	Mostly used in studies of wintering raptors allowing comparisons at a spatial scale and the assessment of temporal population changes	Equipment includes a vehicle
	It can easily be combined with other survey techniques (e.g., vantage point counts, playback calls)	Comparisons of relative abundance only among surveys undertaken in similar conditions.
	Good for conducting supplement studies on the distribution and abundance of wintering raptors in relation to land-use practices	
	Good statistical software is available for data analyses	

TECHNIQUE	PROS	CONS
Foot surveys	Access to almost any terrestrial habitat	Depends greatly on the ruggedness of the terrain
	Suitable for closed habitats	Random routes are not always feasible
	Appropriate for selecting representative habitats in the study area	Bias due to disturbance by the observer might occur
	Allow good design in relation to topography and vegetation of the study area	Bias due to poor detectability at small spatial scales
	Good for locating communal roosts and attempting complete counts of wintering raptors	Variety of raptor responses to an observer on foot
	Easily combined to other methods (e.g., road surveys, vantage points)	Lower encounter rates of raptors compared to other methods
	Can provide complete coverage of sample plots in the study area	Local weather constraints during winter (temperature and precipitation)
	Use of clues of raptor presence (e.g., prey remains, plucking, droppings)	Time and manpower required in order to search the study area
	Relatively cheap in equipment	
Vantage point surveys	Easily combined and supplementary to other survey techniques	Can be applied only when raptor detectability is maximal (displaying, high soaring)
	Good for monitoring population trends locally	Unsuitable over large areas outside the breeding season
Boat surveys	Unique for counting wintering raptors foraging near shorelines on aquatic prey	Habitat specific method
	Allow the following of meandering rivers deep inland in continental areas	Sampling areas is usually restricted to a narrow strip of land

TECHNIQUE	PROS	CONS
	Allow the detection of communal roosts of wintering raptors in coastal areas	Requires safety and technical considerations
	Facilitates the access to wintering raptor concentrations and allows their prolonged observation and data collection apart from counts	Limitations due to the aquatic habitat type surveyed (e.g., boat used, number of passengers, weight and bulk of equipment).
Aerial surveys	The only available and most cost-effective technique for surveying remote, inaccessible areas	Expensive equipment is needed
	Good coverage at extensive landscapes	Requires safety and technical design considerations
	Good for large, conspicuous raptors	Requires the involvement of experienced personnel
	Efficient for locating communal roosts	Not so effective outside the breeding season due to serious weather constraints (wind, precipitation etc.)
	Suitable for assessing the winter distribution range of raptors over vast areas	Might cause serious disturbance to roosting and soaring raptors
	Can be used in conducting studies on winter habitat selection by raptors at large spatial scales	Survey routes include careful selection of flight paths and depend on aviation regulations
	Suitable for winter surveys allowing also to locate conspicuous nests in prominent sites with minimum disturbance (cliff faces, tree crowns etc.).	Good communication among the members of the crew is constantly needed
	Maneuverability (e.g., helicopter) is an asset for surveys in problematic terrain (e.g., canyons, around power lines)	Difficult to obtain ground-truth data

TECHNIQUE	PROS	CONS
Call playbacks	Most suitable for surveying owls and forest raptors	Quite species-specific technique
	Suitable for multispecies surveys of owls	Some species response more than others
	Relatively inexpensive equipment for broadcast vocalizations	Response rates depend of various factors (sex, age, time, lunar cycle, latitude)
		The technique is strongly weather dependent (temperature, wind and precipitation)
		Surveys need repetition during the period of maximal response of nocturnal target species which is normally outside the wintering season
		Validation on the species response calls and response rates is required

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MONITORING RAPTOR POPULATIONS DURING MIGRATION

When raptors are used as “environmental sentinels” to monitor pollutants entering in the food chain, sedentary species are normally preferred rather than migratory ones. The reason for this is that contamination levels in tissues of sedentary species reflect the diffusion of a toxicant in the area where those species spend their entire lifespan. It makes relatively easier to identify the potential sources from which toxic substances originate.

Conversely, migratory birds may have absorbed contaminants both in their breeding grounds, in stopover sites along their migratory routes, and in wintering quarters. In many cases, these areas are thousand kilometres apart and each of them may be subject to different sources of pollution. It is therefore very tough to link contamination levels in raptor tissues and environmental contamination of a given area.

Nevertheless, toxicological studies on migratory raptors can be useful to compare sibling species with similar feeding habits and different migratory behaviour (sedentary vs. migratory) and, especially, to address appropriate conservation measures in case of endangered species.

In any case a thorough knowledge of movements and frequented areas is crucial to interpret analytical data correctly and a combination of survey techniques with certain pros and cons can be used (Table 3, Table 4).

METHODS TO STUDY LONG DISTANCE RAPTOR MOVEMENTS

RINGING

The classic method followed to study bird movements (not only migration, but also post-natal dispersal and wintering movements) is based on the use of rings. Placing a uniquely numbered metal ring at the leg of a bird allows to identify it for sure even many years after ringing. Thus, when ringed birds are recovered, it is possible to trace back to their ringing place and calculate spatial displacements. To obtain a migration pattern of a population, is needed to ring a large number of birds and wait for the recoveries. In Europe, the centralized repository of ringing-recoveries is managed by EURING, who is also coordinating ringing activities among countries. EURING databank host about 25 million recovery data gathered over a century and referred to some 600 avian species. Ringing programmes can be undertaken only by trained personnel with a specific permission issued by the National Ringing Centre.

COLOUR MARKING

To increase the chance to obtain recoveries, sometime the use of metallic ring is associate with colour-rings, leg flags or wing tags with alphanumeric codes that can be read from far away. Colour marks permit to identify the bird without catching or recovering it dead or hurt. This method fosters displacement data gathering in a shorter time than ringing, but normally colour marks tend to fade or break relatively soon and therefore they are of limited use especially in case of long lived-species such as vultures and eagles. To avoid overlapping schemes, alphanumeric codices are coordinated at European level through the European colour-ring Birding platform. Before starting a colour-ring project, a permit from the National Ringing Centre is required.

FEATHER BLEACHING

In some monitoring programmes, bird identification is assured by bleaching of certain wing or tail feathers. This technique is especially used to follow released bird in the framework of restocking projects. Disadvantages of this method include the reduced life span of markers due to the moult onset and the lack of a European coordination among monitoring programmes.

TRACKING DATA

Tracking data are gathered through satellite/GPS devices fixed on the back of the birds. This technology is dating back to several decades ago, but only recently tracking studies have become more numerous, thanks to minor costs and technical improvement of tracking devices. In the last years, size reduction and increased power of transmitters are allowing to gather a great amount of information even in case of small sized raptors, such as lesser kestrel. Tracking studies can be focused on single populations or cover nearly the entire range of a species. GPS tracking data and contaminant concentration analysis in blood samples can be usefully combined to investigate the source of pollution affecting distinct raptor populations. In Europe, repositories of bird tracking data are managed by the Max Planck Institute for Ornithology (Movebank) and BirdLife Hungary (SatelliteTracking.EU). In most European countries capture, handling and tagging of wild birds require special permits issued by national or regional authorities.

STABLE ISOTOPES RATIOS (SIRS)

Origin of birds can be traced with stable isotopes ratios (SIRs) present in animal tissues which reflect those of local food webs. The method relies on predictable isotopic signatures of stable carbon, nitrogen, sulphur and hydrogen isotope values measured in different environments. Stable isotopes are incorporated into plants during nutrient uptake and are transferred through the food web, so that SIRs in the body tissues of an animal are related to SIRs in the environment where those tissues were grown. Appropriate tissue has to be chosen carefully for isotopic analysis, as tissues differ in metabolic activity. In birds, feathers, made of keratin, an insoluble and chemically inert protein, can be used to infer where the feather was grown. To describe long-distant movements of birds, metabolically inert tissues are more suitable, whereas metabolically active tissues with rapid turnover rates are more appropriate to study recent movements.

TRACE ELEMENTS

Trace elements are used as chemical markers, similarly to stable isotope ratios, in that they allow to distinguish chemical profiles of different geographic locations. The patterns of trace elements measured in feathers reflect the chemical profiles of the areas where those feathers were grown. This method can allow to distinguish the natal place of first year juveniles or to discern among moulting areas reached by individuals belonging to the same population, nevertheless to obtain reliable information it is necessary to analyse a high number of elements and to know the chemical profile of many geographical locations (Hobson and Norris 2008). Moreover, a potential bias is due to acquisition of same trace elements after growth for external contamination of feathers.

GENETICS

DNA markers can concur to study bird migrations, supplementing information obtained from ringing, telemetry and isotope analysis. Most populations, if not all, show some levels of genetic structuring and this information can be used to assign a probability that a given individual came from a given (known) subpopulation. The identification of population structure can be done by means of allozymes, mitochondrial DNA sequences, and DNA fragment analyses, such as microsatellites and amplified fragment length polymorphism. However, insufficient genetic differentiation among populations of migratory birds can render this method of limited effectiveness.

TABLE 3– Pros and cons of the main study methods for long distance raptor movements

METHOD	ADVANTAGES	DISADVANTAGES
Ringing	Familiar and widely used standardized method, suitable for all raptor species; it assures a permanent non-invasive marking; large support from volunteers.	Permission to handle, capture and ring birds; a ringing network has to be settled; valuable results are obtained long time after ringing.
Colour marks	Practical and cheap method that allow to gather more data than ringing; large support from volunteers. Colour rings: non-invasive and suitable for all raptor species; Wing tags: suitable for species with a slow mode of flight such as kites, harriers, eagles and buzzards; easily read by observers.	Permission to handle, capture and mark birds; relatively low lasting marking. Colour rings: for most species, rings are not easily spotted and read; Wing tags: specific training are required; wing tags may have negative effect on reproduction and survival.
Ringing	Familiar and widely used standardized method, suitable for all raptor species; it assures a permanent non-invasive marking; large support from volunteers.	Permission to handle, capture and ring birds; a ringing network has to be settled; valuable results are obtained long time after ringing.
Feather bleaching	Practical cheap and non-invasive method that allow to gather more data than ringing; large support from volunteers.	Permission to handle, capture and mark birds; it require coordination to avoid overlapping schemes; low lasting marking that can be used for a limited number of birds.
Satellite tracking: transmitters and GPS-loggers	Widely used method that allows to gather very detailed data in a short time; it does not rely on search on the	Size and weight of satellite/GPS devices may have a negative effect on reproduction and survival, especially on small sized species with flapping

METHOD	ADVANTAGES	DISADVANTAGES
	field; no subject to spatial biases.	fly; high costs; relatively short transmitter life.
Stable isotopes analysis	It can provide information on origin or moulting areas of migratory raptors.	Lack of isotopic basemaps for several elements; it requires expensive analytical equipment, complex sample processing and accurate data interpretation.
Trace elements	It can provide information on origin or moulting areas of migratory raptors.	Lack of basemaps for several trace elements; it requires expensive analytical equipment, complex sample processing and accurate data interpretation.
Genetics	It can provide information on the population from which a bird originates.	It requires expensive analytical equipment, complex sample processing, and accurate data interpretation.

METHODS TO ASSESS MIGRATORY RAPTOR POPULATIONS

During migrations most raptors tend to avoid flying over open seas. It is particularly true for soaring species, that take advantage of the warm air raising from terrains exposed to the sun. For them, flying over water bodies implies to spend a great amount of extra energy to maintain flight altitude. Furthermore, it carries the risk of falling into the water and drowning. Thus, many migratory species converge towards those pathways that allow them to reduce as much as possible the sea crossing, even at the cost of lengthening they journey of hundred or even thousand kilometres.

In some places laying along these preferential routes, raptors concentrate in significant numbers (migration bottlenecks). Here they can be counted through visual observation and/or radar monitoring. Privileged raptor watchsites are mainly on straits, headlands, small islands, and also mountain passes. A provisional list of Important Bird Areas that are currently known to be major congregatory bird of prey sites in Africa and Eurasia is included in the Annex 3 of the Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia (Action Plan of the CMS MoU Raptors; https://www.cms.int/raptors/sites/default/files/basic_page_documents/raptors-mou_annex3_action-plan_e.pdf).

VISUAL COUNTS

Counts of migrating raptors in migration bottleneck watchsites are currently performed to study different aspects of raptor migration (phenology, ecology, flight behaviour) and to estimate population size and conservation status of migratory raptors breeding in wide geographical areas. This method is based on the spotting, identification and counting of each raptor actively flying in the surroundings of the watchsite. It requires standardized field protocols to harmonize data collection and allow comparisons across years and sites. Raptor monitoring at watchsites entails the efforts of trained observers for long periods, but monitoring programmes are supported by many volunteers interested in raptor watching and conservation. In Europe and the Middle East is active a network of raptor watchsites, most of which across the Mediterranean.

RADAR STUDIES

Visual counts at watchsites combined with the use of radar allow to gather more detailed information on flying behaviour and numbers of migrating raptors (Panuccio et al. 2018). Radar echoes do not allow species identification but permits to follow birds already recognized by observers when they fly al high altitude, at a great distance or in condition of poor visibility. Different radar systems can be used, each of them having have distinct strengths and weaknesses.

TABLE 4 –. Pros and Cons of the basic methods for the assessment of migratory raptor populations

METHOD	ADVANTAGES	DISADVANTAGES
Point counts	Familiar and widely used method, very cost effective to monitor raptor populations occurring in wide areas; large support from volunteers.	It requires a standardization of methods to compare data across years and sites; results can be biased by low-visibility conditions.
Radar	Useful method when combined with visual counts, it allows to give more precise estimates on numbers of birds passing through a bottleneck.	It requires expensive equipment and accurate data interpretation.

USEFUL LINKS AND REFERENCES FOR MONITORING OF MIGRATING RAPTORS

RINGING

https://euring.org

https://cr-birding.org

TRACKING

https://www.movebank.org/cms/movebank-main

https://www.satellitetracking.eu

VISUAL COUNTS

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FIGURES AND CHARTS

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