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A review of raptor and owl monitoring activity across Europe: its implications for capacity building towards pan-European monitoring

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ABSTRACT
Capsule: A questionnaire identified 1196 raptor monitoring species schemes within 236 monitoring programmes across 37 countries.
Aims: To assess the level of monitoring of status/trends of raptors across Europe, to produce a web-based inventory of activities.
Methods: A questionnaire promoted by voluntary national coordinators assessed monitoring coverage, focusing on breeding populations.
Results: One thousand one hundred and ninety-six species schemes (236 monitoring programmes; 90% active in 2012) were reported from 37 countries. Sixty per cent of schemes were of over 10 years duration and nine countries ran schemes of over 40 years duration. Nineteen species had at least one scheme in 10 or more countries, and 15 species had schemes that ran for over 10 years. Thirteen species had breeding monitoring schemes in over 50% of countries where they breed, including widespread species (e.g. Peregrine Falcon *Falco peregrinus*) and localized species (e.g. Rough-legged Buzzard *Buteo lagopus*). Lanner Falcon *Falco biarmicus*, Levant Sparrowhawk *Accipiter brevipes* and Booted Eagle *Hieraaetus pennatus* had the least representative coverage, and four rare species had no coverage. Coverage was more representative in north and west Europe than further south and east. Coverage was more representative for widespread species and those with more favourable conservation status.
Conclusions: Large potential exists to enhance reporting on status/trends, ecotoxicology analyses and volunteer-based monitoring at the pan-European scale. National coordinators provide an ideal network to develop and disseminate best practice guidance across Europe.

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As predators at, or near, the top of food chains, raptors are key species in ecosystems (Newton 1979, Sergio *et al.* 2005). Raptors are a functional or ecological rather than taxonomic group of birds encompassing four orders (Jarvis *et al.* 2014), three of which occur in Europe: two diurnal orders, namely Falconiformes (falcons) and Accipitriformes (hawks, eagles, vultures and other diurnal birds of prey); and one nocturnal order, owls (Strigiformes) (see also Saurola 2012, Vrezec *et al.* 2012). Raptors are integrated within a range of specialist and generalist trophic systems, and are among the first organisms to show measurable changes in population size or demographic rates in response to environmental changes and human pressures. They can thus act as 'sentinels' – effective indicators of wider biodiversity and environmental quality (Newton *et al.* 1993, Sergio *et al.* 2005, 2006, Rattner 2009). Raptors also often make good 'flagship species' because of their size and visibility, attractiveness and charisma, known vulnerability to threats and long history of cultural value (Kovács *et al.* 2008, Movalli *et al.* 2008). As top predators, raptors can compete directly with, or be perceived as a threat to, economic interests or the conservation of other species of conservation concern, bringing them into direct conflict with humans (Valkama *et al.* 2005, Thompson *et al.* 2010). They can, therefore, play effective roles when there is a need for policy-makers to communicate environmental threats and changes to the public or indeed vice versa (Duke 2008). As they feed at high trophic levels, raptors may be exposed to environmental pollutants that can be persistent and concentrated in food chains (due to biomagnification processes) and

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potentially harmful to the raptors themselves, to other biodiversity and to human health (e.g. Peregrine Falcon *Falco peregrinus*, Ratcliffe 1993; White-tailed Eagle *Haliaeetus albicilla*, Helander *et al.* 2008). The concurrent monitoring of the demography of raptor populations and contaminant levels within raptor tissues can therefore provide important indicators of environmental 'health', operating across a broader range of issues than most monitoring systems (Movalli *et al.* 2008, 2018).

A recent review of raptor conservation status (Burfield 2008) concluded that: 'the conservation status of raptors and owls in Europe is disproportionately poor and has deteriorated over the past two decades'. Of the 56 species that breed regularly in Europe, 18% are of global significance, 64% have an unfavourable conservation status and 87% of European countries contain at least one species of global concern. This position reflects the many threats that raptor populations face, including habitat loss and degradation, legacy and emerging contaminants, illegal shooting and poisoning, collisions with aerial structures such as windfarms, electrocution by power lines and climate change (Newton 1979, Bednarz 2016).

The monitoring of raptors has an important role to play in the context of European Union (EU) environmental policy (Duke 2008). All EU member states have a requirement to monitor, and report on, the conservation status of all species listed in Annex I of the Birds Directive (European Council 1979), which includes most European raptors. Monitoring of raptors is also required to assess progress in relation to EU biodiversity policy targets to halt loss of biodiversity by 2020 and achieve 'a significant and measurable improvement' in the status of all species covered by EU legislation. In 2011 the EU also became a signatory to the Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia (the 'Raptors MOU'), which confers obligations on 57 range state signatories and the EU to support the monitoring of bird of prey populations.

Raptor monitoring initiatives are not in place consistently across Europe. Where they do exist, they may be conducted using widely differing study methods and be implemented at quite different scales, from broad-scale volunteer-based surveys to intensive studies by academic institutions (Kovács *et al.* 2008, Vrezec *et al.* 2012). The large realized and potential value of raptor monitoring prompted the creation of EURAPMON – 'Research and Monitoring for and with Raptors in Europe' – a Research Networking Programme of the European Science Foundation (EURAPMON 2012a; http://www.eurapmon.net/). EURAPMON, which ran from 2010 to 2015, aimed to establish a pan-European, dynamic network of raptor researchers and included objectives to: enhance the coordination and reporting of monitoring effort; share good practice; and assist in building the capacity for rigorous monitoring across a wider suite of countries and priority species (Duke *et al.* 2012). At the core of the programme was the aim to better integrate the work of those that carry out monitoring *for* raptors and their conservation (e.g. monitoring of population change, demographic rates and drivers of population change) with those that monitor *with* raptors, using them as biological indicators of environmental change (particularly but not exclusively their use to monitor the hazards caused by contaminants) (Movalli *et al.* 2008). Establishing the current coverage and effort involved in raptor monitoring of both these types across Europe is an essential pre-cursor to strengthening and expanding monitoring activities in a strategic way.

EURAPMON's survey of raptor monitoring activities in Europe consisted of two parallel studies: (1) inventory of monitoring of contaminants in raptor populations (Gómez-Ramírez *et al.* 2014) and (2) inventory of monitoring of raptor populations themselves (status and trends). This paper reports on the latter. It builds upon a number of other initiatives relevant to building a pan-European understanding of monitoring, and in particular: (i) the MEROS (monitoring Raptors and Owls in Europe) programme, established in 1988 (Mammen 2003; http://www.greifvogelmonitoring.de/; standardized plot-based monitoring data from up to 18 European countries); (ii) the Pan-European Common Bird Monitoring scheme (PECBM 2009; http://www.ebcc.info/pecbm.html; European trends for three raptor species) and (iii) a previous survey (2006–8) of BirdLife partner organizations (responses received from 22 partners across Europe; Kovács *et al.* 2008).

Our study focused on collecting metadata ('who is doing what, and where?') on monitoring activities. It aimed: (1) to draw together a comprehensive review, and to present an interactive map, of current raptor monitoring activity across Europe and (2) to begin to address some of the key evidence-base challenges for the conservation of raptors identified previously (Kovács *et al.* 2008, Vrezec *et al.* 2012), by assessing the level of opportunity to: (i) report on raptor population trends at pan-European scale using schemes currently in operation and (ii) enhance pan-European monitoring activity and reporting for the future.

Methods

Design of the questionnaire survey

A previous questionnaire composed by Birdlife partner organizations in 2006 was used as the basis to design the EURAPMON questionnaire. Its structure and content were further refined, including through a workshop in February 2012 that brought together 56 participants from 27 countries (EURAPMON 2012b). The revised questionnaire was then tested by EURAPMON Steering Committee members and a number of other appropriately experienced volunteers.

When designing the questionnaire, we followed Elzinga *et al.* (2001), defining monitoring 'as the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective'. We did not intend to restrict the questionnaire to strictly defined monitoring activities, however, and also welcomed submission of questionnaire responses that related to shorter term studies. The survey included a wide range of questions about the monitoring that was carried out in each study/scheme, including: species monitored; scale of coverage (geographical areas); national/regional/local schemes; population parameters monitored; monitoring methods; timespan of studies; collection of biological samples (e.g. egg, feather, blood or other tissue samples; raptor carcasses; prey remains); monitoring of other environmental parameters (e.g. habitat change; other specific key threats); and use of a range of regular and more specialist techniques (e.g. ringing and colour-marking; other tagging and tracking devices; DNA profiling). It also included questions to assess the resources (funding and volunteers) available to support monitoring. For efficiency of completion, and to aid consistency, most of the questions allowed answers to be selected from drop-down lists, with free-text space provided for supporting notes to be included.

The questionnaire was designed to enquire about programmes that monitor the 41 species of diurnal raptors (30 species of Accipitriformes; 11 species of Falconiformes) and 15 species of nocturnal raptors (Strigiformes) that occur in the target study area, defined as the whole of geographical Europe, as far east as Russia (to the Urals), the Caucasus and the whole of Turkey.

In early 2012, EURAPMON established a network of voluntary national coordinators for raptor monitoring (Duke *et al.* 2012, Vrezec *et al.* 2012) to facilitate, through their contacts with raptor workers, and in their own language, questionnaire responses within their respective countries. A workshop in 2012 brought together these national coordinators from 28 countries and generated an initial set of information on monitoring activity across Europe, including overview papers from 25 countries (Duke *et al.* 2012) and a synthesis of the first findings (Vrezec *et al.* 2012; http://www.eurapmon.net/activities/inventory-work-package-2). The comprehensive questionnaire was launched on the EURAPMON website in November 2012 and promoted by national coordinators to extend coverage across the study area. It remained open for responses until July 2013. Standardized instructions for filling the questionnaire were provided online but reliance was placed on the network of voluntary national coordinators to promote the questionnaire nationally and assist with its completion. For those countries for which national coordinators could not be found, the survey was additionally advertised via the contacts of raptor experts gathered from the EURAPMON and BirdLife International networks.

Before the formal closure of the questionnaire survey for analysis, the interim results were discussed at a further EURAPMON workshop of national coordinators and other raptor monitoring experts (17 participants from 13 countries; EURAPMON 2013). This provided opportunity to compare the results with those of the previous EURAPMON information gathering exercise (Vrezec *et al.* 2012). It enabled identification of countries and monitoring activities that were apparently missing from the comprehensive inventory survey, and allowed assessment of the difficulties that had been encountered by national coordinators in promoting the survey. Following the workshop, further effort was put into encouraging submission of questionnaire responses covering missing studies/schemes before the survey closed.

Evaluation of survey coverage

The overall results of the questionnaire survey were compared with knowledge of European raptor and owl monitoring activities from the previous EURAPMON initiatives (EURAPMON 2012b, Vrezec *et al.* 2012, EURAPMON 2013) and this allowed some assessment of the approximate proportion of programmes that may have been missed. The comparison suggested that national coordinators had been relatively successful in attracting responses from raptor-specific programmes, particularly those that operate in breeding areas and focus on monitoring breeding population change and productivity. National coordinators differed in the extent to which they had relationships with organizations and groups that run more general monitoring programmes in their countries, however, so that in some cases multi-species monitoring initiatives that are not focused on raptors but cover some raptor species, were not included (periodic bird atlas projects in particular were largely missing from the responses). We also considered programmes that had submitted details to a previous EUMON European Monitoring initiative (http://eumon.ckff.si/) that was not raptor-specific in its scope but almost all of those identified finished prior to 2010 rather than being long-term monitoring schemes.

After closing the inventory, a short survey was sent to all national coordinators asking them how they had promoted the inventory questionnaire in their country, whether any particular difficulties had been encountered and whether they knew of any monitoring programmes that were missing from the inventory. Answers were received for 16 out of 37 (43%) countries covered by the inventory. Of these, 11 countries (69%) reported some monitoring programmes that they were aware of but that had not been reported through the questionnaire. Six of the 16 reported that the complete lack of a national response to the main questionnaire was due to a genuine lack of monitoring initiatives in their country.

Of the 11 national respondents, most (94%) had spent time making personal phone calls to known contacts, sending personal e-mails encouraging them to fill in questionnaires (69%) and/or having face-to-face meetings with contacts (44%). Fewer had spent time themselves trying to identify and submit information on monitoring initiatives within their own countries from secondary sources, such as from programme websites (19%), from local/regional or national reports (31%) or from searching the scientific literature (31%). The respondents reported a range of specific problems involved in gathering the information, such as the language barrier for understanding the questions (25%), a dislike of sharing information (25%) or filling in paperwork (31%), and a lack of national networks to allow them to circulate the questionnaire efficiently (25%). Some (31%) stated that the time required to fulfil their role had been a limitation.

It was not possible to determine exactly the extent of the information that was missing from the inventory, and therefore, for analysis and interpretation purposes, countries were separated into three subjective categories, based on comparisons with previous surveys and feedback from national coordinators. For the majority of countries ($n = 31$), the survey results were considered to satisfactorily represent the state of current breeding population monitoring (only a few local or regional programmes may have been missed): Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Denmark, Estonia, Finland, Germany, Hungary, Iceland, Ireland, Italy, Kosovo, Latvia, Luxemburg, Malta, Netherlands, Norway, Portugal, Russia, Serbia, Slovakia, Slovenia, Sweden, Switzerland, Turkey, Ukraine and the United Kingdom (in the case of Albania and Kosovo there was no monitoring). For eight countries, some information was received but it was considered incomplete: Belarus, Czech Republic, France, Georgia, Greece, Poland, Romania and Spain (shown with diagonal cross-hatching on graphs/maps). Seven countries did not respond at all to the initiative, so information was completely lacking: Andorra, Armenia, Azerbaijan, Liechtenstein, Lithuania, Macedonia and Moldova (shown in white on graphs and maps). A small number of small countries did not take part in the survey because no national coordinator was recruited (Monaco, San Marino and Vatican City).

Analysis of the questionnaire responses

The survey was designed to allow respondents to fill a single questionnaire to cover a specific study of one species or, alternatively, to cover a number of raptor species within a multi-species monitoring programme, on the assumption in the latter case that all the information supplied was applicable to all the species within that programme. In some cases respondents filled several questionnaires for a single coordinated programme if the programme treated different species in slightly different ways. In other cases, rather more general responses were received, encompassing a broad range of species within a single questionnaire. In the absence of any supplementary information, it was necessary to assume that the responses applied to all species within the programme. Responses also varied from broad-scale national (and in a few cases international) multi-species monitoring schemes to more local single-species projects. Due to variation in the way the questionnaire was used by respondents, the number of 'species schemes' rather than the number of programmes (where each species within a multi-species programme is defined as a separate 'species scheme') was used for comparative purposes. Each species scheme was categorized into 'breeding' or 'non-breeding' population monitoring based on the stated purpose of the programme, the breeding areas monitored, the monitoring parameters recorded (breeding population size) and the known geographical distribution of the species. Sixteen programmes included monitoring of both breeding (128 species schemes) and non-breeding populations (33 species schemes). Thirty-three programmes included only non-breeding populations (457 species schemes). In the more detailed analyses of the distribution of monitoring effort geographically and by species, only species schemes monitoring breeding populations were included (647 species schemes).

In order to ensure that the findings reflected the current extent of raptor monitoring activity across Europe, a small number of programmes that either finished more than 10 years ago (two) or only started in or after 2013 (three) were excluded from analysis, as they were not necessarily fully established programmes at the current time. The focus of the survey was on long-term monitoring programmes, but a small number of shorter, time-limited studies were also reported (only 35 schemes of less than 10 years duration that finished before 2013 were reported, 18 of which were migration monitoring only).

In parts of the analysis, species schemes monitoring breeding populations that were stated to have run for more than 10 years (436 species schemes) are reported separately, with the assumption that these are likely to be more suitable for generating trend information, than those stated as running for 10 or less years (192 species schemes). The duration could not be determined with certainty for 22 species schemes.

For comparisons between species distributions and monitoring coverage, data on species distributions, population size and conservation status were taken from BirdLife International (2004). The estimates of minimum and maximum breeding population size (breeding pairs) presented were averaged to give a general indication of population size in each country.

All statistical analyses and mapping were performed in R (R Development Core Team, 2011). As not all questionnaires contained comprehensive answers to all the questions, the numbers of species schemes for which particular analyses were not possible are indicated as 'not applicable' ('NA') within the results.

Results

Overall, 158 ornithologists/researchers from 37 European countries submitted 236 monitoring programmes through the survey (representing 1196 species schemes). Five programmes were excluded from further analysis, and results are based on programmes extant in 2012 or that finished less than 10 years prior to 2012 (including 1143 species schemes from 37 countries).

Time span of monitoring schemes

The questionnaire results provided a valid overview of the present state of raptor monitoring in Europe, with 90.4% ($n = 1033$) of all reported species schemes still active in 2012. The mean (±sd) duration of schemes (up to 2013) was 18.4 ± 12.3 years, with a majority of schemes (60%; $n = 686$; NA = 22) from 35 countries of more than 10 years duration. 37.9% ($n = 434$, NA = 22) schemes from 23 countries were of more than 20 years duration and 3.6% ($n = 41$, NA = 22) of schemes conducted in 9 countries (Estonia, Finland, Iceland, Italy, Ireland, Malta, Slovakia, Sweden and Switzerland) were of more than 40 years duration.

Although some older programmes, especially those that started and finished before the 1980s, were less likely to be reported through the questionnaire survey, the overall number of monitoring programmes in Europe is still slowly increasing (Figure 1). There was no specific year or decade in which a majority of new schemes started (Figure 1).

Geographical coverage and organization

In general, national species schemes ($n = 465$) were more frequently recorded than local ($n = 302$) and regional schemes ($n = 343$), while international schemes were very rare ($n = 34$). Almost all countries ($n = 32$) run at least one species scheme on a national scale, with 15 countries monitoring more than 10 species within national schemes (Cyprus, Denmark, Estonia, Finland, Germany, Malta, the Netherlands, Norway, Portugal, Russia, Slovenia, Sweden, Switzerland, Ukraine and the United Kingdom). 37.7% ($n = 431$, NA = 8) of species schemes were linked to national working groups.

A majority of species schemes (61.7%, $n = 705$, NA = 45) were run by civil organizations rather than governmental (19.3%, $n = 221$, NA = 45) or private (15.0%, $n = 172$, NA = 45), and this applied both at national scale (58.3% civil run; $n = 666$ species schemes) and at regional and local scale (61.7% civil run; $n = 705$ species schemes). Altogether only 137 species schemes from 10 countries conducted at national or international scale were run by governmental institutions. Connected with this is the fact that 54.7% ($n = 626$, NA = 21) of all species schemes used more than 50% of volunteer effort for monitoring.

Only 34 species schemes were run on an international geographical scale. These involved two programmes monitoring only non-breeding populations: 'Mission Migration' from France including 32 species schemes; Short-toed Snake Eagle *Circaetus gallicus* satellite tracking from Italy (Panuccio *et al.* 2015); and one programme monitoring breeding populations of Red-footed Falcon *Falco vespertinus* based in Hungary (Solt *et al.* 2010). Nonetheless, 32.4% ($n = 370$, NA = 8) of schemes reported to be involved in international working groups. Commonly reported international networks were the European Bird Census Council (EBCC) and working groups connected with migration monitoring (Euromigrans, Mission Migration, Batumi

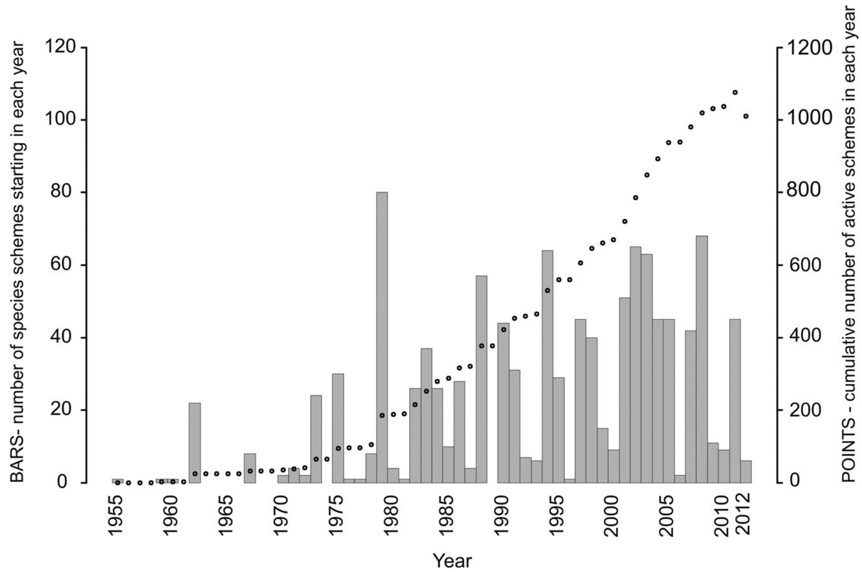

Figure 1. Cumulative number of active European raptor monitoring species schemes (dots) and the number of newly established species schemes (bars) in each year between 1955 and 2012 as reported in the questionnaires.

Raptor Count). Intercontinental groups mentioned included: the World Working Group on Raptors; Wetlands International; the Global Owl Project; and the North Eurasian Working Group on Raptors. A number of species-specific or group-specific groups were also mentioned, including: the Sea Eagle Project Team UK; the European Red Kite Census Group; IBM International Bearded Vulture Monitoring; the European Griffon Vulture group; the International Imperial Eagle Working Group; the Eastern Imperial Eagle Working Group; the European Peregrine Falcon Working Group; the European *Falco cherrug* Conservation Taskforce; a working group for Marsh Harrier (Werkgroep Bruine Kiekendief); the Britain and Ireland Buzzard Working Group; and Balkan Vultures.

Monitoring threats and biological material collection for contaminant and other monitoring

In 57.3% ($n = 655$, NA = 13) of species schemes respondents indicated that the level and effect of the main threats to raptors have not been monitored. By

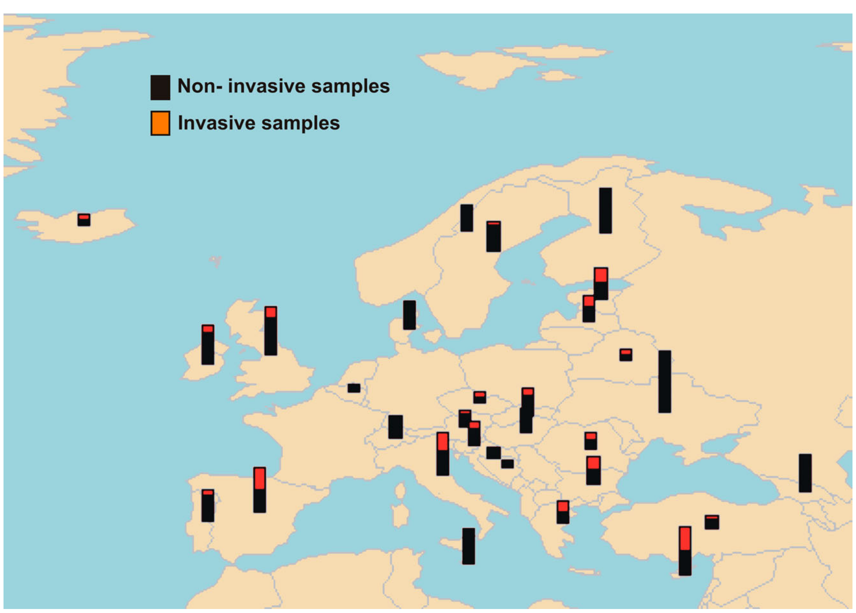

Figure 2. Relative numbers of raptor population monitoring species schemes per country that collect samples of invasive and non-invasive biological material.

far the most reported main threat monitored was direct killing of raptors (including persecution, trapping, poisoning and shooting) in 19.7% of schemes ($n = 225$, NA = 22) from 15 countries, 8.6% ($n = 98$) of which were long-term schemes with a duration of more than 10 years.

The second most often recorded primary threat was forest cutting, tree loss and habitat degradation ($n = 43$ species schemes). The third most often recorded primary threat was electrocution, which was recorded in 7.1% of schemes ($n = 38$).

The questionnaire results demonstrated a wide range of biological material being collected during raptor population monitoring across 32 countries in Europe. Samples of biological material collected involved non-destructive invasive or non-invasive techniques (food remains, $n = 229$ schemes; feathers, $n = 265$; carcasses, $n = 224$; pellets, $n = 223$; egg remains, $n = 165$; tissue, $n = 79$; blood, $n = 97$ and parasites, $n = 63$). Invasive sampling often requires very specific licensing/training and therefore invasive sampling was reported in relatively few raptor monitoring schemes (Figure 2). EURAPMON carried out a separate survey of contaminant monitoring with raptors, which complements these data and provides greater detail on this issue (Gomez-Ramirez *et al.* 2014 – see discussion).

Population parameters, monitoring methods and marking techniques

Breeding success monitoring was carried out by 56.8% ($n = 648$) schemes, and 48.9% ($n = 559$ schemes considered they carried out migration monitoring

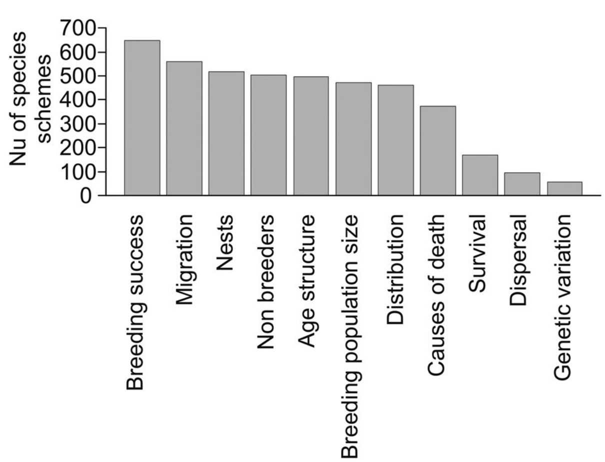

Figure 3. Number of European raptor monitoring species schemes in which breeding success, migration, nests, non-breeders, age structure, breeding population size, distribution, causes of death, survival, dispersal and genetic variation were monitored.

(Figure 3). Very similar numbers of schemes stated that they monitor nests (by repeated nest search and monitoring of occupancy), non-breeders, age structure, breeding population size and distribution (Figure 3). Smaller numbers of schemes indicated that they also monitor survival (14.9%, $n = 170$), dispersal (8.4%, $n = 96$) and genetic variation (4.9%, $n = 56$; Figure 3).

The monitoring methods most frequently used were occasional observations (54.3%, $n = 621$ species schemes) and point or line transects (53.8%, $n = 615$ species schemes), followed by nest searches, territory mapping and simultaneous counts (Figure 4) with some schemes using more than one method. Mark-recapture or resighting was only used in 12.2% ($n = 139$) species schemes (Figure 4). Among individual marking techniques, regular metal ringing was the most often used followed by colour ringing, satellite tracking and wing tagging (Figure 4). Details of the species covered and countries involved are available via the online inventory (http://www.eurapmon.net/for-raptors-search).

Species monitored and monitoring coverage

The mean (±sd) number of schemes per species was 20.4 ± 14.2 (all schemes included regardless of seasonality). The number of schemes did not differ between SPEC conservation status groups of raptors (analysis of variance, $F = 1.09$, $P = 0.372$; Figure 5). However, there was a significant difference between the number of monitoring schemes per species for nocturnal (11.8 ± 8.8 schemes per species) and diurnal raptors (23.6 ± 14.6 schemes per species) (t-test, $t = 2.90$, df = 54, $P = 0.005$; Figure 5).

Based on the number of species monitoring schemes for breeding populations, the three most monitored species in Europe were Peregrine Falcon, Common Kestrel *Falco tinnunculus* and Common Buzzard *Buteo buteo* (Figure 6(a), Table 1). Restricting the analysis to schemes for breeding populations that have been conducted for more than 10 years, the most monitored species in Europe was again Peregrine Falcon followed by Golden Eagle *Aquila chrysaetos* and Common Kestrel (Figure 6(b), Table 1). Overall, there were 19 species with at least one extant species scheme running in 10 or more countries, and 15 species for which these schemes had been running for at least 10 years (Table 1).

The three least monitored species in terms of number of extant species schemes were Steppe Eagle *Aquila nipalensis*, Spanish Imperial Eagle *Aquila adalberti* and Black-winged Kite *Elanus caeruleus* (Figure 6(a), Table 1). According to the questionnaire results, there are four raptor species present in Europe according to

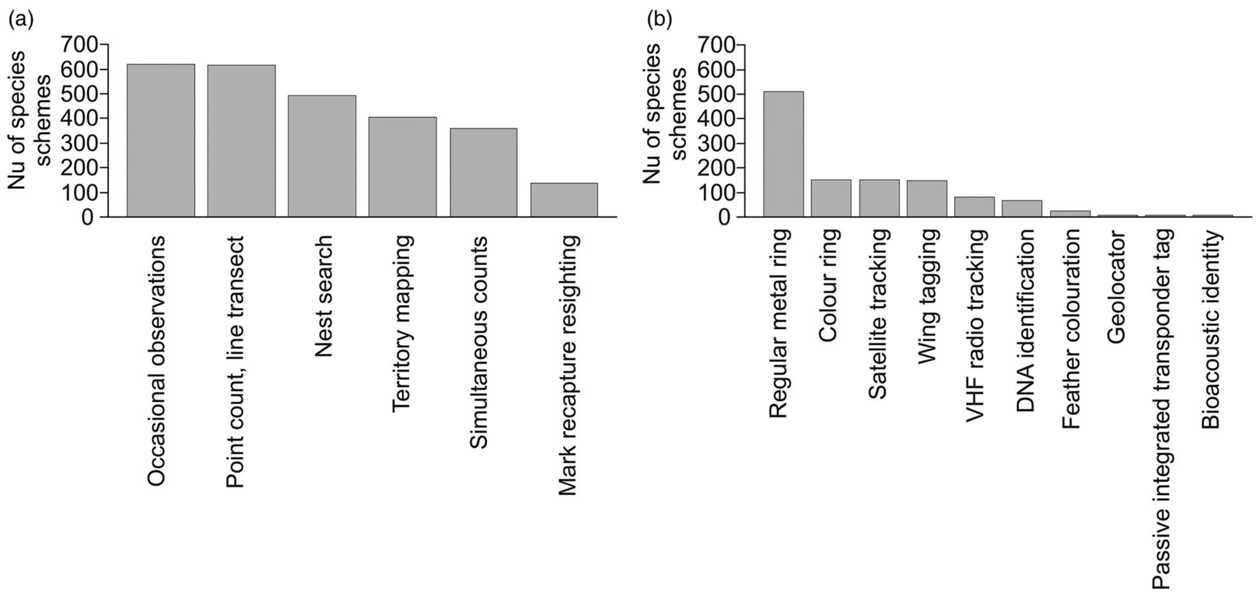

Figure 4. Number of European raptor monitoring species schemes from 37 countries that use different monitoring methods and individual marking techniques.

BirdLife International (2004) that are not monitored (Table 1): Pallid Scops Owl *Otus brucei*, Brown Fish Owl *Ketupa zeylonensis*, Barbary Falcon *Falco pelegrinoides* and Shikra *Accipiter badius*.

To compare the monitoring coverage between individual raptor species, we took into account the distribution across Europe of each species according to BirdLife International (2004; Table 1). We expressed the number of species schemes (both short- and long-term) and the number of countries with breeding schemes as a proportion of the number of countries in which each given species breeds. Information from 45 countries was included (Table 1). These measures gave a broad indication of the degree to which monitoring coverage was representative across a species range in Europe.

Using the proportion of countries with at least one breeding species scheme, there were 13 species with at least one breeding species scheme in 50% or more of the countries in which the species breeds (Table 1 final column). These include a number of very widespread species such as White-tailed Eagle, Peregrine Falcon, Western Osprey *Pandion haliaetus* and Golden Eagle. They also include scarcer/localized species for which there are fewer schemes but these occur in 50% or more of the breeding countries, such as Rough-legged

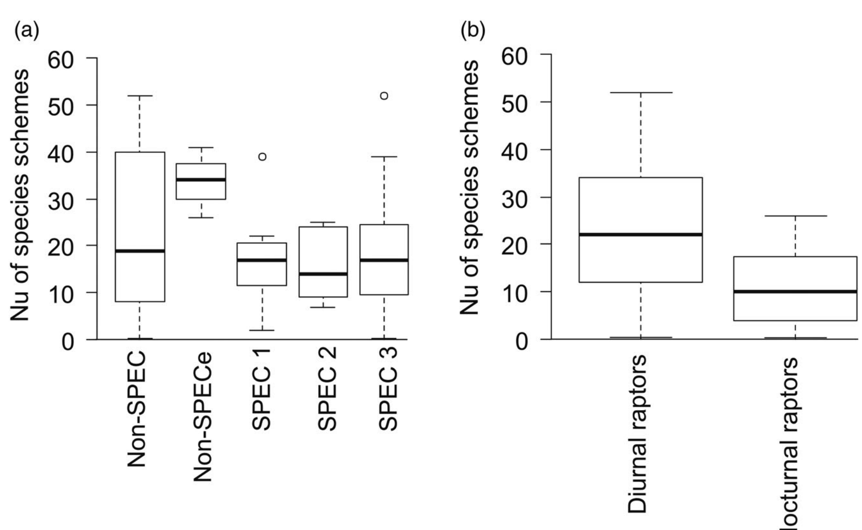

Figure 5. Medians and inter-quartile ranges for the number of monitoring schemes per species grouped into (a) five SPEC conservation status groups of species and (b) diurnal and nocturnal raptors.

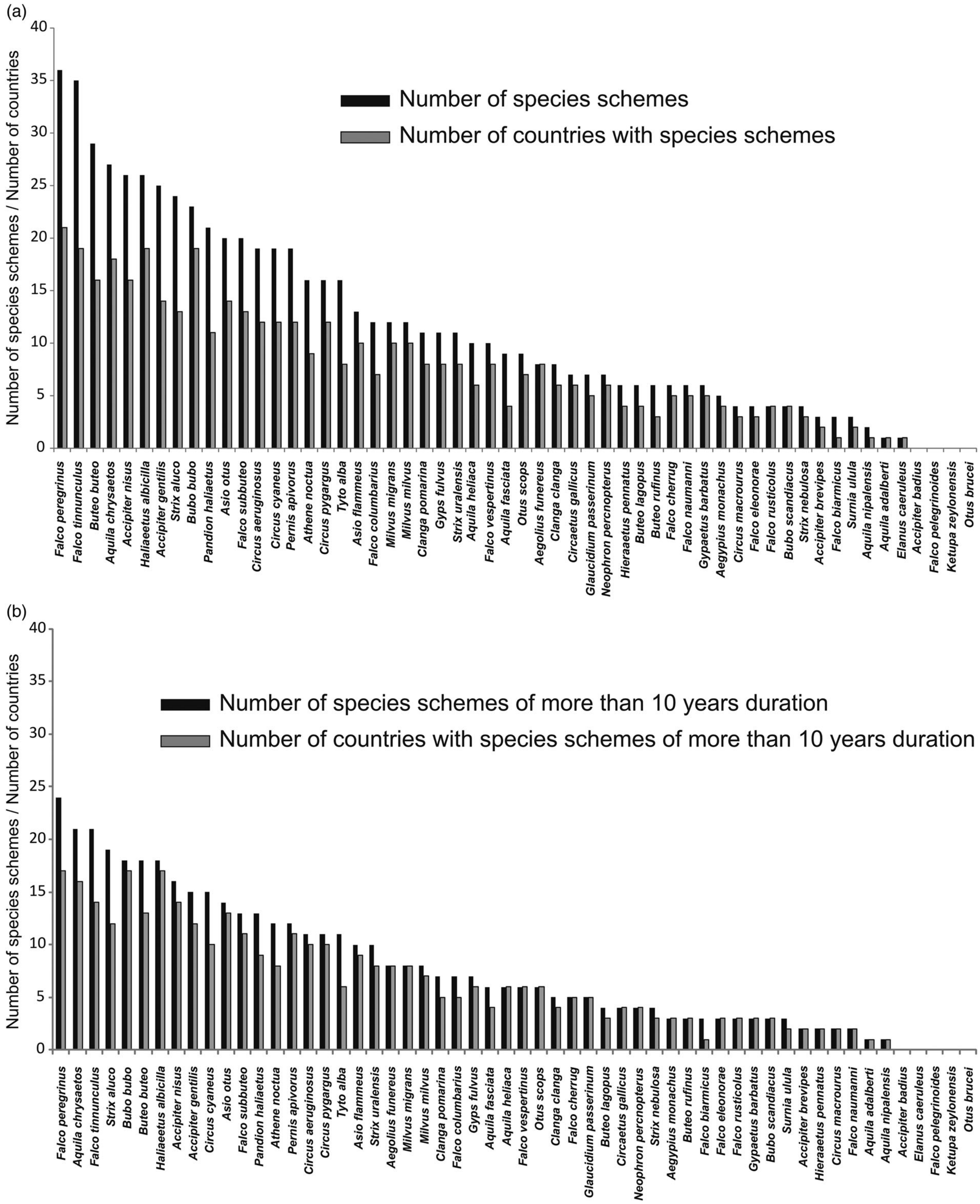

Figure 6. Number of monitoring schemes (black) and number of countries (grey) in which the breeding population of each listed raptor species is monitored: for all breeding monitoring schemes (a) and breeding monitoring schemes of more than 10 years duration (b).

Buzzard, Gyr Falcon *Falco rusticolus*, Greater Spotted Eagle *Clanga clanga*, Snowy Owl *Bubo scandiacus*, Merlin *Falco columbarius*, Spanish Imperial Eagle, Pallid Harrier *Circus macrourus*, Egyptian Vulture *Neophron percnopterus* and Great Grey Owl *Strix nebulosa*.

Using this approach, eight raptor species showed the least representative monitoring coverage, with breeding schemes present in less than 25% of breeding countries: Lanner Falcon; Levant Sparrowhawk; Booted Eagle; Barn Owl *Tyto alba*; Long-legged Buzzard *Buteo*

Table 1. Summary of information submitted to the inventory for the 56 raptor species recorded as breeding in Europe (according to BirdLife International 2004 and del Hoyo *et al.* 2014; the nomenclature after Gill & Donsker 2017). Species are ordered according to the extent to which the submitted monitoring coverage is likely to be representative of their breeding range in Europe (as indicated by the proportion of countries in which they breed that have at least one species scheme monitoring the breeding population of the species; final column).

Scientific name	Common name	European SPEC status (BirdLife International 2004)	Type	Total number of species schemes submitted	Total number of breeding schemes submitted	Number of countries submitting breeding schemes A	Number of breeding schemes of >10 year duration	Number of countries with breeding schemes of >10 year duration	Number of European countries in which the species breeds (BirdLife International 2004) B	Number of breeding schemes per breeding country	Number of countries with breeding schemes / number of breeding countries (A/B)
Buteo lagopus	Rough-legged Buzzard	Non-SPEC	Diurnal	19	6	4	4	3	4	1.50	1.00
Falco rusticolus	Gyr Falcon	SPEC 3	Diurnal	4	4	4	3	3	5	0.80	0.80
Haliaeetus albicilla[a,b]	White-tailed Eagle	SPEC 1	Diurnal	39	26	19	18	17	28	0.93	0.68
Clanga clanga	Greater Spotted Eagle	SPEC 1	Diurnal	22	8	6	5	4	9	0.89	0.67
Bubo scandiacus	Snowy Owl	SPEC 3	Nocturnal	4	4	4	3	3	6	0.67	0.67
Falco columbarius	Merlin	Non-SPEC	Diurnal	29	12	7	7	5	12	1.00	0.58
Falco peregrinus[a,b]	Peregrine Falcon	Non-SPEC	Diurnal	52	36	21	24	17	40	0.90	0.53
Pandion haliaetus[b,c]	Western Osprey	SPEC 3	Diurnal	38	21	11	13	9	21	1.00	0.52
Aquila chrysaetos[a,b]	Golden Eagle	SPEC 3	Diurnal	34	27	18	21	16	35	0.77	0.51
Aquila adalberti	Spanish Imperial Eagle	SPEC 1	Diurnal	2	1	1	1	1	2	0.50	0.50
Circus macrourus	Pallid Harrier	SPEC 1	Diurnal	16	4	3	2	2	6	0.67	0.50
Neophron percnopterus	Egyptian Vulture	SPEC 3	Diurnal	21	7	6	4	4	12	0.58	0.50
Strix nebulosa	Great Grey Owl	Non-SPEC	Nocturnal	4	4	3	4	3	6	0.67	0.50
Circus cyaneus[a]	Northern Harrier	SPEC 3	Diurnal	39	19	12	15	10	25	0.76	0.48
Bubo bubo[a,b]	Eurasian Eagle Owl	SPEC 3	Nocturnal	24	23	19	18	17	40	0.58	0.48
Falco vespertinus	Red-footed Falcon	SPEC 3	Diurnal	25	10	8	6	6	17	0.59	0.47
Gyps fulvus	Eurasian Griffon	Non-SPEC	Diurnal	19	11	8	7	6	17	0.65	0.47
Falco tinnunculus[a,b]	Common Kestrel	SPEC 3	Diurnal	52	35	19	21	14	44	0.80	0.43
Falco eleonorae	Eleonora's Falcon	SPEC 2	Diurnal	14	4	3	3	3	7	0.57	0.43
Gypaetus barbatus	Lammergeier	SPEC 3	Diurnal	9	6	5	3	3	12	0.50	0.42
Surnia ulula	Northern Hawk Owl	Non-SPEC	Nocturnal	4	3	2	3	2	5	0.60	0.40
Buteo buteo[a,b]	Common Buzzard	Non-SPEC	Diurnal	50	29	16	18	13	42	0.69	0.38
Accipiter nisus[a,b]	Eurasian Sparrowhawk	Non-SPEC	Diurnal	44	26	16	16	14	43	0.60	0.37
Strix uralensis	Ural Owl	Non-SPEC	Nocturnal	13	11	8	10	8	22	0.50	0.36
Milvus milvus[c]	Red Kite	SPEC 2	Diurnal	24	12	10	8	7	28	0.43	0.36
Circus pygargus[a]	Montagu's Harrier	Non-SPECe	Diurnal	34	16	12	11	10	34	0.47	0.35

(*Continued*)

Table 1. Continued.

Scientific name	Common name	European SPEC status (BirdLife International 2004)	Type	Total number of species schemes submitted	Total number of breeding schemes submitted	Number of countries submitting breeding schemes A	Number of breeding schemes of >10 year duration	Number of countries with breeding schemes of >10 year duration	Number of European countries in which the species breeds (BirdLife International 2004) B	Number of breeding schemes per breeding country	Number of countries with breeding schemes / number of breeding countries (A/B)
Aegypius monachus	Cinereous Vulture	SPEC 1	Diurnal	10	5	4	3	3	12	0.42	0.33
Aquila heliaca	Eastern Imperial Eagle	SPEC 1	Diurnal	13	10	6	6	6	18	0.56	0.33
Aquila nipalensis	Steppe Eagle	SPEC 3	Diurnal	7	2	1	1	1	3	0.67	0.33
Clanga pomarina	Lesser Spotted Eagle	SPEC 2	Diurnal	25	11	8	7	5	24	0.46	0.33
Circus aeruginosus[a]	Western Marsh harrier	Non-SPEC	Diurnal	40	19	12	11	10	36	0.53	0.33
Elanus caeruleus	Black-winged Kite	SPEC 3	Diurnal	10	1	1	0	0	3	0.33	0.33
Accipiter gentilis[a,b]	Northern Goshawk	Non-SPEC	Diurnal	40	25	14	15	12	43	0.58	0.33
Asio otus[a,b]	Long-eared Owl	Non-SPEC	Nocturnal	24	20	14	14	13	43	0.47	0.33
Strix aluco[a,b]	Tawny Owl	Non-SPECe	Owls	26	24	13	19	12	41	0.59	0.32
Falco cherrug	Saker Falcon	SPEC 1	Diurnal	19	6	5	5	5	16	0.38	0.31
Falco subbuteo[a]	Eurasian Hobby	Non-SPEC	Diurnal	34	20	13	13	11	42	0.48	0.31
Pernis apivorus[a]	European Honey Buzzard	Non-SPECe	Diurnal	41	19	12	12	11	39	0.49	0.31
Asio flammeus[c]	Short-eared Owl	SPEC 3	Nocturnal	19	13	10	10	9	33	0.39	0.30
Aquila fasciata	Bonelli's Eagle	SPEC 3	Diurnal	17	9	4	6	4	14	0.64	0.29
Milvus migrans[c]	Black Kite	SPEC 3	Diurnal	31	12	10	8	8	37	0.32	0.27
Athene noctua	Little Owl	SPEC 3	Nocturnal	16	16	9	12	8	35	0.46	0.26
Falco naumanni	Lesser Kestrel	SPEC 1	Diurnal	18	6	5	2	2	20	0.30	0.25
Otus scops	Eurasian Scops Owl	SPEC 2	Nocturnal	9	9	7	6	6	28	0.32	0.25
Aegolius funereus	Boreal Owl	Non-SPEC	Nocturnal	10	8	8	8	8	36	0.22	0.22
Circaetus gallicus	Short-toed Snake Eagle	SPEC 3	Diurnal	23	7	6	4	4	27	0.26	0.22
Glaucidium passerinum	Eurasian Pygmy Owl	Non-SPEC	Nocturnal	8	7	5	5	5	23	0.30	0.22
Buteo rufinus	Long-legged Buzzard	SPEC 3	Diurnal	11	6	3	3	3	14	0.43	0.21
Tyto alba[b]	Barn Owl	SPEC 3	Nocturnal	16	16	8	11	6	38	0.42	0.21
Hieraaetus pennatus	Booted Eagle	SPEC 3	Diurnal	22	6	4	2	2	23	0.26	0.17
Accipiter brevipes	Levant Sparrowhawk	SPEC 2	Diurnal	7	3	2	2	2	14	0.21	0.14
Falco biarmicus	Lanner Falcon	SPEC 3	Diurnal	12	3	1	3	1	11	0.27	0.09
Accipiter badius	Shikra	Non-SPEC	Diurnal	0	0	0	0	0	1	0.00	0.00
Falco pelegrinoides	Barbary Falcon	Non-SPEC	Diurnal	0	0	0	0	0	1	0.00	0.00
Ketupa zeylonensis	Brown Fish Owl	SPEC 3	Nocturnal	0	0	0	0	0	1	0.00	0.00
Otus brucei	Pallid Scops Owl	SPEC 3	Nocturnal	0	0	0	0	0	1	0.00	0.00
			SUM	1143	648		436				

[a]Species with schemes of >10 years duration in 10 or more countries.
[b]Species with top contaminants monitoring coverage (from Gómez-Ramírez *et al.* 2014).
[c]Species with breeding schemes in 10 or more countries.

rufinus; Eurasian Pygmy Owl *Glaucidium passerinum*; Short-toed Snake Eagle and Boreal Owl *Aegolius funereus*.

Geographical distribution of raptor breeding population monitoring

In the 31 countries considered to be well covered by this study and considering all monitoring schemes, a mean (±sd) of 27.7 ± 24.3 (n = 858) schemes per country was reported, with 21 countries conducting more than 10 schemes and 12 countries (Cyprus, Estonia, Finland, Italy, the Netherlands, Portugal, Russia, Slovenia, Sweden, Turkey, Ukraine and the United Kingdom) conducting more than 30 schemes. Considering the sub-set of schemes monitoring breeding populations in the 31 well covered countries, a mean of 20.2 ± 20.4 (n = 627) schemes per country was reported, with 17 countries conducting more than 10 schemes and 5 countries (Russia, Slovenia, Sweden, the United Kingdom and Ukraine) more than 30 schemes.

When the geographical coverage of raptor and owl breeding population monitoring from this study is compared with the distribution and abundance of breeding raptors across Europe (Figure 7), it is clear that coverage is likely to be more comprehensive and representative in countries of the north and west of Europe than those further south or east (excluding Russia). This pattern is apparent for breeding species of all European conservation status classes but overall coverage is more representative for the more widespread species and those of more favourable conservation status (Non-SPEC and SPEC 3). Species of largest current conservation concern (SPEC 1 and SPEC 2) overall have populations most concentrated in southern Europe, making these least well represented by current monitoring coverage (Figure 7).

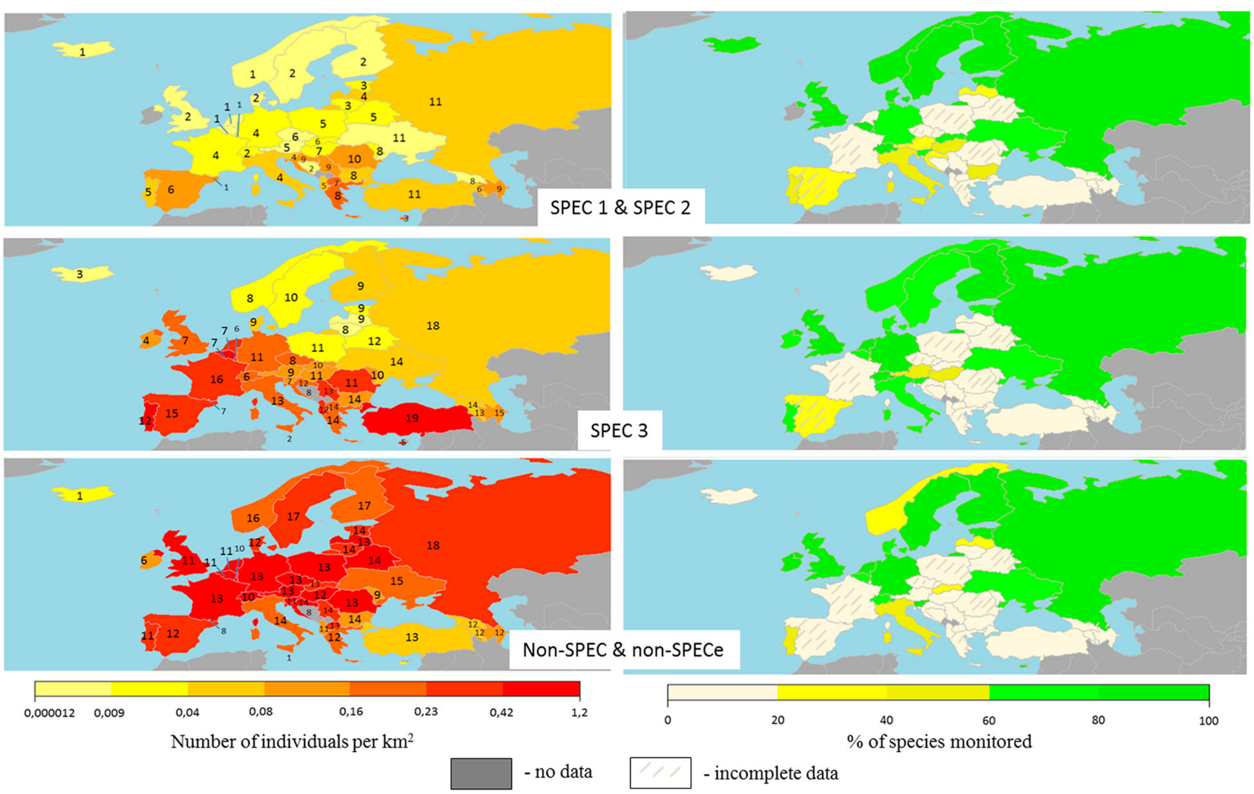

Figure 7. Comparison between the average breeding population size (left-hand maps) and per cent of species included in any breeding population monitoring (right-hand maps) in 31 European countries considered to be well covered by the current study for three raptor species groups following the classification in of BirdLife International (2004): SPEC 1&2; SPEC 3; non-SPEC & Non-SPEC^E (see definitions below). Numbers on the left-hand maps indicate the number of raptor species of the relevant SPEC categories breeding in each country. Colours on the right-hand maps indicate the percentage of raptor species breeding in a country included in at least one breeding population monitoring scheme. SPEC 1 – European species of global conservation concern, i.e. classified as CE, E, V, NT or DD under the IUCN Red List Criteria at a global level (Bird Life International; IUCN 2004). SPEC 2 – Species whose global populations are concentrated in Europe, and which have an Unfavourable conservation status in Europe. SPEC 3 – Species whose global populations are not concentrated in Europe, but which have an Unfavourable conservation status in Europe. Non-SPEC^E – Species whose global populations are concentrated in Europe, but which have a favourable conservation status in Europe. Non-SPEC – Species whose global populations are not concentrated in Europe, and which have a favourable conservation status in Europe.

Discussion

Constraints of survey approach and inventory design

There were two major areas of limitation of our study. First, the design of the questionnaire, as with all such surveys, had to represent a balance between comprehensive questioning on the one hand, and length on the other. The probability that raptor researchers would complete it would be reduced if it was too long and took too much time to complete. The second, related constraint was that of the language barrier. There was neither the time nor the resource to translate the questionnaire into many different languages. Reliance was placed on national coordinators to help scheme organizers understand the questionnaire. Of those coordinators that responded to our short post-questionnaire survey, a quarter suggested that language had been a barrier to schemes responding. As less than half of coordinators replied to this post-questionnaire survey, the proportion of countries for which language was a barrier may well have been higher. If such a questionnaire survey is to be repeated, presentation of the questions and associated guidance on filling the questionnaire in national languages would probably be the single most important change that could improve the number and utility of responses. Other barriers to responding, such as a dislike of form filling and information sharing, and lack of national networks by which to disseminate the questionnaire, would be more difficult to mitigate.

Many respondents probably considered that the questionnaire was more focused on breeding population monitoring, and less focused on migration studies, such that we consider the latter in particular were not well represented in the findings. This was also, at least in part, influenced by the mix of participants that became involved in the EURAPMON networking initiative (many of whom acted as the national coordinators), in which those working on migration studies were less well represented than those working on breeding populations. While migration programmes were not the focus of the inventory, we nonetheless obtained information on 21 migration monitoring programmes; details are available in the online inventory (http://www.eurapmon.net/for-raptors-search).

For the majority of countries (67%; 31 of a total of 46), the survey results were considered to satisfactorily represent the state of current breeding population monitoring (and certainly most large and national programmes would have been reported). For two of these, Albania and Kosovo, it was known that no monitoring was in place. For eight countries, some information was received but it was considered incomplete (see also Abuladze 2012, Bakaloudis 2012, Dombrovski 2012, Sánchez-Zapata 2012, Sielicki & Mizera 2012, Urcun 2012): Belarus, Czech Republic, France, Georgia, Greece, Poland, Romania and Spain. For six of these eight countries, however, an overview of raptor monitoring activity was provided earlier in the EURAPMON programme (Duke *et al.* 2012, EURAPMON 2012b), so that together with the new inventory there is much information on these countries. A small number of countries did not respond at all to this or the previous initiative, so information was completely lacking: Andorra, Armenia, Azerbaijan, Liechtenstein, Lithuania, Macedonia and Moldova. All of these countries are relatively small (Andorra and Liechtenstein very small) and therefore the lack of information from them is not a major omission in terms of understanding the broad patterns in European monitoring coverage, although it would be useful to fill these knowledge gaps in future.

Due to variation in the way the questionnaire was used by respondents, the number of 'species schemes' rather than the number of programmes (where each species within a multi-species programme was defined as a separate 'species scheme') had to be used for comparative purposes. 'Schemes' were likely to be extremely heterogeneous in terms of their spatial extent and the parameters monitored, and it was difficult to differentiate between national and particularly regional and local schemes. This made interpretation of some of the results problematic, particularly with respect to comparisons between countries. For example, France reported an exceptionally large number of small species schemes (over-inflating the picture of monitoring coverage), while Finland reported most monitoring within a single national response (under-emphasizing monitoring effort using the measures available to us; see also Saurola 2012). For these reasons, the number of countries with monitoring schemes for a particular species (and this compared to the number of countries in which a given species occurs) may provide a more accurate description of monitoring coverage that is more suitable for comparative purposes.

Current state of monitoring coverage across Europe and reporting potential

This study demonstrated the large number, and broad geographical spread, of population and demographic studies of breeding diurnal and nocturnal raptors across Europe, and established a detailed searchable online inventory available for access by the research and policy community (http://www.eurapmon.net/for-raptors-search). No inventory on this scale can ever be entirely complete or up to date. However, it is considered to be sufficiently comprehensive to give a strong steer as to the potential to: (a) report more fully on the demographic health of raptor populations at supra-national (pan-European) scale; (b) report on recent changes in these populations; and (c) increase the linkages between studies of populations and demography and those on contaminants in raptors, the latter both to support the conservation of the raptors themselves, and to monitor human health risks via biological samples from raptors.

With at least 1196 species schemes (within 236 monitoring programmes) present in 37 European countries, more than 90% of which are considered to be in current operation, there is huge potential to foster enhanced collaboration between countries and schemes and move towards strategic programmes that can monitor current status and changes, and report more fully, at pan-European scale. With more than 600 species schemes across 35 countries running for at least 10 years, more than 400 for more than 20 years and 40 for more than 40 years, there is considerable potential to report more fully on long-term trends for a wide range of species, and to assess how trends for individual species may differ between countries or biogeographical regions of Europe with differing ecological conditions or perceived threats.

Our questionnaire survey was best suited to collating comprehensive information on the monitoring of breeding populations. Considering the findings specifically for breeding population monitoring, there were 19 species with at least one extant species scheme in 10 or more countries, and 15 species for which these schemes had been running for at least 10 years (Table 1). There is currently the greatest opportunity to report and compare trends in breeding populations for these 15 species, and to build on the extant schemes for the 19 species to achieve representative pan-European coverage. The 19 species include a similar number of species of moderate conservation concern (SPEC 3; 7 species) and more favourable conservation status (Non-SPEC; 10 species), with much lower representation of SPEC 1 and SPEC 2 species (two species). This is of course not unexpected, because by definition these species may already be scarcer and less widespread across Europe, and in some cases more difficult to monitor because of their elusiveness. There are additional species that could be added to such pan-European reporting of monitoring trends, however, because their breeding populations are monitored in a high proportion of the countries in which they breed, such that monitoring coverage should be broadly representative of their European populations; these include Rough-legged Buzzard (non-SPEC), Gyr Falcon (SPEC 3), Greater Spotted Eagle (SPEC 1), Snowy Owl (SPEC 3), Merlin (Non-SPEC), Spanish Imperial Eagle (SPEC 1), Pallid Harrier (SPEC 1), Egyptian Vulture (SPEC 3) and Great Grey Owl (Non-SPEC). The inventory compiled by our study now provides some information on the extent to which the submitted schemes and programmes already report on their findings and the extent to which they are set up to be able to share information with other schemes. However, further work is required ahead of identifying the full potential for pan-European analysis and reporting in a standardized manner.

Potential to expand raptor population and contaminant monitoring coverage across Europe

In terms of the monitoring of raptor breeding populations, the study clearly demonstrates more comprehensive and representative coverage of breeding species in north-west Europe, with lower coverage (across all European conservation status categories) in south and east Europe except apparently for the large territory of Russia (Figure 7). Due to constraints in the design of the questionnaire survey, it was not possible to acquire unambiguous information on the extent to which even national monitoring programmes were representative of the species range in each country. But it was necessary to treat questionnaire findings in a consistent manner across all countries. This means that some of the findings should be treated with caution. For example, given the size of Russia, it is unlikely that monitoring coverage is as comprehensive over the whole territory (see also Galushin 2012) as suggested by Figure 7. We know that information received from a number of other countries was incomplete, although it is unlikely that further information would substantially alter the overall picture of monitoring coverage across Europe described above, or the broad conclusions reached. Before using inventory information for any strategic planning to increase monitoring coverage for one or a number of species, it would be wise to contact the schemes and programmes of interest to find out more about current methods and sampling design in relation to the relevant species distribution and abundance in the countries of interest.

During a parallel piece of inventory work under the EURAPMON programme (Gómez-Ramírez *et al.* 2014), 12 diurnal and nocturnal raptor species were identified as being most monitored for contaminants across Europe. All 12 of these species feature in our own study of species receiving most breeding population monitoring coverage across Europe (Table 1). In almost all cases, however, there is extant population monitoring in more countries than those from which biological material is collected for contaminant monitoring currently, indicating the potential for more collaboration between those monitoring populations and those monitoring contaminants to increase the geographical spread of biological samples collected. The same study (Gómez-Ramírez *et al.* 2014) identified single raptor species and groups of species with different ecological traits, as these could influence contaminant accumulation patterns. The current study demonstrates additional opportunities for ecotoxicologists to work with programmes and schemes carrying out population monitoring on species spanning most of the discrete species groups identified by Gómez-Ramírez *et al.* (2014). Only three contaminant 'species groups' (each containing a single species) are not represented in the top 20 species studied for population monitoring: Rough-legged Buzzard, Egyptian Vulture and Eurasian Scops Owl *Otus scops*. The first two of these species nevertheless receive monitoring coverage of breeding populations in more than 50% of breeding countries which provides an opportunity to increase sampling for ecotoxicology purposes. There would be multiple benefits for both population and contaminant monitoring of increasing monitoring coverage of Eurasian Scops Owl across Europe.

As part of EURAPMON, Espin *et al.* (2016) combined data from Gómez-Ramírez *et al.* (2014) with data from our study, which together allowed assessment of which sample matrices might be most available for monitoring and which contaminants are currently prioritized for monitoring in birds of prey and owls in Europe. The two inventories together provide, for the first time, information on the extent of raptor monitoring and sample collection throughout Europe

Our study has identified important population monitoring gaps, which must be a high priority to fill, in terms of a number of species whose monitoring coverage within Europe is either negligible or poorly representative, despite there being substantial European breeding populations of these species. These include Lanner Falcon, Levant Sparrowhawk, Booted Eagle, Barn Owl, Long-legged Buzzard, Short-toed Snake Eagle, Eurasian Pygmy Owl and Boreal Owl.

The inventory provides comprehensive information on extant programmes/schemes and therefore organizations and groups that could provide expertise and experience for capacity building in raptor monitoring that could be shared with others attempting to increase monitoring coverage in their countries/regions. As more than 60% of species schemes are run by civil or non-governmental organizations and more than half of all species schemes rely on greater than 50% volunteer effort, this is clearly a frequent model from which expertise and experience could be captured through the development of best practice guidance (e.g. Hardey *et al.* 2013). Best practice guidance was reported by national coordinators within EURAPMON network as the main benefit expected from international networking and collaboration (Vrezec *et al.* 2012). It would be beneficial for such guidance to cover not only the design of monitoring coverage, survey and recording methods and methods of analysis and reporting, but also experience of how to recruit, train, motivate and retain volunteer observers to take part in the monitoring work (Vrezec & Bertoncelj 2015). There will be many reasons why the current coverage of monitoring is more comprehensive in north-west Europe than further south and east, including such factors as: population wealth (e.g. GDP levels); attitude to conservation; human population density (to provide volunteers); past culture of interest in natural history; past culture of volunteering or leisure time available for volunteering; nature of terrain and climate; current state of nature degradation and so on. When developing good practice guidance to assist capacity building it will therefore be important to take into account the context (geographical area) in which each new or enhanced programme intends to operate, and ensure that guidance is fit for purpose for that area. The network of national coordinators established during the EURAPMON programme, who assisted with developing the inventory, would provide an ideal starting network for developing such guidance.

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