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A review of constraints and solutions for collecting raptor samples and contextual data for a European Raptor Biomonitoring Facility

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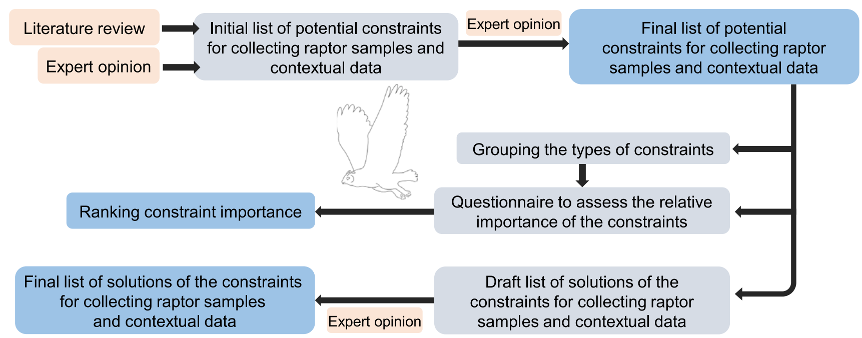
HIGHLIGHTS

- ERBFacility COST Action aims to use raptors to biomonitor chemicals across Europe.
- We reviewed potential constraints to implement a long-term monitoring scheme.
- We identified 31 constraints in 4 categories: legal, methodological, spatial, skills.
- Main constraints relate to complex contextual data and number of existing schemes.
- We explain and contextualize the constraints and present the main solutions to them.

GRAPHICAL ABSTRACT



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ABSTRACT

The COST Action 'European Raptor Biomonitoring Facility' (ERBFacility) aims to develop pan-European raptor biomonitoring in support of better chemicals management in Europe, using raptors as sentinel species. This presents a significant challenge involving a range of constraints that must be identified and addressed. The aims of this study were to: (1) carry out a comprehensive review of the constraints that may limit the gathering in the field of raptor samples and contextual data, and assess their relative importance across Europe; and (2) identify and discuss possible solutions to the key constraints that were identified. We applied a participatory approach to identify constraints and to discuss feasible solutions. Thirty-one constraints were identified, which were divided into four categories: legal, methodological, spatial coverage, and skills constraints. To assess the importance of the constraints and their possible solutions, we collected information through scientific workshops and by distributing a questionnaire to stakeholders in all the countries involved in ERBFacility. We obtained 74 answers to the questionnaire, from 24 of the 39 COST participating countries. The most important constraints identified were related to the collection of complex contextual data about sources of contamination, and the low number of existing raptor population national/regional monitoring schemes and ecological studies that could provide raptor samples. Legal constraints, such as permits to allow the collection of invasive samples, and skills constraints, such as the lack of expertise to practice necropsies, were also highlighted. Here, we present solutions for all the constraints identified, thus suggesting the feasibility of establishing a long-term European Raptor Sampling Programme as a key element of the planned European Raptor Biomonitoring Facility.

1. Introduction

There is growing concern in the European Union (EU) and worldwide about the negative impacts of various chemicals on the environment (Krabbenhoft and Sunderland, 2013; Hallmann et al., 2014; Malaj et al., 2014; Jepson and Law, 2016) and on human health (Movalli et al., 2018).

The European Union (EU) aims to achieve a non-toxic environment, and a wide range of legislation has been implemented to reduce these negative impacts on the environment and human health. This includes Regulation EC 1907/2006 and amendments (REACH—Registration, Evaluation, Authorisation & Restriction of Chemicals) concerning industrial substances, Regulation EC 1107/2009 concerning the authorisation of plant protection products, Regulation EC 726/2004 concerning the authorisation of human and veterinary pharmaceuticals, and the Biocidal Product Regulation (BPR, EU Regulation 528/2012). However, legal restrictions on the use of chemicals should be accompanied by effective monitoring methods, to provide early warning of emerging contaminant problems in the environment, inform substance risk assessments and evaluate the effectiveness of risk management measures (Shore and Taggart, 2019; Rodríguez-Estival and Mateo, 2019; García-Fernández, 2020). Biomonitoring with sentinel species is an important tool for early detection of negative impacts of chemicals on all ecosystems, with potentially strong links to human health (Smits and Fernie, 2013; García-Fernández et al., 2020). Raptors (defined here as birds belonging to the orders Accipitriformes, Falconiformes and Strigiformes) are especially suitable for monitoring persistent substances in the environment because: (a) they are generally long-lived apex predators; (b) they effectively integrate contaminant exposure over time and over relatively large spatial areas; (c) they can be sampled without a need to sacrifice or harm the birds by sampling of feathers, blood, preen oil and/or addled/deserted eggs; (d) as charismatic birds, raptors found dead or injured are frequently delivered to wildlife rehabilitation centres or museums by the general public, providing good sources of tissue samples (internal organs, muscles, bones), and (e) their populations can be relatively easily monitored and quantified (Movalli et al., 2008; Gómez-Ramírez et al., 2014; Espín et al., 2016; Movalli et al., 2017; García-Fernández et al., 2020). Monitoring contaminants using raptors can usefully complement biomonitoring in humans within a One Health approach, which acknowledges the interconnection between the health of people, domestic animals, and our shared environment, including wildlife and plants (Duke, 2008; Walker et al., 2008; Berny et al., 2015; Movalli et al., 2018; Badry et al., 2020; García-Fernández et al., 2020).

With this in mind, the COST Action European Raptor Biomonitoring Facility (hereafter ERBFacility; https://erbfacility.eu/ and https://www.cost.eu/actions/CA16224/) was established with the aim to design and build key elements of a "Facility" (or framework) for pan-European raptor biomonitoring, in order to enhance the evaluation of effectiveness of chemicals regulations and conventions, improve risk assessment of specific chemicals and provide early warning of emerging contaminant problems. Under this Facility, samples from key species would be collected, transported, stored, and analysed following harmonized methodologies. The three key elements of ERBFacility are: a European Raptor Sampling Programme, which gathers raptor samples and related 'contextual data' from the field; a distributed European Raptor Specimen Bank which stores these samples and related data; and a European Raptor Biomonitoring Scheme, which analyses raptor samples for contaminants (Movalli et al., 2019; Badry et al., 2020; Espín et al., 2021).

The creation of ERBFacility presents a significant challenge, with a number of constraints to be addressed. These constraints relate to the 'field arena' where samples are gathered, to the 'collections arena' where samples are stored, and to the 'analysis arena' where samples are analysed for contaminants. This paper addresses constraints relating to the first of these arenas, and the establishment of a European Raptor Sampling Programme as a key element of the planned Facility. This covers the process from collecting samples from raptors in the field up to the point of arrival of the samples at a collection (e.g., a natural history museum or environmental specimen bank or research collection) or an analytical laboratory.

Constraints relate both to the gathering of samples, and to the gathering and interpretation of reliable 'contextual data', that links the sample to other relevant data, e.g., on population parameters. Such contextual data provide the individual, population and ecological context for the better interpretation of contaminant data in raptor samples.

Previous work has illuminated some of the potential constraints in this regard. Raptor population monitoring schemes, which offer important potential for gathering raptor samples and contextual data, are not uniformly spread across Europe, apply diverse methods and are conducted at varying scales, from intensive academic research projects to broad-scale volunteer surveys (Kovács et al., 2008; Vrezec et al., 2012). However, we also know that there is an important number of raptor population monitoring schemes, widely distributed across Europe (Derlink et al., 2018). Alongside these, several existing monitoring programmes focus on contaminants in raptors populations (García-Fernández et al., 2008; Gómez-Ramírez et al., 2014; Carneiro et al., 2015; Espín et al., 2016). Many natural history museums, a small number of environmental specimen banks and some other research institutes hold substantial collections of frozen raptor carcasses and/or tissues suitable for contaminant monitoring (Movalli et al., 2017, 2018; Ramello et al., Unpublished results). In addition, wildlife rehabilitation centres and other institutions have potential as suppliers if raptor samples. These previous studies demonstrate the wealth of existing activity on which the planned Facility can be build.

Beyond identifying constraints to implementation of the ERBFacility, it is crucial to identify effective and realistic solutions to address these constraints. Accordingly, we set for the present study two major objectives: (1) to conduct a comprehensive review of the constraints that may limit the collection of raptor samples and contextual data and assess their relative importance across Europe; and (2) to identify and discuss possible solutions to the key constraints that were identified.

While this paper focuses on constraints faced in the field arena, other work under ERBFacility addresses constraints in the collections arena (e.g., Ramello et al., Unpublished results; Sbokos et al., Unpublished results; Vlachopoulos et al., Unpublished results) and in the analysis arena (e.g., Badry et al., 2020; Espín et al., 2021).

2. Methods

This study focused on all 39 Member and Cooperating Member countries in the European Cooperation in Science & Technology network (COST, https://www.cost.eu/who-we-are/members/), including the 28 member states of the European Union plus Near Neighbour and International Partner Countries. We used a participative approach, to make effective use of the opinion of experts and people involved in collecting raptor samples and contextual data.

In order to accomplish the first objective (i.e., a comprehensive review of the relative importance of constraints that may limit the gathering in the field of raptor samples and contextual data), we drafted a preliminary list of potential constraints through a bibliographic review and use of expert knowledge (based on a questionnaire to a smaller group of experts and a workshop). As a further step, we created a second questionnaire for a larger group of experts to classify the relative importance of each constraint, by constraint type (i.e., legal, methodological, skills, and spatial coverage) and by the different categories of involved actors. In order to accomplish the second objective (i.e., identifying possible solutions to major constraints) we implemented sought expert opinion through a second workshop involving experts from several participating countries.

For the purpose of this study, we use the term "raptor samples" to mean: (1) non-invasive samples that do not require manipulation of birds (e.g. carcasses of birds found dead, moulted feathers, addled/deserted eggs, regurgitate pellets) but that may generate disturbance in some circumstances (e.g. when collecting them from active nests), and (2) invasive (but non-destructive) samples that require manipulation of live birds (e.g. blood or plasma, pulled feathers, preen oil). All raptor sampling must be done under relevant permit, where applicable. We use the term "contextual data" to include all the information related to the sample, individual, or the population that can provide relevant context for the interpretation of the contamination levels detected in a given sample (see Table S1 in Supplementary Material ESM1).

2.1. Identification of potential constraints

The first step to identify potential constraints consisted of a literature review of scientific papers on contaminant monitoring studies using raptors as study species. We initially searched for papers using Google Scholar, published between 2000 and 2019, with the search terms: birds of prey, contaminant, contamination, eagle, ecotoxicology, falcon, owl, raptor, or their combinations. We limited the year interval of our search to avoid an excessive number of articles but also to avoid identifying potentially outdated constraints. We looked for additional relevant papers by inspecting the list of references in each paper. Overall, 66 papers were reviewed in detail to find any mention of possible constraints associated with the process of collecting and analysing samples.

The second step involved building a list of potential constraints based on expert opinion. We designed three short surveys, distributed via email to a group of 29 experienced researchers in raptor ecology and ecotoxicology from 19 different European countries to identify further constraints. These researchers were chosen among ERBFacility collaborators in order to ensure a broad country coverage, but also the representativeness of different institution types (universities, research institutions, natural history museums, non-governmental organizations, wildlife rehabilitation centres).

The third step was to discuss the list of potential constraints with a group of 46 experts working with raptors and owls during an ERBFacility workshop in Thessaloniki, Greece (February 2019) (ERBFacility, 2019a). These experts represented 20 participating countries. The participants were asked to provide contributions about the completeness of the list of constraints regarding their experience in the countries for which they had knowledge. The constraints were then grouped within four types: (1) legal; (2) methodological; (3) skills; and (4) spatial coverage constraints.

2.2. Classification of the importance of the constraints

Once we reached a final list of potential constraints, the fourth step was to design an online anonymous questionnaire with the aim of obtaining a classification of the relative importance of each constraint as it is perceived in different countries and by different groups of people involved in collecting raptor samples and contextual data. The questionnaire was divided into three main parts, all with facultative questions (Table S2 in Supplementary Material ESM1). The first part was designed to characterize the respondents, in terms of their professional role, expertise with raptors, and specific skills and permits held to work with raptors. In the second part of the questionnaire, respondents were given 45 questions in which they were asked to rate the importance of general and case-study-specific constraints. We used a classification from 1 (not a constraint) to 5 (strong constraint). Finally, in the third part of the questionnaire, we asked participants to select the five most relevant ways to address constraints and thereby improve the collection of raptor samples and contextual data in their country from a list of nine suggestions. In addition, we asked an open question allowing them to suggest further solutions.

The questionnaire was initially distributed to the 69 ERBFacility Management Committee Members and Alternate Members, representing 27 participating countries. In turn, these national representatives distributed the questionnaire to individuals involved in the collection of raptor samples and contextual data (researchers, bird ringers, non-governmental organization workers, wildlife rehabilitation centre workers, museums curators, veterinarians, among others) in their respective countries. Considering the people to whom we first sent the questionnaire and the number of people we know to have been contacted by the national representatives, we estimate that the questionnaire was received by at least 150 people. We obtained 74 answers to the questionnaire, from 24 of the 39 COST countries.

2.3. Identification of potential solutions

Building on the list of key constraints, we drafted a list of possible solutions to each constraint. The solutions were divided into five types of action: (1) best practice guidance, (2) capacity building, (3) coordination, (4) species and contaminant prioritization, and (5) funding. The draft list of solutions was then presented and discussed at a ERBFacility workshop in Florence, Italy (March 2019; ERBFacility, 2019b), involving 23 experts in raptor sampling, ecology, and ecotoxicology. The participants were divided into groups based on the five types of action. Each group was asked to discuss the most suitable solution to solve the potential constraints, including practicalities on how to implement the solutions, which actors should be involved, and the time needed for implementation.

2.4. Data analysis

The results from the questionnaire were compared using non-parametric tests – Wilcoxon rank sum test; and Kruskal-Wallis rank sum test followed by a post-hoc Dunn test (library "dunn.test"). Significance value was set at $p < 0.05$. Analyses were carried out using the statistical software R version 4.0.2 (R Core Team, 2020).

3. Results and discussion

3.1. What are the potential constraints for a European Raptor Sampling Programme?

Using our participative approach, we identified a total of 31 potential constraints to collecting raptor samples and contextual data. Six of these constraints concerned legal aspects, 13 were methodological constraints, 5 were related to the skills of participants, and 7 were related to spatial coverage (Table 1, see a detailed description of the constraints in Table S3 in Supplementary Material ESM1).

Table 1
Summary of constraints and solutions for collecting raptor samples and contextual data.

#	Constraint	Possible solutions
Legal constraints		
1	Legal restrictions on transportation of samples within country	Provide best practice guidance. Improve knowledge of the best shipping conditions. Establish national coordinators
2	Legal restrictions to holding and storing raptor samples (carcass, feathers, eggs)	Provide training/guidance to obtain licences for storing raptor samples
3	Legal restrictions for sampling blood or other invasive samples	Provide training to field workers to obtain licences for collecting invasive samples
4	Legal restrictions for handling live wild birds	Provide training to obtain licences for handling live wild birds
5	Legal restrictions for visiting active nests	Provide training to obtain licences to visit active nests
6	Legal restrictions to access private property	Provide best practice guidance. Establish national coordinators ambassadors
Methodological constraints		
7	Difficulty in collecting contextual data on potential sources of contamination	Increase knowledge on local contamination sources
8	Difficulty in collecting contextual data on diet	Provide guidance and training to study diet
9	Difficulty in collecting contextual data on reproductive performance	Provide guidance and training on how to collect breeding parameters
10	Difficulty in collecting mandatory or high priority contextual data (age, sex, feather type)	Provide guidance and training on raptor identification and collecting contextual data
11	Lack of contextual data because of non-precise location of samples	Provide guidance on how to record locations
12	Lack of amount of sampled blood for nestlings	Use another sample matrix (e.g., nestling feathers) or pool blood samples from the same nest.
13	Lack of information on adequate protocols for collecting samples	Improve distribution of the existing protocols for sampling and increase access to training for field workers
14	Difficulty of providing sampling material	Provide the sampling material from reference laboratories (syringes, containers, anticoagulants, etc.)
15	Difficulty in Harmonisation of contextual data related with the sample	Improve data flux and organization. Creation of a suitable database (application or software).
16	Difficulty in adequate short-term storage of the samples	Best practice guidance and increased capacity building for storage
17	Difficulty to relate sample to specific contextual data	Design specific ID code
18	Difficulty to find an institution to send the sample for analysis	Establish National Coordinators that coordinate with different institutions
19	Difficulty to support the shipping cost or ensure correct transportation	Funding for the expenses to be covered by the European Raptor Biomonitoring Facility. Having a national coordinator that can pick up samples and provide transportation protocols
Spatial coverage constraints		
20	Focal raptor population with very low abundance or uneven distribution	Consider monitoring a set of raptors with similar diet and habitat
21	Low number of monitoring schemes and ecological studies to provide access to raptors samples	Increase the number of projects working with raptors
22	Low number of monitoring schemes and ecological studies to provide complex contextual data	Increase the number of projects working with raptors
23	Low number of suitable sampling areas in the country	Consider monitoring in a set of similar habitats
24	Difficulty to access raptor breeding areas	Increase efforts to get samples without necessity to access breeding areas e.g., moulted feathers or carcasses. Work with species that are easy to access
25	Difficulty to access to the nests	Increase efforts to get samples without necessity to access nests e.g., moulted feathers or carcasses
26	Lack of institutions to participate in the Sampling Programme	Collaborate with a neighbouring country. Motivate the participation of more institutions

Table 1 (*continued*)

#	Constraint	Possible solutions
	Skills constraints	
27	Lack of skilled people for field sampling	Provide training and guidance for fieldwork
28	Lack of means for capacity building by field coordination institutions	Increase the funding for capacity building
29	Lack of motivation among field workers	Improve feedback. Establish national ambassadors
30	Lack of skills required for post-processing of carcasses (necropsies)	Improve training and guidance for necropsies
31	Lack of skills to collect complex contextual data	Improve training and guidance to collect contextual data

3.1.1. Legal constraints

There are many regulations and laws aimed at protecting raptors. At the international level, CITES (Convention on Trade in Endangered Species) has the purpose of ensuring that no species of wild fauna or flora becomes or remains subject to unsustainable exploitation because of international trade. CITES plays an important role in regulating the transportation of raptor samples between countries. In the EU, the Birds Directive (Directive 2009/147/EC) aims to protect all wild bird species naturally occurring in the EU and regulates the handling of any readily recognisable parts or derivatives of such birds. Each Member State must transcribe this into national legislation or administrative measures. Because of variations in transcription, constraints under this Directive may therefore differ between countries, but generally all countries limit actions that can disturb or harm raptors, particularly during the breeding period. Legal constraints often exist at the outset of collecting raptor samples and contextual data in the field in terms of gaining access to private property (e.g., when a raptor breeds or dies on private land). These constraints vary between countries and locations with the varying percentage of private land among European countries and the varying willingness of landowners to allow access for research purposes. Many countries restrict visits to active raptor nests; in some cases, active nests are protected by legislation in order to prevent persecution or disturbance or other potential damage to threatened and sensitive bird species. In addition, there are legal restrictions for handling live raptors. Across Europe, handling usually requires evidence of specific training and experience and proper facilities in order to obtain the appropriate licence. Restrictions are even stricter for sampling of blood or other samples when involving manipulation of live birds (namely Directive 2010/63/EU as amended by Regulation EU 2019/1010). There are moreover national and international legal restrictions that apply to the transportation of sample material within a country (and between countries), and to the storing of raptor samples. The possession and transport of biological samples, and especially those from protected species such as raptors, may be subject to legal restrictions including under CITES convention, the Nagoya Protocol on Access and Benefit-sharing (www.cbd.int/abs), IATA Dangerous Goods Regulations (DGR), the UN European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), and country-specific regulations for national postal services. The complexity and lack of knowledge of the legislation, or the logistical difficulties it raises, may hamper development of a European Raptor Sampling Programme as a key element of the European Raptor Biomonitoring Facility. Legal constraints relating to the shipment of samples, and measures to address them, are tackled by a separate ERBFacility study (Sbokos et al., Unpublished results).

3.1.2. Methodological constraints

All raptor samples should be collected following adequate protocols that allow for subsequent rigorous chemical analyses and interpretation, as well as ensuring the safety of both fieldworkers and birds (Espín et al., 2021). Despite the existence of field and sampling protocols specifically for raptors (e.g., Bird and Bildstein, 2007; Hardey et al., 2013; Espín et al., 2014, 2021), the insufficient dissemination and awareness of these protocols may be an important constraint to a European Raptor Biomonitoring Scheme. When a sample is collected it may be necessary to carry out short-term storage before it is sent for long-term storage in natural history museums, environmental specimen banks or other research collections. Unsuitable short-term storage (e.g., high temperatures, inadequate containers, incorrect conservation method) or improper sample collection (e.g., insufficient sample amount, cross-contamination) may result in sample deterioration or the sample not being suitable for chemical and biomarker analysis (Espín et al., 2014, 2021). Samples must be sent as soon as possible to a collection for appropriate long-term storage or alternatively to an ecotoxicology laboratory for chemical analysis. Field workers may not be aware of the most suitable institutions to which to send the samples, in order to make them available for biomonitoring. Moreover, samples must be transported following adequate transport protocols, and considerable associated shipping costs might discourage the participation of fieldworkers in the sampling programme. If these constraints are not solved, they could lead to the loss of a great number of potential samples and/or cause an under-representation of some regions of Europe in sampling.

All collected samples must have at least basic contextual data relating directly to the sample itself, such as: species, age group, sampling location, matrix type, and date. In the case of carcasses, it is relevant to obtain the information needed to estimate the time of death (Valverde et al., 2020). If this information is missing, a sample is unlikely to be suitable for use in the Biomonitoring Scheme. Additional contextual data about the individual and the population from which it is known to derive, such as diet composition, habitat, moulting or migration patterns can be important for the interpretation of the results (Elliott et al., 2007; Lourenço et al., 2011; Lodenius and Solonen, 2013; Bustnes et al., 2013; Roque et al., 2016). Some contextual data, such as diet and reproductive performance, can be particularly relevant depending on the aims of the Biomonitoring Scheme (Palma et al., 2005; Schipper et al., 2012; Badry et al., 2019) but recording these data often entails considerable time investment and expertise. Finally, in many case studies it is relevant and valuable to have information available on contamination sources local to the area of sample collection (Elliott et al., 2007; Espín et al., 2014; Badry et al., 2019).

3.1.3. Skills constraints

Specific skills and experience are necessary to obtain and process raptor samples (particularly taking blood or carrying out a necropsy) and to collect complex contextual data (e.g., determine sex and age of raptors, carry out rigorous population monitoring). Most frequently, field workers have good raptor identification skills but may lack training in sample collection. To be able to train field workers it is first necessary to develop capacity building among field coordination institutions. Contributing to a European Raptor Sampling Programme will often be a voluntary action, and through time there can be a loss of motivation to participate without effective work from a coordinating organization. For a successful Programme, it will be important to keep fieldworkers well motivated to obtain raptor samples and collect relevant contextual data.

3.1.4. Spatial coverage constraints

One of the greatest challenges of a European Raptor Sampling Programme as proposed by ERBFacility is ensuring wide geographical coverage. There are several candidate raptor species that could be selected as priorities for a European Raptor Biomonitoring Scheme (Badry et al., 2020) but among these some species may have a low abundance in some European countries, or an uneven distribution within a country (especially in countries with large territories), leading to unrepresentative monitoring or high costs/effort needed to obtain a minimum number of samples. Several species that are underrepresented in existing monitoring studies within Europe are mainly common and widespread species (e.g., Common Buzzard *Buteo buteo*, European Honey Buzzard *Pernis apivorus*, Northern Goshawk *Accipiter gentilis*, Eurasian Sparrowhawk *A. nisus*) and species breeding predominantly in southern and eastern Europe (e.g., Long-legged Buzzard *Buteo rufinus*, Booted Eagle *Hieraaetus pennatus*, Short-toed Snake Eagle *Circaetus gallicus*) (Vrezec et al., 2012). The lack of ongoing population monitoring schemes and ecological studies may hamper the collection of raptor samples and contextual data (e.g., diet, reproductive performance, population trends, behaviour). Moreover, some contaminants are associated with specific habitats or land-uses (e.g., a specific plant protection product), and sampling needs to take into account that these areas may be poorly or not represented, or be very localized, in some countries. In addition, the access of fieldworkers to some regions where raptors occur may be difficult or impossible, for example in remote or roadless areas, isolated islands, or restricted areas (e.g., military zones). Some raptor nests may also be difficult to monitor, (e.g., on high cliffs or in treetops). Nest visits are essential to obtain several sample types (e.g., eggs, feathers, pellets, nestling feathers or blood) and certain contextual data (e.g., some measures of reproductive performance or diet composition). Finally, the lack of institutions to store and ship samples in one or more countries/regions may limit spatial coverage.

3.2. Which are the strongest constraints for collecting raptor samples and data?

Responses to our questionnaire to the strength of the constraints included reasonable representation from the various groups involved in field work with raptors. Of the 74 respondents, 64% worked with raptors as their professional job, 26% as both professional job and volunteers, and 10% as volunteers. Regarding the institutions in which respondents carry out their work with raptors, 50% exclusively work in governmental institutions (e.g., universities, research institutes, natural history museums), 27% work exclusively for non-governmental organizations (NGOs) or as volunteers (e.g., ringers), 20% work for both governmental research institutions and NGOs (or as volunteers), and 3% work for private companies or as independent professionals. According to the profile, we grouped the actors involved in collecting raptor samples and contextual data into two types: (1) governmental – people having as main institution a governmental organization dedicated to research, either in zoology, ecology or ecotoxicology, including universities, research institutes, and natural history museums (62%, n = 46); and (2) non-governmental – people working professionally or as volunteers in NGOs, private companies, or as independent workers (i.e. without any connection with governmental organizations; 38%, n = 28).

Among respondents, southern European countries were more represented than northern and eastern European countries (Fig. 1). This spatial bias is similar to that obtained in a previous study that assessed the existing monitoring programmes measuring contaminants in raptor samples until 2012 (Gómez-Ramírez et al., 2014). There was a significant gap in participation of central and eastern European countries, such as Poland, Latvia and Lithuania, despite our efforts to involve specific expertise from co-authors and workshops participants from the countries less well represented.

According to the questionnaire results, the most common skill among governmental and non-governmental workers is the skill of carrying out field surveys and monitoring of raptor populations, e.g., collecting data on basic population or reproduction parameters (Fig. 2). Both types of actors have similar skills in monitoring raptors populations, including permits to handle birds. However, for collecting invasive samples (e.g., blood) there is a greater number of governmental workers with the required skills in comparison to non-governmental workers. The skills related with the shipping of samples are also more

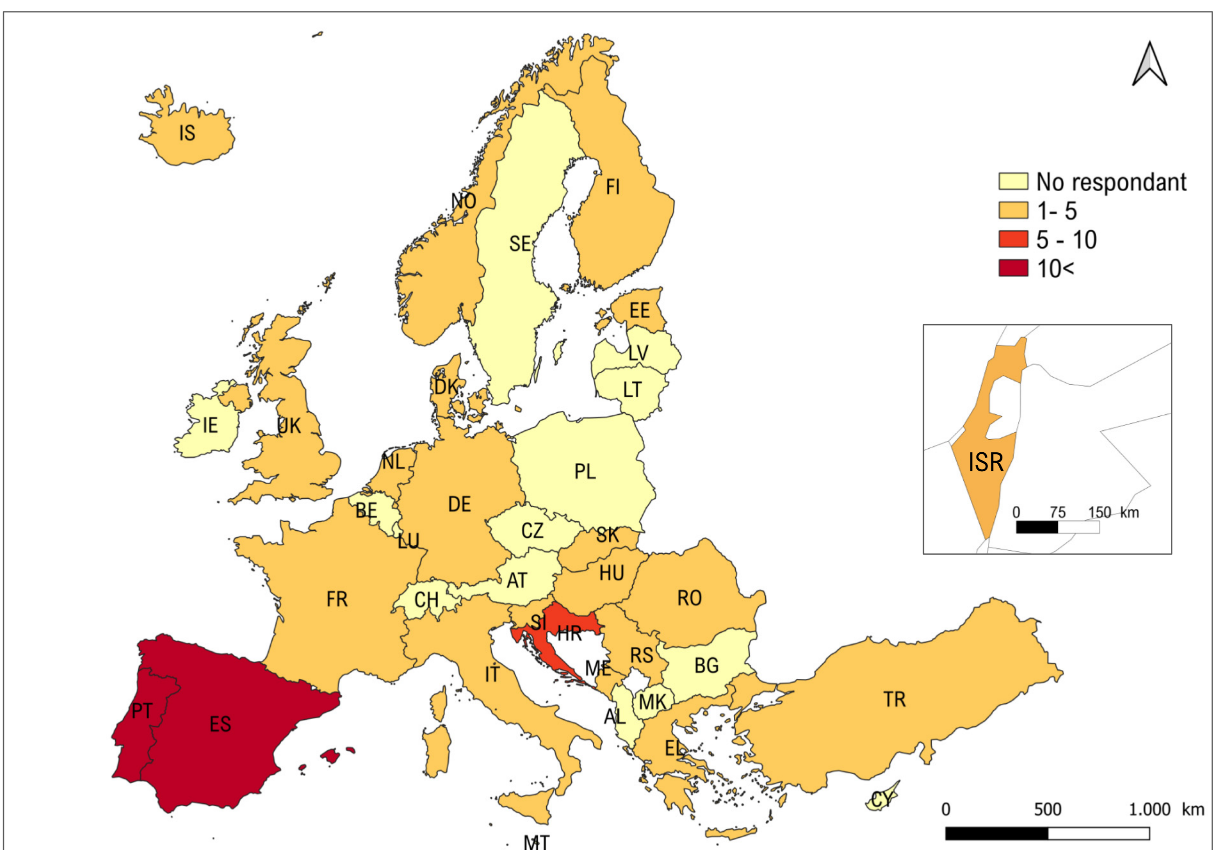

Fig. 1. Number of questionnaire responses received per country (two letter abbreviation of country names).

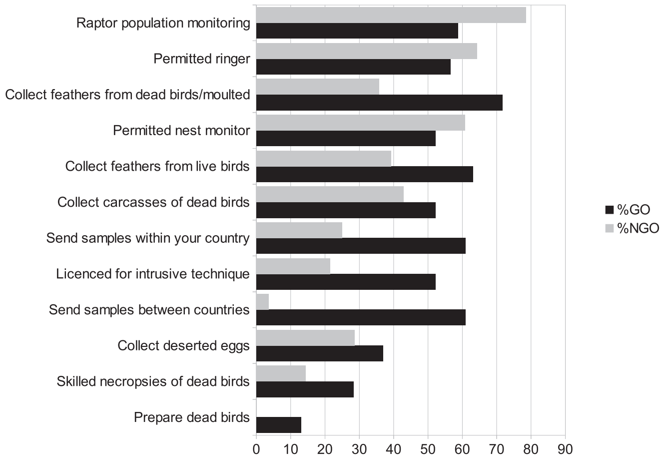

Fig. 2. Skills of respondents (n = 74) to the questionnaire according to actor type -governmental institutions (GOs) or non-governmental organizations (NGOs).

common among governmental actors. The capacity to carry out necropsies is the least common skill, held only by governmental respondents.

3.2.1. Classification of constraints by actor type

The questionnaire covered different kinds of actors likely to be involved in a sampling programme. There were in general significant differences in the scores given between actors carrying out their work with support of non-governmental versus governmental institutions (Wilcoxon rank sum test: W = 645,796; $P < 0.001$). Non-governmental field workers generally gave higher scores to the questions on constraints than governmental field workers (Fig. 3). Methodological, spatial, and skills constraints seem to represent stronger limitations for collecting samples and contextual data by field workers supported by non-governmental organizations. Despite experiencing more difficulties to obtain raptor samples, non-governmental institutions may provide valuable knowledge about complex contextual data, as more than 60% of species population monitoring schemes are run by non-governmental organizations and more than half of all species schemes rely on greater than 50% volunteer effort (Derlink et al., 2018).

3.2.2. Perceived relevance of each constraint type

We found a difference in the mean scores given by respondents to the four types of constraints (Kruskal-Wallis rank sum test: chi-squared = 13.77, df = 3, $P = 0.003$; Post-hoc Dunn test: legal-methodological: $P = 0.001$; legal-skills: $P = 0.008$; legal-spatial: $P < 0.001$; methodological-skills: $P = 0.19$; methodological-spatial: $P = 0.27$; skills-spatial: $P = 0.30$). Among the respondents to the questionnaire, the set of legal constraints was less relevant than the constraints related to methodological aspects, skills, or spatial coverage (Fig. 4).

The top ten constraints perceived to be the most important with median scores above 3 (Fig. 5) included all four types of constraints. The top three constraints were related to methodological limitations to obtain reliable data on local contamination, including general sources of contamination (e.g., pesticides used, hunting practices) and more specific examples as biocides and non-steroidal anti-inflammatory drugs (NSAIDs). The respondents also highlighted other methodological constraints, such as the shipping cost or the inadequate transportation of samples. Also, in the top 10 were spatial coverage constraints relating to the low number of existing monitoring schemes and ecological studies and the low number of institutions involved in contaminant biomonitoring. The legal constraint with the highest score was the collection of invasive samples (e.g., blood from nestlings or adults). The lack of skills to do a necropsy was identified in the top 10, as an important constraint to obtain raptor samples. The abundance of raptors seemed to be the least relevant constraint (median = 2 for all species, see Fig. S1 in Supplementary Material ESM1).

3.3. How can we solve the constraints related to biomonitoring with raptors?

Once the constraints were identified (Table 1), a list of potential feasible solutions was discussed among experts. The potential solutions were classified into five topics of action: (1) best practice; (2) capacity building; (3) coordination; (4) selection of focal species and contaminants; and (5) projects and funding.

3.3.1. Disseminating best practice

23% of the constraints identified may be solved by a consolidation of best practices for field sampling across Europe. To achieve this, it is necessary to provide and disseminate protocols to harmonize sampling methods, thus improving the potential for pan-European comparison of results. Preferably, all materials (e.g., protocols, related audio-visual materials) to provide guidance on collecting raptor samples and contextual data should be provided or indicated in an "advice hub" – i.e., an online platform where new guidance to fill gaps, and links to existing good practice guidance could be provided to a broad public. Some examples of best practice guidance required include: (1) identifying the most adequate sampling material, (2) defining the minimum/optimum sample

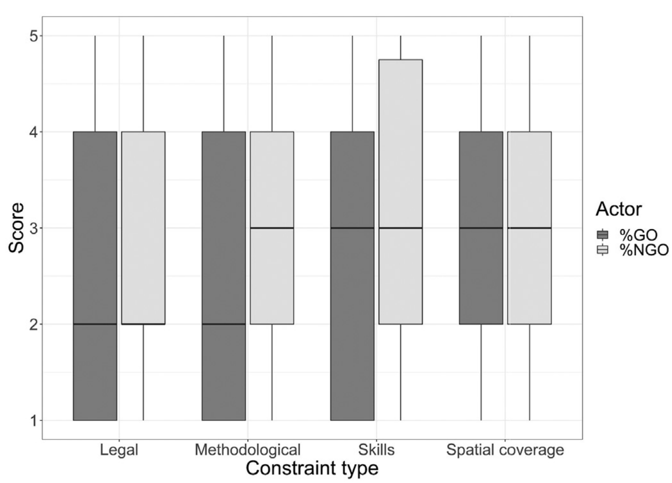

Fig. 3. Difference in scoring of the four types of constraints (legal, methodological, skills, and spatial coverage) according to actor type: field workers with support from governmental or non-governmental organizations. Boxplots showing median, quartiles and range.

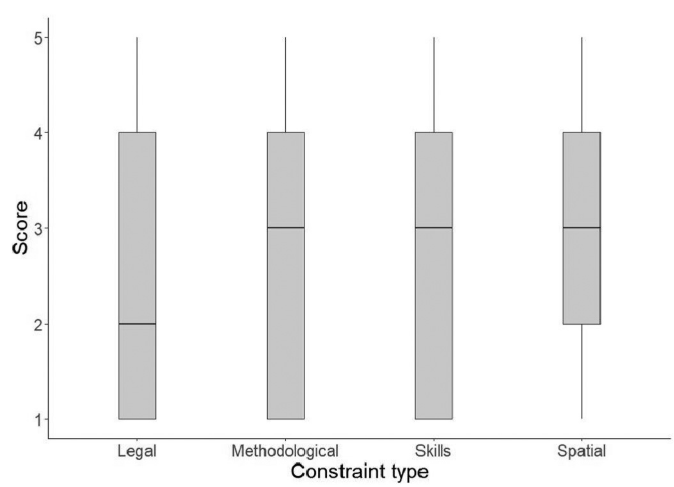

Fig. 4. Classification of the different types of constraints by respondents to the survey (median and 95% confidence intervals; scores range from 1 (low) to 5 (high) relevance of constraint). Boxplots showing median, quartiles and range.

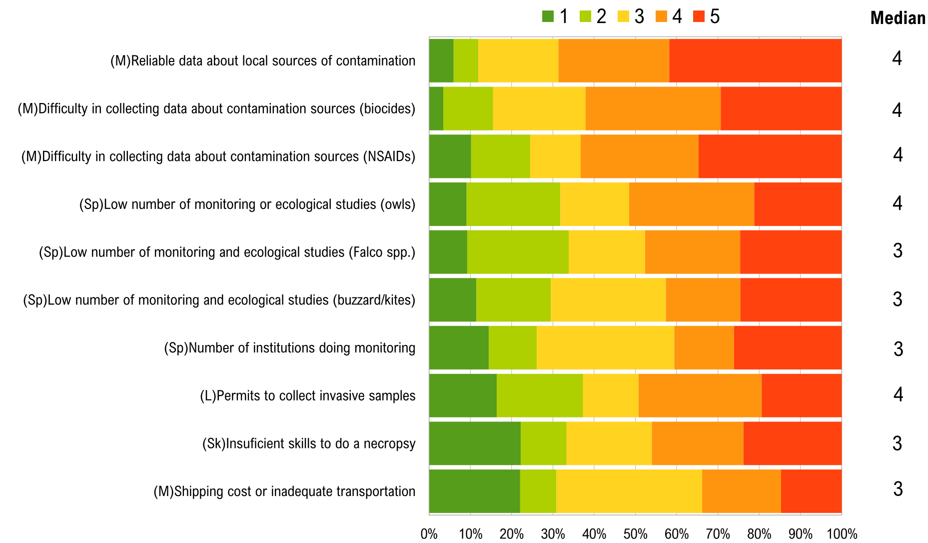

Fig. 5. Scoring of the top ten questions regarding constraints to the sampling of raptors. Scores indicating the importance of constraints from 1 (low importance) to 5 (high importance). Letters in brackets preceding the constraint indicate its type: (L) Legal; (M) Methodological, (Sk) Skills; (Sp) Spatial coverage. Complete figure of questions about constraints detailed in Fig. S1 in Supplementary Material ESM1.

size for analysis, (3) specifying the required short-term storage conditions, and (4) defining comparable methods to collect contextual data (e.g., breeding parameters, diet; see Table S1 in Supplementary Material ESM1). Important steps towards providing this guidance have already been taken (e.g., Hardey et al., 2013; Espín et al., 2014, 2016, 2021; Valverde et al., 2020; see also https://www.sertoxmur.com/?page_id=5322), but there is a need for existing protocols and training audio-visual material to be more widely distributed, made more readily available (e.g., by translation into national languages; being available in stable and permanent online webpages), and established as reference guidelines to sample raptors for monitoring pollutants. In addition, there is a need for a European Raptor Specimen Database that captures relevant data on available (frozen) specimens, and to link this to a raptor tissue sample database (for tissues samples destined for contaminant analysis) and databases of contaminant data arising from these tissues. The attachment of a unique identifier to each specimen and to tissues arising from each specimen will permit association of contextual field data with contaminant data and therefore enable more informed interpretation of contaminant data. Separate work is ongoing under ERBFacility on the design of a raptor specimen database (Vlachopoulos et al., Unpublished results), aligned with the Distributed System of Scientific Collections DiSSCo (www.dissco.eu). These databases and guidance must be maintained and updated in order to promote their use as relevant sources for future needs.

3.3.2. Promote capacity building and training

Another set of solutions involve increasing the availability of training activities across countries, as this would help to solve 39% of methodological, legal and skills constraints. These activities are necessary to allow people involved in collecting samples to obtain specific skills and knowledge. These new competences will often be complementary to people's skills, and include for example, how to record basic contextual data (e.g., identification of species, age, sex) and complex contextual data (e.g., diet, behaviour, reproductive performance, survival, population trend, geographic distribution range), and how to collect samples, with special focus on sampling from live birds and on performing adequate necropsies to obtain samples from carcasses. Access to specific training is usually essential to obtain relevant permits to sample raptors, such as permits to visit nests, handle birds, collecting invasive samples or to hold and store samples that are of a restricted nature. It is therefore highly recommended that regular training activities are provided across Europe prior to, and during, the implementation of a European Raptor Sampling Programme. These can be carried out at a national level and international level in "training camps" for people involved in collecting samples but also perhaps most usefully to train up trainers who can themselves go on to offer training more locally.

3.3.3. Improve coordination

To successfully implement a long-term biomonitoring European Raptor Sampling Programme, it is important to improve coordination between individual researchers and institutions in order to facilitate sample and data flux and storage, and thus increase the number of raptor samples available for analysis. As a solution to improve coordination within ERBFacility, we suggest establishing a role such as a national/regional coordinator should be established. These coordinators could play a pivotal role in the ERBFacility and facilitate in each country access to crucial information such as best practice guidelines, sampling protocols, guidance on legislation, and contact between relevant stakeholders. They could promote coordination between institutions and provide guidance on the flux of samples to the most adequate destinations: museums, collections, laboratories or ecotoxicology researchers. Depending on their logistic capability, coordinators could also help with storage of samples for short periods, assuming a centralizing and distributing role. Coordinators associated with environmental specimen banks and natural history museums might also be able to ensure the long-term storage of samples within their country or region (this issue of long-term storage is addressed more fully by related work under ERBFacility on development of a distributed European Raptor Specimen Bank). Coordinators could be very useful to help to solve several key constraints, centralizing questions and providing expertise and consistent solutions within their geographical area of operation (e.g., facilitating information on short-term storage and shipping of samples, advising on their country's legal framework for collecting samples) and could also be valuable in providing more local feedback on the results of the European Raptor Biomonitoring Scheme to fieldworkers, thus motivating participants in the longer term. Finally, coordinators could also centralize and facilitate information that may be difficult to access, such as potential sources of contamination, and practical information such as where to get the specific materials needed to collect samples.

3.3.4. Selection of the most suitable focal species and contaminants (prioritization)

To solve constraints relating to spatial coverage, it will be important to select focal species that can maximise the representativeness of different countries and regions (Badry et al., 2020). The most suitable focal species will vary depending on the chemicals targeted by the Monitoring Scheme. A suitable set of focal species should also minimize potential spatial gaps in data resulting from: incomplete coverage by the Sampling Programme; raptors with uneven distributions; and difficulties in accessing breeding areas. Whether it is possible to obtain an adequate amount of the matrix (e.g., blood, liver) from the focal species should also be considered, and, if not, larger species will need to be selected or samples pooled for analysis. The choice of focal species should take into account spatial representativeness but also the susceptibility of the species (high probability of exposure) to the focal chemical; species and population traits, such as distribution, diet composition and food web, foraging behaviour and habitats, and migratory movements, i.e., migratory versus resident need consideration here (Lourenço et al., 2011; Badry et al., 2019, 2020). Badry et al. (2020) indicated that common buzzard and tawny owl (*Strix aluco*) are suitable species for a European Raptor Biomonitoring Scheme for many contaminants, because of their wide distribution and abundance. Although other species may be regionally better suited for particular chemical threats, such as the golden eagle (*Aquila chrysaetos*) for lead, the northern goshawk for mercury across areas including Northern Europe, or vultures for non-steroidal anti-inflammatory drugs (NSAIDs).

3.3.5. Increase the number of monitoring actions (projects and funding)

Finally, there will be a need to implement measures that contribute to an increase in the number of raptor monitoring projects that can work as national or regional support to a European Raptor Sampling Programme. This can be achieved by a coordinated support from national or regional funds, but also by promoting international consortia supported by EU funds. Indirectly, a greater number of contaminant and raptor monitoring projects would also contribute to increase spatial coverage and to reduce skills constraints as well as improve pan-European accessibility of raptor samples. Some countries have good examples of long-term monitoring schemes (e.g., Berny et al., 2015; Vrezec et al., 2012; Walker et al., 2008) that bring valuable experience to bear on development of the European Raptor Biomonitoring Facility.

Questionnaire respondents were asked to identify the most important solutions to the constraints for sampling raptors. The most frequently highlighted solution by the questionnaire respondents was increasing the overall number of monitoring schemes and projects (30%) (Fig. 6). Best practice guidance, including the dissemination of protocols to collect and process samples, were also highly scored solutions (27%). In contrast, capacity building activities related to training in ringing and handling live birds (9%) were the solutions least prioritised by respondents.

3.4. Limitations of the study

The approaches used to identify constraints and solutions present some limitations. The number of respondents from each country was not balanced, and in some cases, we only had one respondent from a country, which limits the comparison of constraints between countries. Also, the number of respondents working on research in universities was higher than for other relevant professional occupations and the results of the questionnaire could have a slight bias towards the situation of researchers working in southern European countries, who were the most frequently represented group in the study. We made an effort to compensate for this bias by including the specific experience of workshop participants and the manuscript co-authors, which covered some of the least represented countries in the questionnaire.

4. Conclusions

Our participatory approach, combining the opinion of experts and participants involved in collecting raptor samples and contextual data, has provided important information on the constraints associated with implementing a European Raptor Sampling Programme in support of a European Raptor Biomonitoring Scheme, both key elements of a European Raptor Biomonitoring Facility. The approach presented here might be applied elsewhere prior to the development of long-term biomonitoring schemes so that constraints can be anticipated and mitigated with effective solutions. Our approach provides information on the actors that can potentially be involved in sampling programmes and about their current capacity to provide raptor samples. Among the constraints to collecting raptor samples and contextual data, legal constraints appear of less importance to respondents than methodological, skills, and spatial coverage constraints. This is somewhat reassuring, as legal constraints, if they exist, could be more difficult to resolve than those in the other constraint categories. Most constraints highlighted refer to methodological aspects of collecting samples and contextual data. The lack of protocols to collect invasive samples in a harmonized way has been identified as one of the most important constraints to be solved. Disseminating existing protocols could be an effective way to harmonize methodological procedures to obtain raptor samples for contaminant monitoring from

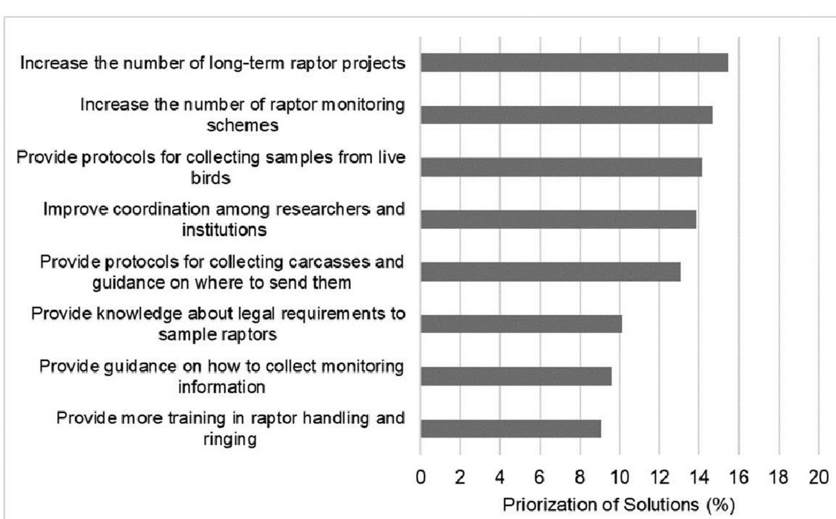

Fig. 6. Frequency of the most prevalent solutions to constraints for sampling raptors, as identified by questionnaire respondents.

across Europe. However, national adaptation of international protocols may face additional legal and linguistic barriers. Increasing the number of raptor contaminant monitoring schemes that can contribute to create the necessary network of people and institutions at national and regional level that may ensure the long-term collection of both samples and complex contextual data will demand funding and effective sharing of knowledge from existing schemes. Our approach suggests that establishing a long-term European Raptor Sampling Programme as a key element of a European Raptor Biomonitoring Facility is feasible considering that all the constraints that we identified may be solved by reasonable solutions.

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CRediT authorship contribution statement

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Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

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