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ORIGINAL PAPER

Habitat monitoring in Europe: a description of current practices

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Abstract Monitoring of biodiversity at the level of habitats is becoming increasingly common. Here we describe current practices in habitat monitoring based on 150 schemes in Europe. Most schemes were initiated after 1990 in response to EU nature directives or habitat management/restoration actions, with funding mostly from European or national sources. Schemes usually monitor both the spatial distribution and the quality of the habitats, and they frequently collect data on environmental parameters and potential causes

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of changes. Many schemes are local or regional rather than national or international in scope, and sampling effort varies greatly across spatial and temporal scales. Experimental design is used in half of the schemes, however, data are rarely analysed by advanced statistics. Most schemes require two months or less per year in manpower and are typically run by professionals rather than by volunteers. Estimated salaries plus equipment costs average 650,000 Euro per year per scheme, and add up to 80 million Euros annually. Costs are particularly high for schemes based on European or international law and for schemes funded by European or national sources. Costs are also high in schemes in which sampling sites are selected subjectively rather than based on sampling theory, and in schemes that do not use field mapping or remote sensing to document spatial variation in habitats. Our survey demonstrates promising developments in European habitat monitoring but also underlines the need for better spatial coverage, documentation of spatial variaton, improved sampling design and advanced data analysis. Such improvements are essential if we are to judge progress towards the 2010 biodiversity targets.

Keywords 2010 target · Biodiversity research · Ecosystem monitoring · Habitats Directive · Nature conservation

Introduction

A primary cause of the currently ongoing biodiversity crisis is the destruction, deterioration and fragmentation of habitats (Groom et al. 2006). As a result, an increasing number of studies and monitoring programmes are focusing on changes in the quantity and quality of habitats at the global, regional, national and landscape levels. Habitat monitoring, defined here as the repeated recording of the condition of habitats, habitat types or ecosystems of interest to detect or measure deviations from a predetermined standard, target state or previous status (after Hellawell 1991), has several advantages over species or site-based monitoring. For example, habitat monitoring can cover large geographical areas. Therefore, it can be used to evaluate pressures and drivers of biodiversity change over large spatial and temporal scales, which may be difficult to reveal at smaller spatial scales (e.g. fragmentation in neotropical rainforests, Asner et al. 2005; Peres et al. 2006). Furthermore, according to the hierarchical theory of biodiversity (Noss 1990), monitoring at the level of habitats or ecosystems also provides information on the status of lower organisational levels of biodiversity, e.g. on typical or characteristic species. When the link between such species and habitat types is established, habitat monitoring can be used as a cost-effective substitute for simultaneous monitoring of several species (Nagendra 2001; Turner et al. 2003; Gottschalk et al. 2005).

Habitat monitoring often includes a strong spatial aspect. The spatial aspect is typically handled either by field mapping (and sampling) or by remote sensing. Field mapping, typically based on the mapping of habitat types, vegetation, or plant associations, is the traditional way of obtaining information on habitats. Remote sensing, a more recent, technologically sophisticated way to collect information on habitats is based on computer-aided interpretation and visualization of satellite imagery over larger areas (Turner et al. 2003). Aerial photography can aid both approaches, either as a basis for field-mapping or as a basis for ground-truthing of remotely sensed information at higher resolutions. The monitoring of some specific habitats (e.g. wetlands, bogs, fens, etc.) may be more biased towards monitoring the changes in the quality, as opposed to the distribution (range, area etc.) of the habitat types. Long-term monitoring programmes using permanent plots to study vegetation dynamics (Bakker et al. 1996), for example, are usually more interested in changes in habitat quality than quantity. These monitoring programmes thus may lack a strong spatial aspect.

Habitat monitoring is developing at a fast rate. Both between and within the two basic approaches (field mapping, remote sensing), new methods are being developed and incorporated in habitat monitoring within short times. Field mapping, for example, is revolutionised by application of object-oriented methods or wireless sensor systems (e.g. Polastre et al. 2004; Bock et al. 2005). Recent technological advances in remote sensing and spatial informatics have resulted in widespread production and use of spatial information on biodiversity (Duro et al. 2007; Papastergiadou et al. 2007). Despite the growing interest in habitat monitoring, to our knowledge, neither the past nor the current practices of habitat monitoring have been reviewed in Europe or elsewhere.

In this paper, we overview the current practices of habitat monitoring in Europe. We do so by using metadata on habitat monitoring schemes collected within the project 'EuMon', a policy-oriented STREP project financed by the European Commission under the 6th Framework Programme (http://eumon.ckff.si). We identify those properties of monitoring schemes that can be recommended for future practices. We also identify gaps, lack of knowledge or shortcomings in methodology in current practices, where improvements are expected. This paper is accompanied by two additional papers related to habitat monitoring. A literature review of approaches and major methods as well as a framework for the integration of habitat monitoring is given in Lengyel et al. (2008), whereas the scientific quality of habitat monitoring schemes based on sampling design, precision and cost-effectiveness is evaluated in Lengyel et al. (in review).

Methods

We use the term 'habitat' in a wide sense when generally referring to the physical, chemical and biological components of a defined geographical area. In this conceptualization, the term 'habitat monitoring' covers monitoring programs that are referred to as 'ecosystem monitoring' in some studies (Pereira and Cooper 2006). The term 'habitat type' is reserved for specific kinds of habitats that have been described as separate from other such entities in international or national habitat classification systems (e.g. Annex I of the 'Habitats' Directive: Council of the European Communities 1992; CORINE: Devillers et al. 1991; EUNIS: http://eunis.eea.europa.eu). Examples of habitat types are "*Fagus* woodlands" (EUNIS code G1.6) and "Pannonic loess steppic grasslands" (E1.2C).

We collected metadata on habitat monitoring schemes in Europe in 2005 and 2006. We have developed a questionnaire containing eight questions on basic features and 35 questions on specific properties of the schemes. The questionnaire is available as an online data entry interface at the EuMon website at http://eumon.ckff.si/monitoring. Between February 1 and August 31, 2006, we asked coordinators of monitoring schemes, ministry officials and representatives of other stakeholder groups involved in monitoring in all European countries to fill out the questionnaire. We sent emails or letters to over 1,600 individuals and to several national or international mailing lists. All information on monitoring were entered by the coordinators of the monitoring schemes online. The information entered were organised into the EuMon database.

We used all information as they were given by the coordinators. To estimate the salary costs of manpower necessary to run the schemes, we used information on the number of professional and volunteer participants and on average salary per country (World Bank

2006). We multiplied the average salary per country by the total number of person-days for professionals, but not for volunteers as given by the coordinators. We estimated total costs by adding the salary estimates and the material/equipment costs given by the coordinators. In cases when person-days were not given ($n = 28$), only the material/equipment costs were used.

As of August 31, 2007, the EuMon database had information on 150 habitat monitoring schemes. Sample sizes may differ in different comparisons because complete information was not available for all schemes. Because most variables used were not normally distributed and/or had unequal variances, we used non-parametric statistics in all analyses of data. Statistical analyses mostly involved χ^2-tests evaluating differences in proportions, which were calculated for biologically meaningful comparisons and when reasonable expected frequencies could be predicted based on available data. We also used Kruskal–Wallis non-parametric ANOVAs to test differences among groups. Means ± SDs and two-tailed probabilities are reported in the text.

Results

Starting year, motivation and funding

Most habitat monitoring schemes have been started relatively recently. For example, 93% of the schemes have been initiated after 1990 (Fig. 1). The number of schemes in the most recent (2005-) time period is low because data were collected in 2005 and 2006 only. Because most (71%) of the schemes have been operating for less than 10 years (1997-), we did not evaluate changes in monitoring practices with time.

The most frequent reason for the launching of habitat monitoring ($n = 148$ schemes) was given by coordinators as the European nature directives (41.2%), followed by habitat management or restoration activities (31.1%) and scientific interest (13.5%). Only a few schemes were launched based on national law (6.8%), other international obligation (4.7%), or for other reasons (2.7%). Reasons arising from EU directives and restoration/management were significantly more frequent than other reasons ($\chi^2_5 = 106.880$, $P < 0.001$).

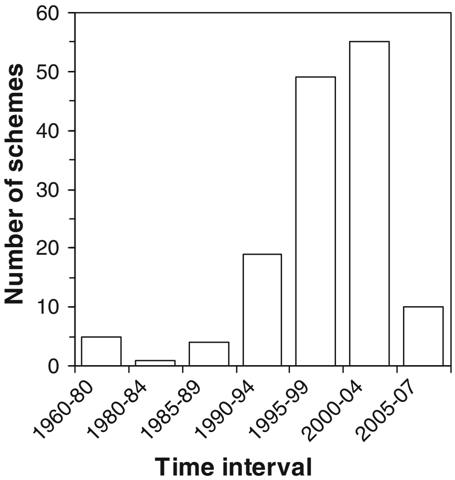

Fig. 1 Number of habitat monitoring schemes started in different time periods between 1960 and 2007 ($n = 143$ schemes)

The main funding sources (available for 130 schemes) were the European Union (48.5%) and national governments (35.4%). Regional sources funded 7.7% of the schemes, whereas private, scientific or other sources were rare (3.9, 3.1, 1.5%, respectively). These differences were significant ($\chi^2_5 = 157.538$, $P < 0.001$), indicating the importance of funding from European and national sources compared to other sources.

Geographical scope and representation of countries, protected areas and habitat types

Despite the majority of projects being launched and funded by European regulations and programmes, only one (or 0.7%) of the schemes was conducted at the geographical scope of Europe and only four schemes (or 2.7%) were international in scope. Most schemes were local (55.4%), regional (23.6%) and national (17.6%) in scope. More than 16 schemes were reported from Spain, Greece, the UK and Poland, between 6 and 13 schemes were described from France, Hungary and Germany, whereas other countries were represented by three or fewer schemes (Table 1).

A high proportion (61.3%) of the schemes ($n = 137$) were conducted entirely within protected areas and 33.6% were conducted partly in protected areas. Only 5.1% of the schemes were run in non-protected areas. Considering that the proportion of protected areas per country area ranges between 1.1% and 31.3% in Europe (UNEP-WCMC 2004), we concluded that habitat monitoring is primarily conducted in protected areas. The number of habitat types monitored ranged from 1 to 116, with 44% of the schemes monitoring only one habitat type. Based on 156 EUNIS habitat types marked by coordinators in 142 schemes, the most frequent targets of monitoring were forests (28%), marine habitats (16%), grasslands (14%) and coastal habitats (13%). Rivers and wetlands (8%), bogs and fens (8%) and heaths and scrubs (7%) were less frequently monitored, and caves, arable lands and complex habitats were marked in less than 5% of the schemes (Lengyel et al. 2008).

Sampling methodology and sampling effort

A relatively high proportion (52.4%) of the schemes were reported to use an experimental design. This proportion was especially high in schemes monitoring the impacts of habitat restoration or management (29 of 45 schemes).

Table 1 Number of habitat monitoring schemes by countries in the EuMon database (as of 31 August, 2007)

Country	No. of schemes	Proportion (%) of total
Spain	33	22.0
Greece	28	18.7
United Kingdom	22	14.7
Poland	17	11.3
France	12	8.0
Hungary	10	6.7
Germany	7	4.7
Cyprus	3	2.0
Estonia, Norway, Switzerland (two each)	6	4.0
Belgium, Czech Republic, Ireland, Italy, Malta, Netherlands, Slovenia, Turkey (one each)	8	5.4
Other international	3	2.0
Pan-European	1	0.7
Total	150	100.0

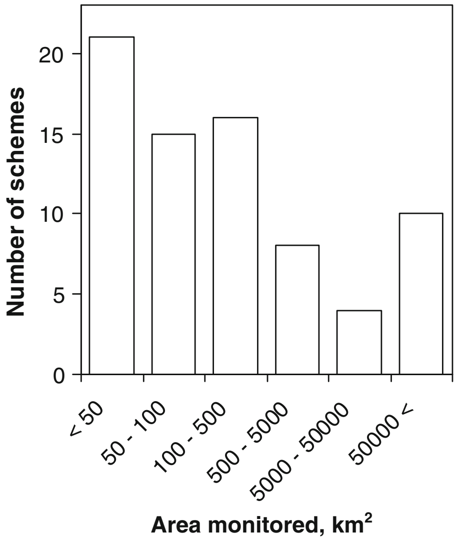

Fig. 2 The distribution of habitat monitoring schemes according to the area monitored (*n* = 74 schemes)

Most (69.0%) of the schemes (*n* = 142) collected data on both the species composition and the distribution (range, area) of habitat types, whereas only species composition was monitored in 21.8% and only distribution was monitored in 9.2% of the schemes. Similarly, most schemes (72.4%, *n* = 134) collected data on both the presence/absence and abundance of species used in habitat monitoring, whereas 21.6% monitored the abundance of the species of interest and 6% monitored presence–absence only.

The area monitored (to which results can be extrapolated) by schemes averaged 26.6 km^2, and showed large variability (SD 93.12, range 1–550,000 km^2, Fig. 2). Spatial variation in habitats was documented in only 45% of the schemes (*n* = 149), with 30% of the schemes using field mapping and only 15% of the schemes using remote sensing. No spatial method was marked for 55% of the schemes. Sampling was conducted at an average of 56.1 ± 93.46 sites (range 1–566, *n* = 62 schemes) and the number of samples collected was on average 38.7 ± 116.41 (range 1–900, *n* = 73).

Monitoring in most schemes was implemented every year (43 of 77 schemes), but there were also many (25 of 77) schemes that were run once every 5 years or less frequently. Sampling visits took place usually once (25 of 53 schemes), twice (10) or three times (8) a year, and visits more frequent than three per year were rare (10).

Data processing and information obtained

Despite the frequent use of an experimental approach, only 14.3% of the schemes (*n* = 140) applied advanced statistics (general linear, additive or mixed models, time series, etc.) and 3.6% used linear regression to analyse the data collected, whereas 17.9% used graphics and descriptive statistics. "Other statistical methods" were marked for 50.0% of the schemes. Data were not analysed in 11.4% of the schemes or were analysed by someone else in 2.9% of the schemes.

Many schemes were declared capable of obtaining additional information on the habitat types monitored, such as data on environmental parameters, habitat quality and causes for the changes observed. Environmental parameters were measured in half (49.7%) of the schemes ($n = 149$) and habitat quality criteria were monitored in 91.2% of the schemes. The most often (27.9%) monitored habitat quality criterion (based on $n = 315$ multiple choice data entries) was the composition of species, followed closely by indicator/keystone/umbrella/typical species (marked for 24.4% of the schemes). Structural changes in the habitats (18.1%), changes in the physical-chemical environment (15.2%) and fragmentation (14.3%) were also frequently marked as the monitored criterion for habitat quality.

A high proportion (85.6%) of the schemes were also declared to make inferences on the causes of the habitat-level changes observed. The most frequently monitored potential cause was "land use" (Table 2), which also included active habitat management in 12 schemes. In the latter group, livestock grazing was the most frequent management type monitored (seven occurrences), followed by water management and arable land farming (four each) and fire management (1).

Time requirements of habitat monitoring

The time requirements of monitoring showed high variation among the schemes (Table 3). The large variation in person-days for sampling was because it required 40 days or less per year in 94.8% of the schemes, but in three schemes, sampling was carried out using 110, 1,000 and 2,000 person-days per year, respectively. Similarly, the total time requirement per year was 1,500 person-days or less for all but two of 53 schemes, which two schemes required 8,800 and 10,000 person-days, respectively. Generally, sampling involved only ca. 11% of the total time necessary to run the schemes in a year (58.2 out of 527.7 person-days), likely indicating that habitat monitoring involves substantial data processing and analysis. Another striking feature of habitat monitoring is that only 33.3% of the schemes ($n = 63$) involved volunteer participants and most monitoring work is conducted by professionals (ca. 85% of total number of persons conducting monitoring were professionals, Table 3). This may be related to the fact that habitat monitoring often requires special

Table 2 Frequency of causes that can be inferred from the data obtained in habitat monitoring according to the scheme coordinators

Rank	Cause of change	Number of mentions	Percentage
1	Land use	121	34.6
2	Fragmentation	65	18.6
3	Pollution	55	15.7
4–5	Invasive species	33	9.4
4–5	Habitat succession	33	9.4
6	Catastrophic event	27	7.7
7	Climate change	16	4.6
	Total	350	

Table 3 Number of persons participating and time requirements in habitat monitoring schemes entered in the EuMon database

Variable	Mean ± SD	Min-Max	*N*
Number of professionals	24.9 ± 82.16	0–600	63
Number of amateurs	4.3 ± 19.51	0–150	63
Total number of persons	29.3 ± 88.32	1–640	63
Person-days for sampling	58.2 ± 290.81	0.1–2000	58
Total number of person-days	527.7 ± 1802.17	1–10000	53

skills. For instance, 80.5% of the schemes ($n = 149$) required training or expert knowledge from the participants.

Costs of habitat monitoring

The average estimated cost of running the schemes in the EuMon database is 653,842 Euro per year (SD: 970,188 Euro, range: 0–5.955,396 Euro, $n = 122$ schemes). A minimum estimate of the total cost for all schemes in the database is close to 80 million Euro per year (79.768,744 Euro total, $n = 122$ schemes). This number includes schemes for which both salary costs could be estimated and material/equipment costs were given ($n = 53$), and for which only the costs of materials/equiment were given ($n = 69$). Costs could not be assessed in 28 monitoring schemes due to lack of information.

Total estimated costs (salaries plus material/equipment) were highest in schemes launched in response to obligations from EU directives or other international law and those launched to monitor habitat management and restoration activities (Fig. 3A, Kruskal–Wallis $H = 21.843$, df = 5, $P = 0.001$). As a possible consequence, schemes funded from European or national sources had higher total costs than schemes funded from other sources (Fig. 3B, Kruskal–Wallis $H = 48.965$, df = 4, $P < 0.001$).

Interestingly, the methodological refinements were directly related to the costs of monitoring. Schemes in which sampling sites were selected based on scientifically sound criteria (exhaustive, systematic or random sampling) had considerably lower costs than schemes that did not use such criteria (Fig. 4A, Kruskal–Wallis $H = 14.899$, df = 4, $P = 0.005$). Furthermore, schemes in which the spatial variation in habitats was not considered had much higher costs than schemes in which spatial variation is documented by either field mapping or remote sensing (Fig. 4B, Kruskal–Wallis $H = 46.057$, df = 2, $P < 0.001$).

There were no differences in total costs among monitoring schemes by geographical scope, use of an experimental design or type of data collected (Kruskal–Wallis tests, n.s.). Finally, there were no correlations between total costs and single variables of either sampling effort (number of sites, number of samples, annual frequency, number of visits per year) or areal extent (area monitored, number of habitat types monitored; Spearman rank correlations with significance levels adjusted for multiple comparisons, n.s.).

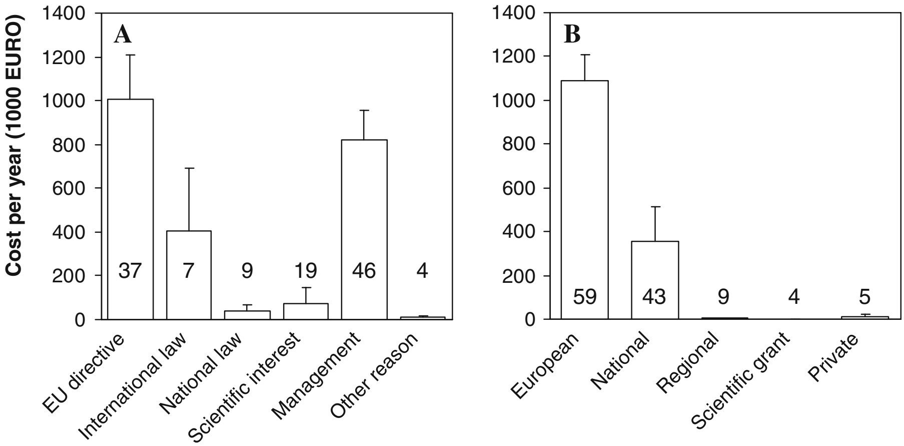

Fig. 3 Total estimated costs (mean ± SE) of running habitat monitoring schemes according to (**A**) reason for launching the scheme and (**B**) main source of funding. Sample sizes are given at the base or above bars

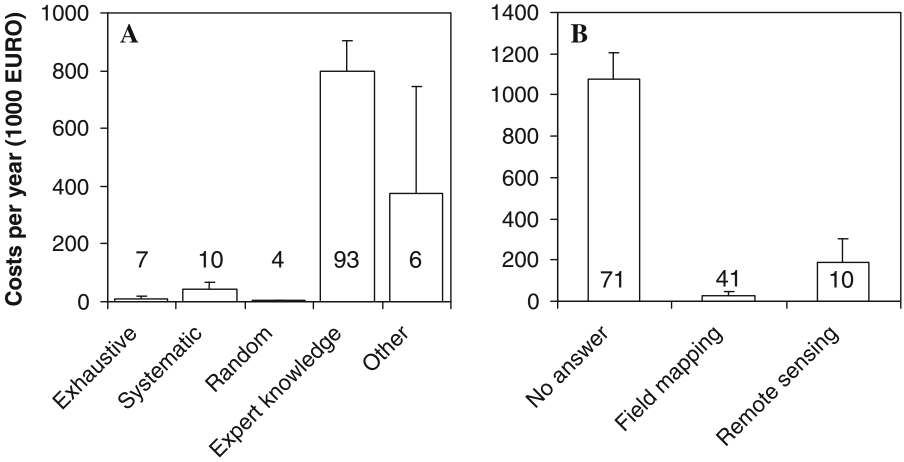

Fig. 4 Total estimated costs (mean ± SE) of running habitat monitoring schemes according to (**A**) method of selection of sampling sites and (**B**) method of documenting spatial variation in the habitats. Sample sizes are given at the base or above bars

Discussion

Our study suggests that European nature directives play an important motivating role in the initiation of habitat monitoring schemes in Europe. Most of the currently ongoing schemes have been started after the Habitats Directive was adopted by the European Commission in 1992 (Fig. 1). Furthermore, European sources are also important in funding habitat monitoring in Europe and national governments finance only one-third of the schemes. Most habitat monitoring is conducted in protected areas, which is a reasonable pattern as these host the intact, restored or managed habitats. The monitoring of such habitats are important from European perspectives (e.g. habitat types listed in Annex I of the Habitats Directive) or from management/restoration perspectives.

There are several promising developments in the current practices of habitat monitoring. For example, most schemes monitor both the distribution (range, area) and species composition (quality) of the habitats. Most schemes also collect data on species abundance beyond the simple presence/absence of species, a common practice in suboptimal monitoring according to Legg and Nagy (2006). Half of the schemes monitored species composition or indicator/keystone/umbrella species, indicating that community changes due to invasive species or extinction of native species are thoroughly monitored. Furthermore, many schemes measure background variables, such as environmental parameters and habitat quality, and many schemes are reportedly able to make inferences about the causes of the changes observed. Finally, many schemes use an experimental design, which offers the opportunity to compare the changes observed to some control or reference status of the habitats involved.

Our survey also identifies weaknesses in current practices. In more than half of the schemes, it is not clear whether and how data collected from monitoring are analysed, i.e., turned into information useful for stakeholders and politicians. Our results suggest that advanced statistics may be used infrequently because in most schemes sampling sites are selected based on expert/personal knowledge rather than on pre-defined criteria derived from sampling theory. Furthermore, in more than half of the schemes, spatial variation in the habitats is either not monitored or monitored by unspecified methods. Field mapping and remote sensing are the primary accepted methods of quantifying spatial variation (Forman 1995; Turner et al. 2003). Especially low (15%) was the database representation of schemes that used remote-sensing as their main data collection method. One potential explanation for the ignorance of spatial variation is that most schemes are either local or regional in scope, operate at small spatial scales (Lengyel et al. 2008) and monitor only a few habitat types. The high incidence of no responses regarding the spatial aspect, however, may also indicate that coordinators could not decide on or did not think it important to report their spatial method. Such tendencies would be unfortunate as a spatial aspect of monitoring is necessary to detect changes in the range, area or fragmentation of habitat types. Finally, although an experimental design was used in 52% of the schemes, the ability to infer the causes of changes was reported in 86% of the schemes. According to basic scientific and ecological theory, causation can be inferred from experiments (Platt 1964; Popper 1968; Underwood 1997). Therefore, it needs further study to explore how such inferences can be made from data collected in schemes not using an experimental design.

The large variation among habitat monitoring schemes regarding their time requirements can be explained that a few schemes are particularly labour-intensive, whereas most schemes require reasonable time periods, e.g. 40 or fewer person-days per year. Contrary to species monitoring schemes (Schmeller et al. in review), habitat monitoring schemes involve greater number of professionals than volunteers. Volunteers are involved in a relatively smaller fraction of the schemes (33%) and work in a low proportion (15%) of the total number person-days. This may be because habitat monitoring often (81%) requires special skills from participants. Special skills necessary in habitat monitoring may range from field mapping (e.g. vegetation mapping, GPS use), through the identification of individuals of poorly known taxa (e.g. non-flowering plants, insects, etc.), to the interpretation of remotely sensed information using advanced techniques.

The annual costs of running the monitoring schemes were relatively high. However, it has to be noted that several schemes are run over large geographical areas, with the participation of up to 600 professionals, sometimes with considerable costs for salaries and in other cases (e.g. remote sensing schemes) with considerable material/equipment costs (e.g. permanent sampling plots, field surveys, travel costs, etc. for field-based schemes, and satellite imagery data service, computing power, etc. for remote sensing-based schemes).

Schemes launched from European or other international requirements and funded from European or national sources appeared more costly than others. Total costs also differed by two important aspects of methodology. Schemes in which spatial variation is not documented or which use expert knowledge to select sampling sites cost considerably more than schemes documenting spatial variation or which use scientifically sound criteria for site selection. These patterns suggest that the introduction of measures that greatly increase the quality and quantity of information that can be obtained in ongoing schemes will probably not lead to significant increases in total costs. Therefore, quantifying spatial variation and selecting sites based on sound criteria appear as highly cost-effective ways to improve current practices in habitat monitoring.

Surprisingly, total costs were not related to either the spatial or the temporal aspect of sampling effort. The lack of such relationship can be explained if the costs are correlated with effort variable(s) that went unmeasured in this project. Alternatively, it appears plausible that some combination of sampling effort variables is related to total costs. Furthermore, different costs (salaries, material/equipment) can be related to sampling effort variables in different ways. In a related study (Lengyel et al. in review), we have estimated precision from variables describing sampling effort and quantified cost-effectiveness as either precision or quality of sampling design divided by total costs. The results showed that precision was highest in schemes funded by European and private sources, whereas cost-effectiveness was higher in schemes funded by scientific grants and regional sources. Cost-effectiveness was also higher for schemes using field mapping rather than remote sensing, in schemes monitoring all rather than only some habitats in a focal area and in schemes where sampling sites are chosen based on scientifically sound criteria rather than on expert knowledge (Lengyel et al. in review).

We acknowledge that our results and conclusions depend on the completeness and comprehensiveness of the EuMon database. Based on previous catalogues of monitoring programmes, we estimate that ca. 30–40 ongoing monitoring schemes are missing from the database used here (Lengyel et al. in review). Most of the missing schemes are global, pan-European or international in scope, and many of them are site-based (e.g. International Long-Term Ecological Research sites). Therefore, our results are most relevant for monitoring at the national and sub-national scales but enable us to draw some general conclusions on the practice of habitat monitoring in Europe. We are also aware of the limitations of studies based on questionnaires (White et al. 2005), therefore, we attempted to avoid overly bold statements regarding the importance of our results.

Country coverage may also influence our results. For example, some countries, e.g. Greece and Spain are probably overrepresented (Table 1), whereas some countries, e.g. Italy, are underrepresented in our survey. Some countries are simply not present in the database (e.g. Austria, Finland, Portugal) and some schemes (e.g. several marine monitoring programmes, the GLORIA project of monitoring alpine habitats, etc.) are also known to be missing. Even though we attempted to cover each European country by sending out questionnaires to numerous potential respondents, the return rate of replies showed high variation among countries, which may affect our results. Our experience, however, suggests that we generally had more responses from countries where habitat monitoring is well established (for an overview, please see Lengyel et al. 2008). Furthermore, an analysis of a potential country bias found no significant correlations between the number of schemes per country and country area, population size, population density, GDP and percentage of country area protected by national laws (Lengyel et al. in review). These patterns suggested that country bias had little influence on our results.

What will the future bring in habitat monitoring? There have been several concerns over the current practices in biodiversity monitoring due to lack of a general, hypothesis-testing framework (Yoccoz et al. 2001; Balmford et al. 2003), and inadequacy of sampling design and effort (Di Stefano 2001), which result in a poor ability of monitoring programmes to detect trends (Legg and Nagy 2006). Our overview provides evidence for some of these concerns but also highlights areas for future development (see also Lengyel et al. in review). For example, the decreasing costs of obtaining and processing spatial data (satellite imagery, remotely sensed information, aerial photography) will likely lead to the increasing use of such information. With intensive ongoing research in the area of biodiversity indicators (e.g. Gregory et al. 2005; Heer et al. 2005; Mace et al. 2005; Scholes and Biggs 2005; Pereira and Cooper 2006), monitoring will likely become more standardised as better indicators of biodiversity become available. To reliably assess changes in biodiversity over large spatial and temporal scales, the integration of data or monitoring activities will become a necessity (Henry et al. this issue; Lengyel et al. 2008). Finally, the reporting requirements of member states of the European Union on the status of Natura 2000 species and habitats will lead to a further interest in the theory and best practice of biodiversity monitoring. At the global scale, the reporting mechanisms required from countries by the

Convention on Biological Diversity (http://www.biodiv.org) is foreseen to have a similar impact. Such increased interest will likely lead to advances in a general theory of monitoring and a better alignment of monitoring practices with this emerging theory.

Our general conclusion is that although habitat monitoring has become widespread and developed considerably in Europe since 1990, there is still much room for improvement. Improvements we judge as most important are the wider application of spatially explicit data collection, better adherence to sampling principles and better use of advanced statistical–analytical methods. Spatially explicit data collection would enable schemes to expand monitoring to larger areas, more habitat types and to non-protected areas. To introduce a spatial aspect, we recommend a scale-specific combination of remote sensing methods, which are capable of monitoring changes over larger spatial scales, and of field mapping methods, which are capable of monitoring small-scale changes. All sampling should be based on pre-defined criteria derived from sampling theory, which can provide the foundation for statistical analysis. Data from monitoring need to be analysed, preferably by using advanced analytical methods and by allocating priority to data from projects using an experimental approach to evaluate drivers and pressures of biodiversity change. These developments will result in higher precision of measurements, better and more accurate information on habitat changes and higher cost-efficiency. Such improvements are essential if we are to reliably measure changes of habitats at the European scale and to assess progress towards the 2010 target of halting the loss of biodiversity in Europe.

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