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ORIGINAL PAPER

# A review and a framework for the integration of biodiversity monitoring at the habitat level

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**Abstract** The monitoring of biodiversity at the level of habitats is becoming widespread in Europe and elsewhere as countries establish national habitat monitoring systems and various organisations initiate regional and local schemes. Parallel to this growth, it is increasingly important to address biodiversity changes on large spatial (e.g. continental) and temporal (e.g. decade-long) scales, which requires the integration of currently ongoing monitoring efforts. Here we review habitat monitoring and develop a framework for integrating data or activities across habitat monitoring schemes. We first identify three basic properties of monitoring activities: spatial aspect (explicitly spatial vs. non-spatial), documentation of spatial variation (field mapping vs. remote sensing) and coverage of

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habitats (all habitats or specific habitats in an area), and six classes of monitoring schemes based on these properties. Then we explore tasks essential for integrating schemes both within and across the major classes. Finally, we evaluate the need and potential for integration of currently existing schemes by drawing on data collected on European habitat monitoring in the EuMon project. Our results suggest a dire need for integration if we are to measure biodiversity changes across large spatial and temporal scales regarding the 2010 target and beyond. We also make recommendations for an integrated pan-European habitat monitoring scheme. Such a scheme should be based on remote sensing to record changes in land cover and habitat types over large scales, with complementary field mapping using unified methodology to provide ground truthing and to monitor small-scale changes, at least in habitat types of conservation importance.

**Keywords** Biodiversity indicators · Biodiversity research strategy · Ecosystem monitoring · Habitats Directive · Nature conservation

## Introduction

Many countries have pledged to reduce the accelerated rate of the loss of biodiversity by 2010 (Convention on Biological Diversity, http://www.biodiv.org). European countries went further by committing themselves to halt the loss of biodiversity in Europe by 2010. In order to judge whether these ambitious goals are met, detailed information on different components of biodiversity are necessary. Such information needs to be collected by properly designed monitoring systems (Pereira and Cooper 2006). Recently, much work has been focused on describing the desirable properties of monitoring systems or the indicators proposed to measure large-scale trends in biodiversity (Gregory et al. 2003; Weber et al. 2004; Balmford et al. 2005; Gregory et al. 2005; Mace et al. 2005; Heer et al. 2005).

To measure the biodiversity changes in light of the ambitious targets, the integration of monitoring systems over large, supra-national spatial scales and possibly over long time scales is essential (Balmford et al. 2003). Integrated monitoring systems can come about in two ways. First, a monitoring system can be designed ‘from scratch’ based on general recommendations of current ‘best practices’ (top-down approach). Alternatively, currently existing monitoring systems can be integrated to form a large-scale system to monitor changes in biodiversity (bottom-up approach, Henry et al., in review).

An example for a newly designed, large-scale monitoring system for species is the Pan-European Common Bird Monitoring scheme (PECBM, Gregory et al. 2005). The PECBM scheme attempts to quantify trends in populations of European breeding birds, and to develop an index of biodiversity to measure progress to the 2010 goals. Currently, no such explicit monitoring of habitats exists at the European level. The CORINE Biotopes project (Devillers et al. 1991) was the first effort at describing habitat types according to a unified typology. The CORINE Land Cover project (http://reports.eea.europa.eu/COR0-landcover/en) contained some components of habitat monitoring as it collected data on land cover types using remote sensing and its own typology. The CORINE Land Cover project conducted the first pan-European mapping of land cover in 1990, and the revised survey was repeated in 2000, providing information on the changes in major land cover types over a decade (European Environmental Agency 2006). Finally, the BioHab project developed and tested field-based methods for Europe-wide monitoring of habitats using a typology based on plant life forms and an emphasis on landscape-scale data collection (Bunce et al. 2005). Despite these promising developments, most monitoring programmes in Europe remain small in scope both spatially and temporally (Balmford et al. 2003; Lengyel et al., in review).

The aim of this article is to develop a common framework for the integration of monitoring systems focusing on habitats. Integration can progress in two ways. The first approach combines information obtained by separate monitoring schemes in the form of raw, processed, interpreted, or analysed data, whereas the second approach combines and integrates monitoring methodologies to unify resources, from smaller spatial units into a large-scale monitoring system. Here, our primary question is how to integrate different monitoring schemes but we will also briefly address data integration. We first identify which properties of monitoring schemes are important from the perspectives of integration and then develop different avenues for the integration of different types of habitat monitoring schemes. Next we demonstrate the most important integration avenues by highlighting their advantages and potential problems. Finally, we evaluate the chances of such integration by drawing conclusions from data collected on existing habitat monitoring schemes in Europe by the EuMon project (see Henle et al., in review) and make recommendations for pan-European habitat monitoring. We do not attempt to provide a worked-out example of integrating habitat monitoring, which is likely to differ case by case and, therefore, would be beyond the scope of this paper. Rather, we present general guidelines and draw on examples pointing towards integration. In this paper, we focus specifically on habitat monitoring. Integration and benefits related to species monitoring as well as options to combine different measures and estimates obtained from monitoring are discussed in Henry et al. (in review).

## Definitions and types of habitat monitoring

### Habitat, habitat type and habitat monitoring: definitions

We use the term ‘habitat’ in a wide sense when generally referring to the physical, chemical and biological components of a defined geographical area (cf. Blondel 1995). We use the term ‘habitat type’ for specific kinds of habitats that have been described as separate from other such entities in 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).

Habitats are characterised by a *typology* relating the various habitats to a specific classification and a given habitat patch to a specific type, where each type has a set of defining characteristics. Using an analogy borrowed from vegetation science (Barkman 1979), the *texture* of habitats concerns the number of patches for each habitat type and the size distribution of habitat patches. The *structure* of habitats is given by the spatial structure or layout of the patches and the geographical relationships between the patches. Most often, the typology, texture and structure of habitats is described on habitat maps, showing the patches of different types. The spatial structure may also be described by a variety of spatial statistics or indices (e.g. fragmentation indices, landscape metrics). Finally, each habitat patch can be characterised by their internal properties, i.e., various aspects of habitat quality (Firbank et al. 2003).

The overall objective of habitat monitoring is to describe and to understand the state and changes in habitat-relevant aspects of biodiversity. Typology is obtained by identifying different habitat types based on similarities in physiognomy, abiotic conditions, plant community composition, plant dominance, succession stage and, occasionally, animal community composition (Dierschke 1994). Texture is assessed when the number of patches and the relative or absolute surface area covered by each habitat type are quantified. Finally, spatial aspects can be described by mapping that identifies the location and spatial relationships of each habitat patch. Monitoring data are either collected in the field (field mapping) or derived from remotely sensed imagery (satellite sensors and/or aerial photography) with the appropriate ground-truthing. The state of habitats is typically evaluated using data on physico-chemical properties, species composition and/or relative abundances and on the distribution of habitat types (absolute and relative surface area, fragmentation etc.). Habitat monitoring often involves collecting additional information on internal properties of habitat patches such as habitat quality (e.g. naturalness, degradation, pollution etc.), environmental parameters (soil type, weather) and potential drivers and pressures (land use, human influence).

## Main types of habitat monitoring

The EuMon survey of habitat monitoring schemes in Europe (Lengyel et al., in review) suggests that there are several properties of habitat monitoring that deserve special attention from the perspectives of integration. Three properties are of central importance: use of a spatial aspect, approach for documenting spatial variation and extent of habitat coverage. These basic differences need to be considered in developing and applying a common framework for the integration of monitoring schemes.

### *Spatial aspect*

The objectives of habitat monitoring fundamentally vary by whether schemes collect qualitative or quantitative information on the habitats of interest. In this article, schemes that collect qualitative information (defined here as typology and texture) on the habitats will be referred to as '*non-spatial schemes*'. For example, many schemes operate by collecting data on community composition and structure at stationary sampling units (quadrats/transects etc.), but without explicitly addressing spatial variation. In contrast, schemes that also collect quantitative information (structure), termed as spatial schemes, also monitor changes in the range/area/shape of the habitat types of interest. Spatial schemes often use georeferenced databases (Geographical Information System, GIS), consisting of either points, lines, raster cells or polygons as features and various attribute information associated with each feature, to create and analyse electronic habitat maps (Longley et al. 2005).

### *Documenting spatial variation: field mapping and remote sensing*

Another basic difference among habitat monitoring schemes is whether they use field mapping or remote sensing as their primary source to document spatial variation in the monitored habitats. Field mapping is based on field surveys and measurements, such as phytocoenological/phytosociological surveys or vegetation mapping. In a phytosociological approach, a detailed description of the plant community is compiled in replicated relevés (Braun-Blanquet 1964). Relevés are often arranged in permanent plots or transects, which are necessary to detect fine-scale changes in habitats (Bakker et al. 1996) e.g. in species composition or relative abundances of species. Field mapping, however, rarely provides complete spatial coverage of the focal area and sampling needs to be invoked in most schemes. Sampling is conducted by restricting actual surveys to certain locations and by making inferences from these locations to non-surveyed areas, either by a priori randomisation or a posteriori spatial modelling or extrapolation.

Remote sensing-based monitoring is based on imagery of the area of interest obtained through aerial or satellite sensors and interpreted by various methods (Turner et al. 2003). A broad range of remote sensing data sources are used for habitat monitoring, e.g. panchromatic or colour photography, multispectral imaging, laser scanning, radar imaging (Lillesand et al. 2003). Satellite-based remote sensing usually covers areas ranging from regional to supra-national, although with the advent of high-resolution scanners (e.g. Quickbird), it has been also applied locally (e.g. Rocchini et al. 2005). A multitude of remote sensing-based habitat mapping and monitoring approaches have been developed, ranging from photo-interpretation by humans to automated quantitative algorithms by computers, often with several methods in combination (e.g. Nagendra et al. 2004; Asner et al. 2005).

Field mapping and remote sensing provide higher accuracy and precision at opposite ends of the continuum of geographical scales. Field mapping is effective at documenting spatial variation at local and regional scales, whereas remote sensing can provide accurate and precise quantitative information at regional, national and supra-national spatial scales. The large-scale mapping of habitats based on remote sensing is faster and cheaper per unit area and requires less ecological expertise than based on field mapping (Lillesand et al. 2003).

### *Extent of habitat coverage of monitoring*

The third distinction in habitat monitoring is whether schemes monitor one or a few specific habitat types or monitor all habitat types within the area of interest. Schemes monitoring all habitat types within an area hereafter will be termed as *holistic* schemes, whereas those monitoring one habitat type will be referred to as *targeted* schemes. These categories are analogous to the ‘full-coverage’ and ‘partial coverage’ approaches of landscape monitoring (Dramstad et al. 2002; Groom 2004). Although the differences between holistic vs. targeted approaches affect the scope and the multivariate nature of monitoring, the basic issues of sampling design and statistical analysis are essentially similar.

## **Integration of data and monitoring schemes**

### Integration of data or processed information

The basic question regarding data integration is: How can the different properties of habitats be characterised for separate data sets and still allow integration of the data sets or of the inferences made from them? When data are integrated, it is first important to clarify whether raw data or some processed information are integrated. Raw data for integration may involve non-processed scenes from remote sensing, whereas processed information can range from data already classified to habitat types in the form of a map to estimates of changes in certain properties of the habitats. We further explore the approaches to integrating estimates derived from monitoring in another paper (Henry et al., in review).

If the basis for integration is raw data, then the origin of those data (targeted/holistic scheme) and their spatial extent and scale or resolution will be important. A special problem with integrating raw data from different spatial scales is the different degree of representativity because data from small geographical scales (e.g. regions within countries) may not be representative at larger scales (e.g. Europe) (Bunce et al. 2006). With maps or estimates as input, commonalities in habitat typology, spatial extent and scale/resolution will be relevant. How the integration should be handled on the basis of this input will depend on the more direct objective of integration, as certain types of input/data will be well suitable for some objectives but not for others. One example for ongoing data integration is the compilation of information provided by member states as part of the first EU-wide baseline assessment of Natura 2000 habitats and species, conducted by the European Topic Centre on Biological Diversity (http://biodiversity.eionet.europa.eu). Specific issues for data integration involve:

- relating habitat information to the same typology (habitat classification), either by having the same basic typology and habitat types, or by transforming the habitat units into a common typology, possibly at a more aggregated level of classification,
- evaluating whether comparable spatial scales are used to identify and measure habitat types or whether they can be converted to comparable scales,
- ensuring that characterisations of spatial structure address the same spatial phenomena and that quantifications of these phenomena can be made comparable, and
- ensuring that aspects of habitat quality address the same quality phenomena and that quantifications of these phenomena can be made comparable.

These criteria are not equally relevant in integration. Experience from previous attempts at integration suggest that common habitat typology is probably the most challenging of the above-mentioned criteria and will also be among the most important criteria in other types of integration explored below. Two ways to resolve this problem are to use broader habitat categories (see e.g. Firbank et al. 2003 describing the integration of the Countryside Surveys of Great Britain and Northern Ireland) or to apply interpretation algorithms (see e.g. Jansen 2004 for thematic harmonisation for landscape-monitoring in Nordic countries) to achieve compatibility.

## Avenues for integration of monitoring schemes

Habitat monitoring schemes can be grouped into six classes based on the three aspects detailed above (Table 1). Integration of two or more schemes can be envisioned both between schemes belonging to the same class (within-class integration, e.g. holistic remote sensing-based with holistic remote sensing-based) and belonging to different classes (between-class integration, e.g. holistic remote sensing-based with targeted field mapping-based) (Table 2). Based on this conceptualisation, ten logical avenues for integration exist for spatial schemes (four within-class and six between-class integration avenues, Table 2).

## Integration of monitoring schemes within class

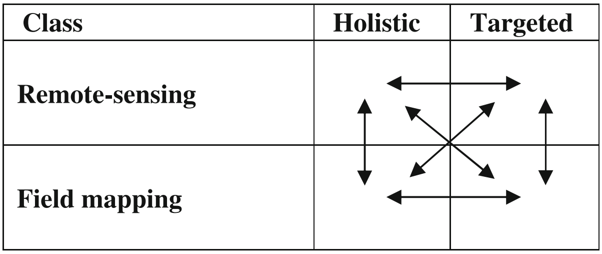
### *Integration of remote sensing-based holistic schemes*

Remote sensing-based monitoring schemes belonging to the holistic approach are highly appropriate for integration (Nagendra 2001). These schemes have a common ‘currency’ in the form of georeferenced, remotely sensed spatial information from entire spatial entities. Thus, holistic remote sensing-based schemes have the best chances to provide a foundation

**Table 1** Six classes of habitat monitoring based on three main properties of schemes and the number of schemes in each class according to the EuMon database of European habitat monitoring schemes (as of August 31, 2007)

| Spatial aspect | Documenting of spatial variation | Extent of habitat coverage | Number of schemes |
|---|---|---|---|
| Spatial (n = 63) | Field mapping | Holistic | 16 |
| | | Targeted | 26 |
| | Remote sensing | Holistic | 16 |
| | | Targeted | 5 |
| Non-spatial (n = 83) | – | Holistic | 66 |
| | – | Targeted | 17 |
| | | Total | 146 |

**Table 2** Illustration of possible integration combinations for the four classes of schemes with spatial aspect. Arrows indicate between-class integration (n = 6 combinations); within-class integration, i.e., integration of schemes of similar class, is not shown (n = 4)



for a pan-European integrated monitoring scheme. The compatibility of such information systems depends on their technical properties, including:

- comparable sampling intensity in space (all parts equally measured in the focal area) and time (seasonally and/or according to phenological changes of the habitat types),
- comparable sensors and spectral resolution, comparable conditions for input imagery (acquisition date/frequency, cloud cover etc.),
- comparable mapping scale or spatial precision: the minimum mapping unit (for vector maps) or the spatial resolution (for raster maps) should be similar,
- comparable mapping accuracy, consisting of thematic accuracy (percent of correctly classified habitats) and spatial accuracy (habitat delineation errors),
- compatible map projections and geo-referencing,
- comparable sensitivity to changes,
- compatibility of habitat nomenclatures (habitat classification systems), compatible level of habitat nomenclature hierarchy.

If all of these criteria are fulfilled, the input data sources can be combined for analysis. A review of methods for integrating data from remote sensing projects is beyond the scope of this review. For concrete methods and technical advice, readers are encouraged to consult reviews (e.g. Hinton 1996; Nagendra 2001; Duro et al. 2007) or textbooks (Lillesand et al. 2003) on the subject. The result of integration can be an increase in the extent and/or the resolution of the area where all habitats are monitored. By combining data, an extended map can be prepared and common parameter estimates can be calculated. If these criteria are not fulfilled, calibration and interpretation of differences are essential prior to a direct combination of remotely sensed data. If such calibration is not possible, separate maps and separate parameter estimates can be used. For example, easily interpretable or comparable indices can be estimated for not comparable data sources (e.g. normalized difference vegetation index, NDVI, Pettorelli et al. 2005).

### *Integration of remote sensing-based, targeted schemes*

In this type of integration, schemes covering disjunct areas are combined in order to increase the monitored area of focal habitat types. In addition to the criteria presented in the previous section, all schemes should cover the same or at least comparable sets of habitats. Issues related to temporal non-compatibility (e.g. different spectral properties due to weather) are likely to be higher in this type of integration than for holistic RS-based schemes. If the types of habitats monitored differ between schemes, the next higher level of the common habitat classification system can be used to accommodate information from both schemes. Such integration can be relevant for monitoring of disjunct but similar habitat types, for example, the alpine habitats in Europe.

Data integration here can also be of two kinds: (1) integration of remotely sensed input data (when all the above criteria apply), and (2) using the input data and/or map results of the scheme with higher spatial and thematic resolution to support and validate results in the less detailed scheme, which potentially covers a larger area. A special case is when several monitoring schemes each monitoring a different target habitat type within some common area are integrated. In such cases, the aim of integration can be to broaden the spectrum of habitats monitored. A reasonable set of such schemes may be collated to form a holistic scheme for the common area.

### *Integration of field mapping-based, holistic schemes*

Field mapping-based, holistic schemes are frequent, but usually cover widely different geographical areas. The scale of habitat or vegetation mapping often varies depending on the scope of the schemes. Even national-level habitat or vegetation mapping schemes vary a lot e.g. by the size of the country involved. Even if spatial coverage is close to 100%, there can be several issues deserving attention, such as:

- the proportion of the focal area actually sampled and refinement of the sampling strategy (e.g. site selection randomly or systematically),
- the use of permanent plots/quadrates/transects in subsequent sampling occasions,
- constancy of sampling intensity in space and time, across habitats and habitat types,
- method of obtaining information for non-sampled areas (extrapolation, other sources etc.),
- comparability of precision (ability to detect trends or changes in the habitats) and error rates (e.g. measurement of observer biases),
- quantification of errors in mapping and data processing e.g. by inherent variability of the attribute vs. accuracy/precision of measurement,
- habitat classification system used.

If these differences can be resolved, the result of integration will be that the area monitored will increase. Such integration has a high potential of becoming a key component of a pan-European habitat monitoring scheme (Bunce et al. 2006). The disadvantage may be that the results may not be generalizable or applicable over non-sampled areas or large spatial scales (a problem inherent in field mapping).

### *Integration of field mapping-based, targeted schemes*

Schemes in this class are concerned with one or a few habitat types, monitored in several distinct sites with similar or different mapping methods. One example for such schemes is the monitoring of bogs or fens. Integration of such schemes is rather straightforward if the schemes to be integrated monitor the same (group of) habitat types. In such cases, only the differences in field mapping methodology is important from the perspectives of integration. If different habitat types are monitored within some common area, integration can be used to broaden the spectrum of the habitats monitored. Theoretically, a reasonable set of such schemes might sum up to form a holistic scheme for the common area.

## Integration across classes

Across-class integration is more challenging than within-class integration, but can provide valuable insight that within-class integrations cannot provide. The end product in such integrations will be a more valuable source of knowledge than the sum of the component parts (Groom 2004). For example, a holistic-targeted integrated scheme will have added values that the constituents do not have individually, such as the ability to monitor large areas with the concomitant ability to monitor small changes of some selected target habitat types. After such integration, the result is increased quality and/or quantity of information in at least some parts of the monitored area. Integration of information from several different sources is also likely to be the most important input in policy support (Wyatt et al. 2004).

### *Integration of remote sensing-based and field mapping-based schemes of the holistic approach*

This type of integration may be advantageous when both are complementary in habitat attributes covered or when the combination is more cost and time-efficient. It makes particular sense to use the high precision field survey data to support interpretation of remotely sensed data or to validate the remote sensing-based mapping and monitoring results (ground-truthing). Field mapping also can provide additional information on environmental variables (e.g. soil quality) not accessible to remote sensing. Alternatively, remote sensing may be used to complement or even adjust spatial information obtained by field mapping, by providing information on spatial patterns of the habitats (e.g. fragmentation, connectivity) that are difficult to detect in field mapping. Criteria for such integration are as follow:

- comparable areas and spatial scales used in each scheme,
- compatibility of habitat nomenclatures (habitat classification schemes), compatible depth of habitat nomenclature hierarchy, exhaustiveness of field mapping,
- comparable thematic precision,
- comparable monitoring/mapping accuracy,
- comparable sensitivity to changes (ability to detect trends),
- common data formats, compatible data management systems (the latter is not necessary if a scheme is only used to validate the results of the other scheme).

### *Integration of holistic and targeted schemes within remote sensing-based and within field mapping-based methods*

The main advantage of this type of integration is that a targeted scheme can complement the holistic scheme in the common area, where the latter does not adequately cover or entirely leaves out certain habitats. A set of targeted schemes that is complete enough over a common area can be combined into a holistic scheme. If the set of targeted schemes is incomplete for a common area, it can still be used to provide additional spatial and thematic detail in some important parts of the common area. For example, monitoring of the NATURA 2000 network, which, by definition, is a targeted scheme, can contribute relevant and detailed focus to a generalized holistic scheme in a region/country or even at the pan-European level. Furthermore, the data from the high-precision field survey can be used in ground-truthing the remote sensing-based mapping results (see above).

## Chances for integration in light of current practices

We evaluated the integration potential of currently existing habitat monitoring schemes in Europe by drawing data from the EuMon project, which attempted to collect descriptive data on such projects between 2005 and 2006 (more on the project: Henle et al., in review; Lengyel et al., in review; http://eumon.ckff.si). The EuMon project database contains information in the form of an online questionnaire filled out by monitoring coordinators (n = 150 schemes at the time of writing, 31 August, 2007). Here we present the most important results that bear on the potential for integration from the analysis of the database.

To evaluate the proportion of spatial vs. non-spatial schemes, we used information given by coordinators regarding the method used in their schemes to document the spatial variation in habitats. Choices offered were ‘field mapping’ and ‘remote sensing’. Schemes for which none of these choices were marked were, therefore, likely to be non-spatial schemes. Interestingly, no method was given for 83 of 149 schemes, which thus were considered as non-spatial schemes. In all, the proportion of spatial and non-spatial schemes (44.3 vs. 55.7%, respectively), was not significantly different from an equal distribution ($\chi^2_1 = 1.940$, $P = 0.164$).

Among schemes that had one of the choices marked (spatial schemes, n = 66), field mapping was more frequent as it was used in 44 schemes, whereas remote sensing was used in only 22 schemes ($\chi^2_1 = 7.333$, $P = 0.007$). Almost a third (29.5%) of all schemes (n = 149) used field mapping and only 14.8% of the schemes used remote sensing.

We evaluated the frequency of the holistic vs. the targeted approach using information given by coordinators whether they monitor all habitats or not in their focal areas. Two-thirds (67.1%) of the habitat monitoring schemes (n = 146 schemes with any data) monitored all habitats within their specified area (holistic approach or ‘wall-to-wall’ monitoring), whereas the rest (32.9%) monitored specific habitat types within a region (targeted approach). This difference in proportions was significantly different from random ($\chi^2_1 = 17.123$, $P < 0.001$).

Interestingly, field mapping-based schemes tended to be targeted in approach, whereas schemes using remote sensing or not documenting spatial variation at all were more often holistic in approach (Table 1) ($\chi^2_2 = 22.598$, $P < 0.001$). It is especially noteworthy that 79.5% of non-spatial schemes (n = 83) were marked as holistic in approach, i.e., monitored all habitat types within a focal area.

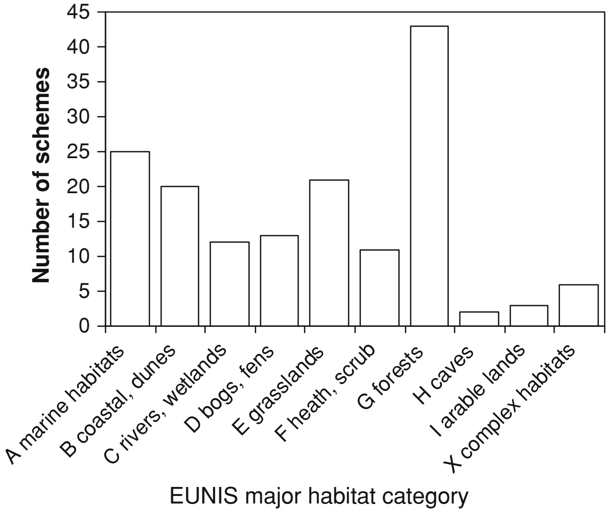


**Fig. 1** Number of monitoring schemes targeting major EUNIS habitat categories according to the EuMon database (based on total n = 156 habitat types marked in n = 142 schemes; more than one habitat type could be marked for each scheme)

The average number of habitat types monitored by the schemes was 5.0 and varied considerably (SD = 11.85). The reason for the high variation was that a large proportion (43.7%) of the schemes (n = 119) monitored only one habitat type, whereas some schemes monitored up to 37–38 habitat types. One national-level scheme monitored 116 habitat types.

To study the frequency of habitat types monitored, we grouped the habitat types marked by the coordinators as focal habitat types in their monitoring schemes in the 10 major habitat groups (level 1) used in the EUNIS system. The most frequent targets of habitat monitoring were forests (27.5% of major habitat types marked by coordinators, total n = 156), followed by marine habitats (16.0%), grasslands (13.5%) and coastal habitat types (12.8%). Other habitat types were subjects of monitoring in less than 9% of the cases (Fig. 1).

There were two other methodological details important from the perspective of integration. First, many schemes are conducted at very small spatial scales. Almost half (49%) of the schemes (n = 41 schemes with information on scale) were operating at scales of 1:300 or lower, another 20 operated within the range 1:2,000 and 1:50,000 and only one marked 1:100,000 as operating scale. Second, only five (or 3.4%) of the schemes (n = 148) use the more recent EUNIS system for the classification of habitats and most use the CORINE system (39.2%) or other, presumably national systems (31.1%). In more than one-quarter (26.4%) of the schemes, no habitat classification system was given by coordinators.

## Discussion

Our survey shows that there are a large number of habitat monitoring schemes in Europe (a full account of current practices is given in Lengyel et al., in review). However, the survey also suggests that habitat monitoring activities are fragmented. Monitoring projects are scattered, data collection methods are not standardised and, thus, processed information is not easily accessible for decision-makers and stakeholders. Most reported schemes have been started only recently (Lengyel et al., in review) and many monitoring schemes are small in geographical scope, operate on small spatial scales, and cover typically only one or a few habitat types. Many of the reported schemes lack an explicit spatial aspect and appear to monitor only qualitative habitat properties. Remote sensing is rare, and the more traditional field mapping is only slightly more frequent. In our data, forests were the most frequent habitat type monitored, followed by marine, grassland and coastal habitats, whereas bogs and fens, heaths and scrubs and especially agricultural areas are monitored less often. Furthermore, the monitoring of inland surface waters is probably under-reported in our data.

These patterns clearly suggest that there is a real need for integration of monitoring efforts if we are to quantify pan-European trends in habitat-level biodiversity by 2010. Our findings thus provide substantial support for previous calls based on less extensive data to substantially expand the geographical and temporal coverage of monitoring activities (Balmford et al. 2003; Vieno and Toivonen 2005) if we are to measure changes in biodiversity across large scales.

The recognition of the need for integration is far from new; this paper is first only in that it presents data on existing practices to underline this need. A discussion of integrating remote-sensing and field-mapping was presented previously by Barr et al. (1993) and various other aspects of integration were addressed by Parr et al. (2002). Calls from the scientific community have struck a chord in policy-making as well: several strategic papers (Anonymous 2004a) and action plan proposals (Anonymous 2004b) by European bodies refer to this need. For instance, the specific objective of key target 8 of the Kyiv resolution on biodiversity ( http://www.unep.ch/roe/programme_biodiv_kiev.htm), a reinforcement of the Gothenburg declaration is that: “by 2008, a coherent European programme on biodiversity monitoring and reporting, facilitated by the European Biodiversity Monitoring and Indicator Framework, will be operational in the pan-European region”. To achieve this target, a joint activity entitled “Streamlining European Biodiversity Indicators” (SEBI 2010) has been launched by the European Environment Agency, the European Centre for Nature Conservation and the UNEP World Conservation Monitoring Centre with the aim to review and test specific indicators in line with the EU list of 16 headline biodiversity indicators. With recognizing the need for a coordinated effort of harmonising national and international monitoring systems, SEBI currently works (among others) on developing indicators for large-scale changes in biodiversity from currently existing data sources and ongoing activities (http://biodiversity-chm.eea.europa.eu/information/indicator/F1090245995).

Similar lines of thought are currently being explored in the integration of landscape monitoring programmes. Monitoring of land cover changes has a long tradition in Europe, starting with the SISPARES programme in Spain in 1956 and the Countryside Survey of the UK in 1973 (Brandt et al. 2002; Firbank et al. 2003; Bunce et al. 2006). In several of these programmes, the integration of different approaches of surveillance and monitoring has already been achieved. For example, the SISPARES programme, the most comprehensive of the national landscape-monitoring schemes, is based on a combination of aerial photography-based interpretation of land cover and field mapping surveys in 206 samples of 4 × 4 km squares (Bunce et al. 2006). The Danish Small Biotope programme, originally started in 1981 as a targeted, field-based programme, has been supplemented with satellite-based, remotely-sensed information on land cover since 1990 (Brandt et al. 2002). The monitoring of agricultural landscapes in Norway is based on aerial photography, and the interpreted spatial information serves as a foundation both for field mapping (beyond ground-truthing) and for applying various landscape metrics to monitor changes (Dramstad et al. 2002). Despite these examples, we know of only one fully worked example when two previously different habitat monitoring schemes were integrated. The only worked example is the integration of the British Countryside Survey with the Northern Ireland Countryside Survey in 2000. This integration was made feasible to a large part because Broad Habitat categories were set up to accommodate the different habitat typologies used previously in the two schemes (Firbank et al. 2003).

The framework proposed here identifies most of the difficulties associated with integration of data or activities of habitat monitoring. The integration of small, scattered monitoring schemes requires some generalisations or finding the common denominator of schemes. Such uniformisation often results in loss of valuable information (Groom 2004, Bloch-Petersen et al. 2006). Alternatively, advance measures can be taken to increase the potential for integration in each of the schemes planned for integration. Our survey shows that the introduction or enhancement of addressing the spatial aspect in monitoring can be one such major improvement. Furthermore, field mapping and recording methods developed for uniform use over Europe, such as the BioHab methodology (Bunce et al. 2005; Bloch-Petersen et al. 2006), can be recommended.

Although recommendations for best practices in monitoring have been given before (e.g. MacDonald and Smart 1993; Yoccoz et al. 2001; Balmford et al. 2005; Mace et al. 2005; Tucker et al. 2005), this study provides new insights into areas for improvements. Obviously, an ideal solution for a pan-European habitat monitoring system would incorporate the best of both the remote sensing approaches (large spatial scales, relatively straightforward integration etc.) and the field mapping-based approaches (small scales, high sensitivity, detailed etc.). An integrated pan-European monitoring system should be based on remote sensing as the main data collection method due to its applicability over large spatial scales. Ideally, such a system would be holistic and cover the whole of Europe. The CORINE Land Cover project can be a good starting point or common reference for such a remote sensing basis, as shown by calculations of changes in habitat types between 1990 and 2000 (European Environmental Agency 2006). The original spatial resolution of the CORINE system (100 by 100 m raster cells), however, may not be appropriate to record small-scale changes, therefore, higher-resolution data from other sources (e.g. LANDSAT data, 25 $m^2$ pixel size; IKONOS, Quickbird: 0.7 $m^2$) could be used. As an intermediate level that helps both in the interpretation of satellite imagery and in the designation of sites for field mapping, aerial photography has proved useful in several landscape monitoring schemes (Bunce et al. 2006). For classification of habitat types, the use of the more recent and more detailed EUNIS system can be recommended. The EUNIS habitat classification is comprehensive and hierarchical, i.e., the levels can be adjusted to accommodate different resolutions. For example, Bock et al. (2005) provide an example for using object-oriented classification of data from remotely-sensed images across different spatial scales. Although the EUNIS system was not primarily designed for integrated monitoring purposes (e.g. “dry” means largely different habitat types in northern and southern Europe), many national habitat classification systems use categories transferable to the EUNIS system.

Beyond remote sensing of habitat cover over large areas, field mapping should also be a component part either as the primary tool for ground-truthing and/or as a means of obtaining more detailed information on habitat types. A scientifically sound system of field mapping as well as taxon-specific studies on the link between habitat-level changes and species diversity (reviews in Nagendra 2001; Duro et al. 2007) is necessary to enable the monitoring of smaller-scale processes. The landscape-scale approach recommended and field mapping methodology developed by the BioHab project could provide information detailed enough to detect changes in habitat types in a uniform manner over larger spatial scales (e.g. Bloch-Petersen et al. 2006). Such in-depth field mapping should focus on habitat types of conservation importance, e.g. priority habitat types of the Habitats Directive or habitats for which a country has high national responsibility (e.g. Dimopoulos et al. 2006). Currently, insufficient attention is paid to such priority habitats (Lengyel et al., in review). Ideally, field mapping or measurements use an appropriate, internationally agreed sampling design and record important background information (environmental parameters, socioeconomic factors, drivers, pressures, threats).

Time until 2010 is probably too short to devise and implement a fully functional integrated European monitoring scheme. Therefore, integration of data from currently existing schemes is fast becoming a high priority (Henry et al., in review). On a longer time scale, however, integration of monitoring schemes appears inevitable. There is no doubt that such integration will bring about a major advance in biodiversity monitoring (Brandt et al. 2002). Independently from pan-European efforts, integrated monitoring schemes can be formed at regional, national and supranational levels. We believe that the common logic and framework developed in this article, together with the EuMon database (available at http://eumon.ckff.si) can contribute to the success of such future efforts.

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