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ENVEurope

Environmental quality and pressures assessment across Europe:

The LTER network as an integrated and shared system for ecosystem monitoring

Conceptual framework for indicator assignment and selection for LTER-sites

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Action 2 Parameters and methods elaboration

Subaction 2.2 List of parameters and harmonized methods

Activity code A2.2.2a: From processes to parameters: development of the conceptual background and a set of guiding questions making decisions how to come from processes and functions to parameters traceable
Activity period: 03-12/2010

Activity code A2.2.2b: From processes to parameters: proposal about focal qualities of monitored systems
Activity period: 10/2010-02/2011

Activity code A2.2.3a: Review and selection of abiotic/biotic indicators: review of indicator-focused action at EU and national level
Activity period: 10/2010-06/2011

Content

1 Introduction

The use of long-term environmental data and related long-term integrated monitoring for the identification, investigation and prediction of trends and developments in ecosystems has been recognized since several decades (e.g. Magurran et al. 2010, Niemi & McDonald 2004, Likens 1992). Nowadays, terrestrial, marine and freshwater ecosystems are monitored by a number of global, continental, national or regional networks, managed by different organizations. Unfortunately, there is a clear lack of integration of the monitoring at a European level, many monitoring programs have a narrow focus (e.g. looking at individual system's components only) and most programs use different measurement protocols and sampling designs (Lindenmayer & Likens 2009, Parr et al. 2002). Hence, there is some redundancy of data, overlapping of efforts and a lack of harmonized data and concepts.

1.1 The project ENVEurope[1]

The project ENVEurope was born and will develop inside the European Long-Term Ecosystem Research Network community. The project aims at the integration and coordination at the European level of long-term ecological research and monitoring initiatives, focused on understanding trends and changes of environmental quality, and on the elaboration of relevant detection systems and methods.

The main target of the project ENVEurope is the analysis of the ecosystem status and the definition of appropriate environmental quality indicators with an integrated long-term, broad scale, cross-domain (terrestrial, freshwater, coastal and marine ecosystems) approach, joining the efforts of 11 countries belonging to the LTER Europe network.

ENVEurope proposes the design of environmental quality monitoring and research sites and the establishing of common parameter sets to be collected across the largest network of long-term ecological research sites in Europe. Focusing on three types of ecosystems (terrestrial, freshwater and coastal/marine) it aims at defining measures relevant to different scales of investigation, with specific monitoring intensities and with methods adjusted to the respective assessment intensity, implementing a multi-level and multi-functional approach.

A further target of the project is the selection of a core list of ecological parameters, indicators and indexes, useful to analyze, compare and report environmental quality at an international level. Thereby, the LTER network's comprehensive data sets will be brought into a larger context and can be harnessed by a broader community which will add substantial value to the precious data. To link the data from the LTER network to the high diversity of concepts and related indicators is the major challenge for ENVEurope. Based on Cocciufa et al. (2007, in Parr et al. 2010), a set of minimum recommended parameters to be measured at LTER-Europe sites as been agreed upon (Table 1). However, according to Parr et al. (2010), there is no guarantee at present that these parameters actually will be measured by most sites or national networks.

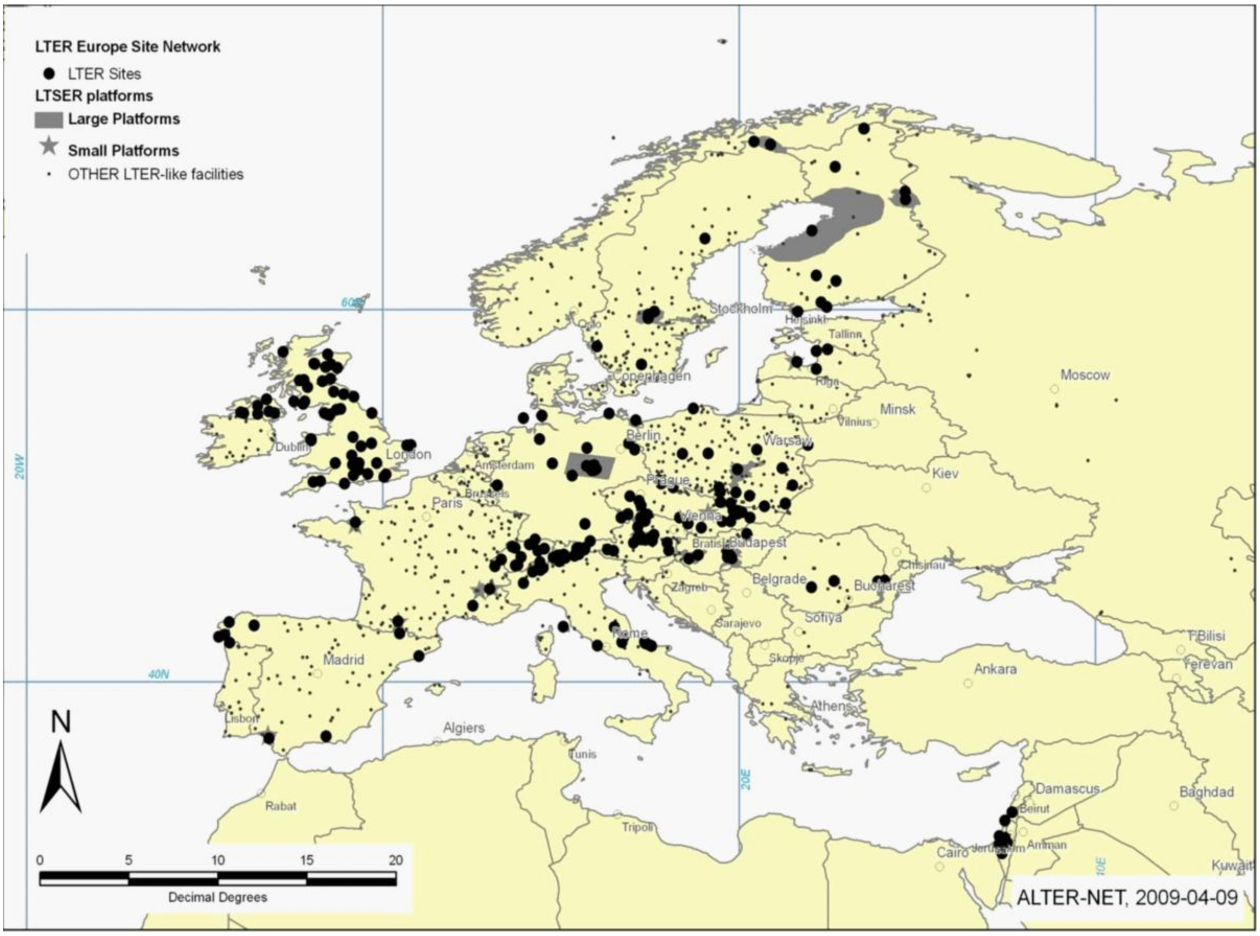
[1] http://www.ENVEurope.eu/

Table 1: Minimum recommended parameters to be collected at LTER-Europe Sites (* = highly recommended) (from Parr et al. 2010)

	Terrestrial	Aquatic
Abiotic (pressures)	Land cover and land use intensity *	
	Physical data (meteorological and water observations)*	
	Atmospheric deposition, water chemistry and eutrophication*	
	Soil chemistry and classification*	
Biotic (states)	Primary producers (vascular plants, phytoplankton, bacteria, biomass, NPP)*	
	Invertebrate taxa (selected on the basis of ecosystem type)	
	Invasive alien species in Europe since 1900 (EU check list)	

1.2 LTER Europe and ENVEUROPE

The European LTER network covers actually 406 LTER-Europe sites and 23 LTSER (Long-Term Socio-economic and Ecosystem Research) platforms. They all are set up to collect long term data from



different ecosystems.

Figure 1: Map of the European LTER and LTSER sites and platforms (map from www.lter-europe.net).

Long-Term Ecosystem Research (LTER) is an essential component of worldwide efforts to better understand ecosystems (Müller et al. 2010, Mirtl et al. 2009; see also: http://www.lter-europe.net). This comprises their structure, functions, and response to environmental, societal and economic drivers as well as the development of management options. Thus data collected within the LTER network are quite heterogeneous, as the sites do not only cover different eco-domains with wide ranges of different habitats, but the motivation for setting up LTER sites and thus, the measurements taken, are heterogeneous too. Together with missing standards about (1) data storage and availability as well as for (2) indicators, parameters and methods, this demands for urgent improvement in order to make the most use of long-term data and time series. At present, the metadata about LTER-Europe sites are available in InfoBase at https://secure.umweltbundesamt.at/eMORIS and updated by the InfoBase Entry Tool available at http://www.lter-europe.net/info_manage/lter-infobase. However, the information about the parameters measured (details about treatment, analysis, method, start and end of measurement, etc) is actually coarse and needs to be refined.

Due to this high diversity of sites and collected data, ENVEurope aims at designing a common indicator/parameter set based on a common conceptual ground broad enough to cover multiple aspects of ecosystems. Data from all sites will be integrated into this concept. To follow up, data from socio-ecological research (LTSER sites) should be integrated, for example by using the concept of *ecosystem services* (chapter 5 of this report). In this context it has to be mentioned, that the comprehensive and long-term data from the LTER sites provides a vast and highly valuable amount of information. Normally, the lack of data is probable the biggest constraint for indicator applications (Parr et al. 2010) but, applying the LTER data in a common indicator set, would add enormous value to national and international monitoring programs.

1.3 Indicator framework for LTER, respective ENVEUROPE

The aim of this documentation is to give an overview of current actions with regard to environmental indicators, compare them with the monitoring activities at the Long Term Ecological Research (LTER) sites and to deliver a concept on how to integrate available LTER data and fill the gaps within a general indicator framework. Finally, a sound scientific base and practical recommendations for harmonized monitoring systems will be provided. The main concepts which will be described in the following and on which the indicator frameworks shall be based on are Ecological Integrity, the DPSIR scheme and Ecosystem Services.

The following five main questions will be used to assess the particular indicators' suitability:

- At which sites has the indicator been measured of what quality?
- Does the indicator represent a relevant component of at least one of the two target concepts Ecological Integrity or Ecosystem Services?
- Does the indicator address national or EU level policy issues (e.g. biodiversity targets)?
- Are there any alternative / surrogate indicators measured or available?
- Which spatial and temporal scale does the indicator refer to?

2 Indicator concepts: background

The development and application of indicators have been very popular issues among scientists and especially at the science-policy interface. Scientists, on the one hand, tend to deliver information, data and related indicators as detailed as possible. Policy and decision makers, on the other hand, are dependent on highly aggregated information and corresponding indicators, which are political relevant, more or less easy to understand and suitable for communication, but often quite simplifying.

2.1 Basic requirements for indicators

Basic requirements for indicators have been well-defined and can be found for example in Müller & Burkhard (2010). Thus, indicators should be

- easily measurable,
- able to be aggregated,
- depict the investigated indicandum (object of indication) - indicator relation in an understandable manner. The indicandum should be clearly and unambiguously represented by the indicators.

The corresponding parameters should

- comprise an optimal sensitivity,
- include normative loadings in a defined extent only,
- provide a high utility for early warning purposes.

Müller and Wiggering (2004) provide a list of further requirements for indicators (Table 2).

Table 2: Requirements for good (ecological) indicators (according to Müller and Wiggering 2004)

- political relevance	- high level of aggregation
- political independence	- target-based orientation
- spatial comparability	- usable measuring requirements
- temporal comparability	- usable requirements for quantification
- sensitivity concerning the indicandum	- unequivocal assignment of effects
- capability of being verified	- capability of being reproduced
- validity	- spatio-temporal representativeness
- capability of being aggregated	- methodological transparency
- transparency for users	- comprehensibility

As further conceptual guidelines for indicator derivation can be named (i) the linkage of the indicators to ecosystem theory, (ii) application of methodologies from ecosystem analysis, and (iii) the relation to political concepts and targets.

Referring to guideline (i), the linkage of indicators to ecosystem theory, ecosystems can be regarded as self-organizing entities, and the degree of self-organizing processes and their effects can be chosen as an aggregated measure to represent the systems' actual states (Müller & Burkhard 2010). The basic theoretical principles of this approach stem from the thermodynamic fundamentals of self-organization and from the orientor principle (see chapter 4 of this report). The application of methodologies of ecosystem analysis (ii) guarantees the depiction of ecological entities in a holistic manner: structures as well as processes are taken into account; whereas the structures represent the performance of the ecosystems (and, in a next step, their capacity to provide ecosystem services). For the indicator sets' utilization in environmental management, a useful indicator set has to be based on political concepts and targets (iii). The awareness of these topics has for example been evidenced by the fact that the Convention on Biological Diversity (CBD) has adapted ecosystem integrity and ecosystem goods and services (ecosystem functioning in terms of their ability to provide goods and services) as focal areas in their Conference of the Parties 2004.

2.2 Review and selection of abiotic/biotic indicators

With reference to the requirements listed above, existing ecological indicator sets comprise different potentials, advances and limitations. With respect to indicator complexity, there are very complex indicator sets with a very high number of proposed parameters (e.g. Schönthaler et al. 2001, Statistisches Bundesamt et al. 2002). On the other hand, there are approaches that include a reduction up to one parameter only (e.g. Jørgensen 2000, Ulanowicz 2000, Odum et al. 2000).

Between indicator systems there is a broad span regarding the necessary data base, the demanded measuring efforts, the complexity of the aggregation methodology, and the comprehensibility of the results as well as the cognitive transparency for the users. These indicator systems can be classified into different categories that include varying levels of integration, ranging from rather reductionistic to holistic indicators, integrating a broad range of environmental information (Burkhard et al. 2008):

1. indicators based on the abundance of selected species;
2. indicators based on the concentration of selected elements;
3. indicators based on ratios between different classes of organisms or elements;
4. indicators based on ecological strategies or processes;
5. indicators based on ecosystem composition and structure; and
6. system-theoretical holistic indicators.

(1) Indicators based on the abundance of selected species include for example direct measurement and observation of selected species abundance, the saprobic classification, Bellan's pollution index, the AZTI Marine Biotic Index, bentix, macrofauna monitoring indices or the benthic response index (Jørgensen et al. 2010). (2) Indicators based on the concentration of selected elements are for example levels of eutrophication calculated e.g. based on phosphorus concentrations or, very commonly used, pH values. (3) Ratios between different classes of organisms or elements are used as indicators for example by Nygard's algal index or the diatoms/non-diatoms ratio. (4) Ecological strategies or processes are the background for process and rate indicators, for example the index of

r/K strategists or the infaunal index. (5) The very commonly calculated Shannon–Wiener index is an example for indicators based on ecosystem composition and structure. Further indicators referring to ecosystem composition and structures are analyses of food webs or ascendency. (6) Systems theoretical holistic indicators can be related to the concepts of vigor, organization, and resilience (VOR model), to exergy /thermodynamic indices, ecosystem health or ecosystem integrity.

2.2.1 Biodiversity indicator initiatives

Biodiversity and especially biodiversity loss have been mentioned as major issues in environmental management and related monitoring (MA 2005). There are numerous biodiversity-related global and European policy instruments, for which biodiversity indicators need to be derived, for example: Ramsar Convention 1971; Bern Convention 1979; Bonn Convention 1979; EC Birds Directive 1979; EC Habitats Directive 1992; Convention on Biological Diversity CBD 1992; Pan-European Biological and Landscape Diversity Strategy 1995; Ministerial Conference on the Protection of Forests in Europe 1990, 1993, 1998; EC Water Framework Directive 2000; EC Biodiversity Strategy 1998 and its four sectorial Biodiversity Action Plans 2001; EU Sustainable Development Strategy 2001 and the Sixth Environment Action Programme 2001, the Millennium Development Goals to be achieved 2015 and the proceedings of the G8+5 and the G20 groups of nations.

Consequently, there are many initiatives to describe and to assess biodiversity (Scholes et al. 2008). But even though there is a high number of biodiversity data, there is no general concept on spatial, temporal and topical data organization. According to the EEA (2002), biodiversity indicators should meet the following criteria:

- be easy to understand and policy-relevant;
- provide factual, quantitative information;
- be normative (possibility to compare to a baseline situation)
- be scientifically sound and statistically valid;
- be responsive to change in time/space;
- be technically feasible and cost-efficient to use within acceptable limits (in terms of data collection);
- be useable for scenarios for future projections;
- allow comparison between member states;
- allow aggregation at national and multinational level;
- take into account region-specific biodiversity; and
- be user-driven.

Table 2A (Annex) provides a list of ongoing and planned international indicator initiatives most relevant to biodiversity in Europe which were checked for above mentioned criteria (from EEA 2002). Unfortunately, not many of the indicator sets fulfilled all criteria (EEA 2002).

In the following, a short overview of some selected biodiversity indicator systems is provided:

SEBI 2010 (Streamlining European 2010 Biodiversity Indicators)

SEBI was established in 2005 as a process to select and streamline a set of biodiversity indicators to monitor progress towards the 2010 target of halting biodiversity loss and help achieve progress towards the target (EEA 2007 & 2009). SEBI is under the umbrella of the Convention on Biological Diversity (CBD). It is a regionally coordinated program that has been initiated in Europe as a collaboration between the EEA (European Environment Agency), PEBLDS (The Pan-European Biological and Landscape Strategy based on the Council of Europe and the UNEP Regional Office for Europe), assisted by ECNC (the European Centre for Nature Conservation) and the UNEP-WCMC (the World Conservation Monitoring Centre). SEBI was formerly known as **IEBI2010** (Implementing European 2010 Biodiversity Indicators). In table A1 (annex), a list of 26 indicators proposed by the SEBI 2010 process is presented.

GEO BON (Group on Earth Observations Biodiversity Observation Network)

Geo BON is a global partnership helping to collect, manage, analyze, and report biodiversity data (GEO BON 2010). It is a voluntary partnership of 73 national governments and 46 participating organizations and was launched in 2002. GEO BON aims at providing a framework for the partners to coordinate their data and observations within the Global Earth Observation System of Systems (**GEOSS**), GEOSS is providing access to data, services, analytical tools, and modeling capabilities. Biodiversity has been named as one of nine GEOSS priority societal benefit areas. GEO BON will integrate key ecosystem functional parameters, many monitored from space with in situ calibration, into a Terrestrial Ecosystem Function Index (**TEFI**). TEFI will integrate data of measurements of the energy, carbon and nutrient balance (GEO BON 2010).

Living Planet Index (LPI)

Developed for land, freshwater and marine vertebrate species, the average population trends over time are calculated. The actual calculations are based on a dataset of more than 2500 species and 8000 population time series over the past 30 years, three indices are calculated: (i) “terrestrial species population index” (based on a set of 555 terrestrial species), (ii) “freshwater species population index” (based on a set of 323 freshwater species) and (iii) “marine species population index” (based on a set of 267 marine species). Each of these individual component indices is set to a baseline of 100 in 1970, and all are given an equal weighting (UNEP-WWF 2004, Loh 2000).

Species Trend Index (STI)

STI uses the number of individuals in populations of selected species to calculate the change in time (trend) of this number. Existing long time biological data series are needed. As a result, a simple linear graph is built, having time (years) on the X axis and population size on the Y axis. A baseline is set at 100 at the monitoring starting year. Increase or decrease percentage is then directly shown on the graphic as relative increase/decrease from the starting point (Cocciufa et al. 2007).

National Biodiversity Index (NBI)

NBI is derived from data on richness and endemism in the four terrestrial vertebrate classes and vascular plants and adjusted to the country area (SCBD 2001).

Red Lists[1]

Last but not least, red lists and red list indices are of high relevance. Red lists provide a fundamental first step for conservation planning and prioritization (Brito et al. 2010). The lists present categories which are assigned to species based on taxonomy, conservation status and distribution and the species status is evaluated according to their extinction risk.

Biomare

The project Biomare (2000-2002) aimed at the implementation of long-term and large-scale marine biodiversity research and at planning the adequate use of the European research infrastructure. Among the outputs of the project was the production of internationally agreed standardized and normalized measures and indicators for biodiversity. Bioindicators have been considered according to the model developed by the OECD: State, Pressure, Use and Response indicators. Therefore, the project carried out a survey and critical evaluation of different types of bioindicators available in Europe (so-called indicator and sentinel species, biological indices, biomarkers, lethal and sublethal tests, bioaccumulators). Additionally, a tentative inventory of existing national monitoring networks (e.g. sea water quality: temperature, salinity, nutrients and contaminants, phytoplankton disturbance (especially by toxic unicellulars) or the bacteriological quality of shellfish by faecal bacteria) was made. The main products of the project concerning bioindicators are reported in Warwick et al. (2003) and Féral et al. (2003).

Conclusion:
Regarding biodiversity-related indicators and their use in Europe and globally, the EEA (2002) concludes that there is an enormous variety of indicators that have been developed to assess some aspect of biodiversity on the national, international or global scale, However, many indicators have been proposed or developed, but only a limited number of them is actually in use on a long term basis.

2.2.2 Integrative environmental indicator initiatives

There are numerous integrative environmental indicator sets and concepts. Relating to different issues, these sets are compositions of aggregations ("indices") of different structure and process indicators as well as socio-economic drivers and pressures (EEA 2002).

[11] http://www.iucnredlist.org/

Sustainability indicators (EU)

One example is the hierarchical system of sustainability indicators derived by the European Union (EC 2005). A high number of indicators are grouped in different levels covering the following 10 themes:

1. Economic development
2. Poverty and social exclusion
3. Ageing society
4. Public health
5. Climate change and energy
6. Production and consumption patterns
7. Management of natural resources
8. Transport
9. Good governance
10. Global partnership

Environmental issues are addressed in theme 5 (e.g. sub-theme climate change), theme 6 (e.g. sub-theme agriculture), theme 7 (e.g. sub-themes biodiversity, marine ecosystems, fresh water resources, land use) and theme 8 (e.g. sub-theme environmental impact of transport).

EEA core set of environmental indicators

This set developed by the European Environmental Agency (EEA) aims at the development and publication of policy-relevant indicator-based reports. They include environmental signals reports and sector-specific reports on transport (TERM) and energy (EERM). Main requirements on a core set of environmental indicators are to meet the increasing political demands for indicator-based reporting, to streamline indicator needs across these demands, to provide countries with clear priorities for environmental data collection initiatives and to allow the many international organizations to work together on a common approach (Kristensen 2003). In the 2003 report there was a differentiation between (a) the core set of more developed indicators: climate change, air pollution, ozone depletion, water (excluding ecological quality), waste and material flows, energy, transport and agriculture and (b) the less developed indicator sets for biodiversity, terrestrial environmental, water ecological quality, tourism and fisheries.

OECD

Also the OECD **(**Organisation for Economic Co-operation and Development**)** derived a set of key environmental indicators (OECD 2004) in order to measure environmental progress, complemented with several sets of sectoral environmental indicators to help integrate environmental concerns in sectoral policies. These indicators are grouped into (a) pollution issues (climate change, ozone layer, air quality, waste regulation, freshwater quality) and (b) natural resources and assets (freshwater resources, forest resources, fish resources, energy resources and biodiversity). Additionally, the indicators' availabilities in the OECD countries are mentioned.

TEEB (The Economics of Ecosystem and Biodiversity)

TEEB (www.teebweb.org) aimed at applying an economic approach to environmental issues in order to help decision makers to determine the best use of scarce ecological resources (TEEB 2010). The major tasks were to provide information about benefits and costs, to create a common language about natural capital and ecosystem services, to reveal opportunities to work with nature by demonstrating where it offers cost-effective means of providing valuable services, to emphasize the urgency of action and to generate information about values for designing policy incentives.

Natural Capital Index (NCI)

NCI is calculated as the product of the size of the residual area of an ecosystem or habitat in a given country or region (ecosystem quantity) and its quality:
NCI = ecosystem quantity * ecosystem quality. A more detailed description can be found in ten Brink (2000).

HANPP

Human appropriation of net primary productivity HANPP (Haberl et al. 2009 & 2007) is calculated as the aggregated impact of land use on biomass available each year in different ecosystems. In many regions, human land use activities have lead to a reduction of net primary production NPP. Land use and end consumption by humans often causes HANPP exceeding NPP of the potential natural vegetation.

Critical Load Exceedence Index (CLE)

CLE is calculated from deposition data (or input flux in general) and critical loads (CL) by computing a simple difference: CLE = INPUT – CL.

Connectivity Indices

These are computed based on different approaches: e.g. on structural measures of connectivity (nearest neighbor measures, buffer measures, incidence function model measures) or functional measures of connectivity (e.g. immigration rates respective dispersal success, search time, population spatial distribution or functional distances).

Corine Land Cover (CLC)

This program of the European Union aims at compiling information on the state of the environment with regard to certain topics which have priority for all member states of the community (EEA 1994). The satellite image interpretation-based CORINE land cover data sets are available as 100 meter grids, 250 meter grids and 1 km grids with minimum mapping units of 25 ha (Burkhard et al 2009). Most of the data can be downloaded for free from the EEA website or can be purchased at marginal costs. The data include 44 land cover classes which are grouped in a three-level hierarchical nomenclature: (1) artificial surfaces, (2) agricultural areas, (3) forests and semi-natural areas, (4) wetlands and (5) water bodies. These classes represent more or less all land cover types occurring in Europe. The classes are clearly defined in the CLC nomenclature (EEA 1994). Besides CLC, there are further easily available sources of satellite-based environmental information (e.g. **MODIS**[1] or **ASTER**[2]).

2.2.3 Indicator initiatives with special focus on marine environments

The policy of the EU Directorate-General (DG) for the Environment concerning marine environments and costs includes four regional sea conventions: the OSPAR, HELCOM, BARCOM and BUCHAREST conventions. More recently, the EU started to develop a marine strategy, aiming at attaining a comprehensive assessment of the state of the marine environment, identifying the main pressures on their respective marine regions, and defining targets and monitoring indicators:

OSPAR[3]

OSPAR (Oslo and Paris Conventions for the protection of the marine environment of the North-East Atlantic) is the Convention for the Protection of the Marine Environment of the North-East Atlantic. Within their strategy for a Joint Assessment and Monitoring Programme JAMP (OSPAR 2006), the following six themes to structure the monitoring and assessments are mentioned: (i) general quality status of the OSPAR maritime area, (ii) biodiversity, (iii) eutrophication, (iv) hazardous substances, (v) offshore activities and (vi) radioactive substances. The results and data are published regularly in the OSPAR Quality Status Reports (QSR). Over the period 1998 to 2008, these reports reflect the contracting parties' efforts to manage, monitor and assess the pressures on the diverse ecosystems of the North-East Atlantic.

HELCOM[4]

HELCOM (Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea) strives to achieve a harmonious balance of all biological components in a healthy Baltic Sea environment, thus supporting a wide range of sustainable economic and social activities. The European Community and all the states bordering the Baltic Sea are parties to this 1992 Convention. The convention covers the whole of the Baltic Sea area, including inland waters as well as the water of the sea itself and the sea-bed. Measures are also taken in the whole catchment area of the Baltic Sea in order to reduce land-based pollution. The present contracting parties to HELCOM are Denmark, Estonia, European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden.

[1] http://modis.gsfc.nasa.gov/
[2] http://asterweb.jpl.nasa.gov/
[3] http://www.ospar.org
[4] http://www.helcom.fi

BARCOM[1]

BARCOM (Barcelona Convention for the Protection of the Marine Environment and the coastal region of the Mediterranean) has been adopted by 22 Mediterranean countries. The contracting parties are determined to protect the Mediterranean marine and coastal environment while boosting regional and national plans to achieve sustainable development. The convention's main objectives are to assess and control marine pollution, to ensure sustainable management of natural marine and coastal resources; to integrate the environment in social and economic development; to protect the marine environment and coastal zones through prevention and reduction of pollution, and as far as possible, elimination of pollution (no matter whether land or sea-based), to protect the natural and cultural heritage, to strengthen solidarity among Mediterranean coastal states and to contribute to the improvement of the quality of life.

BUCHAREST CONVENTION[2]

The Bucharest Convention on the Protection of the Black Sea against Pollution(1992) initiated the environmental cooperation in the Black Sea. Its strategic action plan for environmental protection and sustainable management of the Black Sea is one pillar of the regional cooperation. The European Community is not yet a party of this convention, but an amendment allowing it to participate was proposed in April 2009. The basic objective of the Bucharest Convention is to prevent and reduce the pollution in the Black Sea in order to protect and preserve the marine environment, and to provide a legal framework for cooperation and concerted actions to fulfil this obligation.

Marine Strategy Framework Directive of the European Union[3]

Beside these four conventions, the Marine Strategy Framework Directive of the European Union (MSFD) was recently released by the EU DG Environment. The directive targets on the management of the marine environment. It is the first EU binding law designed to make a significant contribution to the preservation, protection and restoration of marine ecosystems, including pollution reduction and minimization. The marine strategy directive extends the EU water legislation WFD (Water Framework Directive; see below) to the marine environment and constitutes the environmental component of Europe's new cross-sector Integrated Marine Policy. The new directive follows an approach similar to that of the Water Framework Directive. It calls on EU Member States to ensure the "good environmental status" of all of European marine regions and sub-regions in a similar fashion as the Water Framework Directive sets the "good status" of freshwater and coastal waters as its core objective. In more detail, a "good ecological status" (GES) of the European marine ecosystems, securing the function of unpolluted, ecological diverse and dynamic oceans and seas, has to be achieved until 2020. For this, harmonized indicator systems and classification schemes have to be developed as an assessment instrument. Actions must be taken in cases where this GES is not

[1] http://www.unepmap.org/
[2] http://www.blacksea-commission.org/main.asp
[3] http://ec.europa.eu/environment/water/marine/index_en.htm

reached yet. The final goal of this directive, however, is securing the sustainable use of marine resources for the human society, which can be interpreted as a broad diversity of ecosystem services. The MSFD is based on an ecosystem-based approach whose scope is to manage human activities in order to minimize their impacts on the marine ecosystems. It defines 11 qualitative descriptors for determining GES: 1) biological diversity, 2) non-indigenous species, 3) population of commercial fish/shellfish, 4) elements of marine food webs, 5) eutrophication, 6) sea floor integrity, 7) alteration of hydrographical conditions, 8) contaminants, 9) contaminants in fish and seafood for human consumption, 10) marine litter, and 11) introduction of energy, including underwater noise.

Integrated Coastal Zone Management[1] (ICZM)

Since 1996, the European Commission has been working to identify and promote measures to remedy the deterioration of its coastal zones. Special improvement of the overall situation in the marine coastal zones that are particularly exposed to the risks of climate change is needed. To preserve these areas appropriately, the European Commission adopted a recommendation on Integrated Coastal Zone Management (ICZM) in 2002. ICZM integrates all policies, sectors and interests into the planning and management of human activities to achieve sustainable coastal development. The recommendation outlines steps, which the member states should take to develop national strategies for ICZM. Two sets of indicators were established, one aimed to measure progress in ICZM, the other one measuring sustainability on the coasts.

International Council for the Exploration of the Sea (ICES)

Probably the first truly international initiative for a wide-range marine monitoring originated from the establishment of the International Council for the Exploration of the Sea (ICES) in 1902. ICES has been gradually installing a monitoring program mainly focusing on the assessment of fish stocks, but also assessing their food resources.

Regional initiatives

Later several regional initiatives developed with a more detailed monitoring focus on the assessment of the ecological status of marine regions, as e.g. the **Trilateral Monitoring and Assessment Program**[2] (TMAP) in the Danish, Netherland's and German Wadden Sea of the North Sea.

Census of Marine Life

With its many subprograms, the **Census of Marine Life** program created the probably largest research network and datasets with respect to both, regional coverage as well as organism groups covered yet. History of marine animal populations (HMAP); Census of Marine Zooplankton (CMarZ);

[1] http://ec.europea.eu/environment/iczm/home.htm
[2] http://www.waddensea-secretariat.org/TMAP/Monitoring.html

Natural Geography in Shore Areas (NaGISA); Arctic Ocean Diversity (ArcOD) are just a few examples illustrating the broad diversity of topics covered within this program.

Among the research oriented initiatives, the MARS network and the EU network of excellence MarBEF should be mentioned:

European network of marine research institutes stations[1] (MARS network)

The MARS network is a foundation created in the early 1990s as an organization to unite marine institutes and stations, particularly, but not exclusively, those with coastal laboratories immediately adjacent to the sea. MARS member institutes are world leaders in fundamental marine research and have important research facilities available that allow direct access to the oceans. MARS serves furthermore as a forum and as an interest group and communicates with international organizations and the managers of European research, including the Commission of the European Community in Brussels and the Marine Board of the European Science Foundation in Strasbourg. MARS members are located all over Europe, along the shores of the Atlantic Ocean, the North, Irish, Baltic and Adriatic Seas, and the Black and Mediterranean Seas.

Marine Biodiversity and Ecosystem Functioning[2] (MarBEF)

MarBEF is a network of excellence funded by the European Union and consisting of 94 European marine institutes. It is a platform to integrate and disseminate knowledge and expertise on marine biodiversity, with links to researchers, industry, stakeholders and the general public. The specific integration effort of MarBEF is focused into the major activities: creating a virtual centre for durable integration, creating and improving access to resources, providing specialist training, developing an integrated data and information management system and the transformation of MarBEF's long-term, strategic approach into policy.

2.2.4 Indicator initiatives with special focus on freshwater environments

The management of freshwater resources has started quite early because of the major importance of clean drinking water for the development of human settlements and the many conflicts of interest resulting from the huge diversity of water use for other reasons ranging from e.g. waste disposal to recreation purposes. To list the broad variety of large regional, national and binational monitoring programs developed to ensure the availability of clean freshwater for human consumption and to allow early warning in cases of pollution would need more space than available here. Further information on respective indicators can for example be found in Nixon et al. (2003). In fact, in the past, EU framework programs financed different projects for the assessment of water quality in freshwater and inland environments and for the development of stress indicators for water status, also in relation to global climate change. However, the majority of the projects focused on single

[1] http://www.marsnetwork.org/
[2] https://www.marbef.org

indicators or specific aspects of water quality and they were generally limited to short-term data sets.

Remark to river ecosystems: In contrast to terrestrial, but also lake ecosystems, rivers have a very high water/matter/energy throughput, and very low retention times and rates in the system. Hence, the application of a common indicator set and the comparability to other ecosystems is an additional challenge.

European Water Framework Directive[1] (EU-WFD)

The directive 2000/60/ec of the European Parliament and of the Council of October 23rd, 2000 (EU Water Framework Directive, WFD) establishes a legal framework to protect and restore water across Europe and ensure its long-term, sustainable use. The directive establishes an innovative approach for water management based on river basins, the natural geographical and hydrological units, and sets specific deadlines for member states to protect aquatic ecosystems. The directive addresses inland surface waters, transitional waters, coastal waters and groundwater and targets at the achievement of a Ecological Quality Status (EQS) of all freshwater and coastal systems as well as a good ecological potential of heavily modified or artificial water bodies in the European Union until 2015. For this, all member countries had to develop harmonized classification systems for different types of aquatic ecosystems allowing the indication of ecosystem status by a set of defined biotic and abiotic components. The assessments are based on biological and supporting physico-chemical and hydromorphological elements. The status itself is assessed by comparing the observed status with a "reference status"; i.e. the status of the respective indicator in absence of significant anthropogenic pressures (done by comparison with reference sites). Long-term data sets are prerequisites to build up clear definitions of the reference status and to develop comprehensive ecological indicators. The EU-WFD aims to i) prevent degradation of aquatic ecosystems, ii) to preserve and improve their ecological status, iii) to promote sustainable use of water resources, iv) to prevent pollution of groundwaters, v) to enhance water protection by decreasing discharges of pollutants to water bodies and vi) to reduce drought and flood effects. Other objectives of the WFD are vii) to ensure sufficient supplies of good quality surface and ground waters and viii) to preserve coastal waters. Several biological ecosystem elements, including composition and abundance of the freshwater communities of phytoplankton, phytobenthos, macrophytes and benthic invertebrates as well as fish communities, are taken into account in the ecological status classification in addition to water quality and hydro-morphological conditions, which are used as supporting elements. Scientific monitoring programs in freshwaters are diverse and typically different between running and standing waters. While monitoring in rivers and streams is traditionally focused on benthic communities, the monitoring in lakes and reservoirs is focused on communities in the open water zone (i.e. plankton communities). There is an ongoing debate about the fact that zooplankton is an important component in many scientific programs but not included in the EU-WFD.

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[1] http://ec.europa.eu/environment/water/water-framework/index_en.html

Global Lake Ecological Observatory Network[1] (GLEON)

Basic monitoring of lakes focuses on variables defining the trophic state, i.e. nutrient loading and phytoplankton standing stocks. Several lake monitoring programs have recently been brought together in the Global Lake Ecological Observatory Network (GLEON), a voluntary network of researcher institutions. The aim of GLEON is not to define homogeneous standards for lake monitoring, but rather to achieve effective sharing and exchange of data, particularly data having high spatial and temporal resolution.

Further European regulations

Bathing Water Directive (76/160/ EEC): protection of the environment and public health by reducing the pollution of bathing waters.
Nitrates Directive (91/676/EEC): reduction of water pollution caused by nitrates by reducing the nitrogen input to agricultural land.
Urban Waste Water Treatment Directive (91/271/EEC): establishment of levels of treatment according to the size of population served by the treatment works and the sensitivity of the waters receiving the treated effluent. This directive will lead to a reduction in nutrient and organic matter discharges from point sources.
Integrated Pollution Prevention and Control Directive (96/61/EC): control and prevention of water pollution by reducing or eliminating emissions from industry.
Drinking Water Directive (98/83/EC): ensuring that water intended for human consumption is safe. Water intended for human consumption must be free of any micro-organism, parasite or substance that could potentially endanger human health.

The main **policy objectives**, all taken from EU legislation and documents, are:

- to prevent further deterioration and to protect and enhance the status of aquatic ecosystems and to ensure the progressive reduction of pollution of groundwater and prevent its further pollution;
- to achieve levels of water quality that do not give rise to unacceptable risks to human health (and the environment). Drinking water must be free of any microorganism, parasite or substance that could potentially endanger human health and nitrate levels must be less than the standards (guide level 25 mg NO_3/l, maximum allowable concentration 50 mg NO_3/l). In addition bathing water must achieve levels of microbiological contamination that do not give rise to significant impacts on or risks to human health;
- a progressive reduction of anthropogenic inputs of organic matter and nutrients into the water environment where these inputs are likely to cause eutrophication and depleted oxygen problems.

[1] http://www.gleon.org/

3 The DPSIR model as a framework linking environmental and human systems

The Driver–Pressure–State–Impact–Response (DPSIR) model is a tool that helps to identify and describe processes and interactions in human–environmental systems (EEA 2006, Burkhard & Müller 2008). It facilitates the analysis of specific cause–effect relationships within these systems. The first component includes the *Drivers* of human action (e.g. need for food, shelter or energy). These needs and related actions cause a *Pressure* on the environment (e.g. by land use, land cover change, pollution), which might change the *State* respectively the integrity of ecosystems. A change of the ecological state normally has an *Impact* on the provision of ecosystem goods and services and thereby, on social and economic welfare of societies. An alteration of the social and economic welfare leads to *Responses*, which at best will try to improve the situation and to mitigate negative impacts. In a next iteration of this simplifying cause-effect model, the drivers constellation might change, leading to new decisions, new pressures etc.

Referring to the concepts of ecosystem integrity and ecosystem services it can be postulated that ecological integrity (respective relevant ecosystem structures and processes) forms the base for the provision of ecosystem services. These services are the base for human well-being. Human decisions and actions (e.g. land use) again have an impact on the state of the environment (Figure 2).

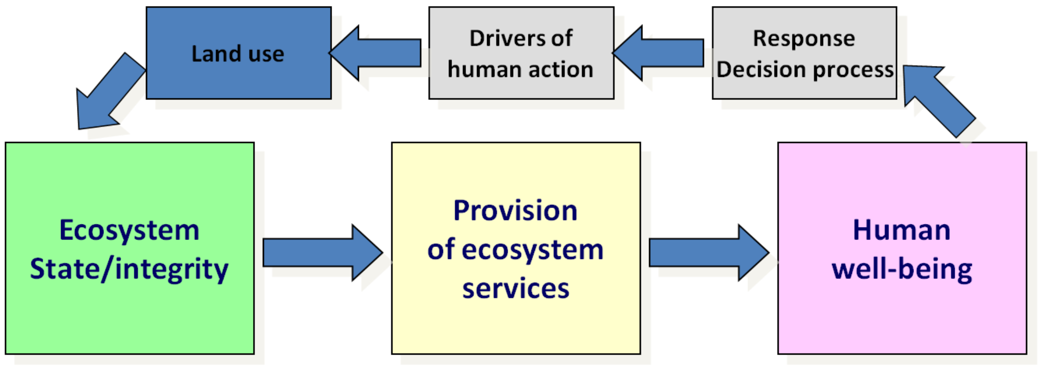

Figure 2: Ecosystem integrity as the base for the provision of ecosystem services and finally, human welfare, based on the DPSIR model.

Land use is one of the most important pressures affecting the structures and processes in ecosystems. This is due to the fact that 50-90% of the land surface is under permanent land management (land use). Land use is affecting natural and semi natural ecosystems or habitats as well as agricultural systems, as the latter often build the matrix for (semi-)natural systems. Land cover/land use and respective changes can be analyzed with the help of remote sensing data (e.g. CORINE land cover data, MODIS). These data provide logical and reproducible information about the earth's surface. From some remote sensing systems, additional information which is relevant for environmental assessments (e.g. for the indication of ecological integrity, of primary productivity) can be derived. Moreover, data from different time periods, which often are available, enable the assessment of temporal dynamics. One of the ideas in ENVEurope is to collect satellite-based land cover information in GIS format from all sites and thereby further integrate land cover/land use assessments into the framework. However, relevant questions of representativeness of these data for the particular sites (and their surrounding), appropriate scales and ground truth needs have to be solved.

4 Ecological integrity as a concept for indicator derivation

Ecological integrity indicator sets can be seen as theoretical holistic system indicators, taking into account the requirements for good indicators mentioned above. Ecological integrity has been defined by Barkmann et al. (2001) as a political target for the preservation against non-specific ecological risks, which are general disturbances of the self-organizing capacity of ecological systems. Therefore, those processes and structures, which are essential prerequisites of the ecological ability for self-organization, have to be supported and preserved. Ecosystem service indicators can be seen as a next step, bringing socio-economic components into the human-environmental system (chapter 5). The differentiation between the concepts of ecosystem health and ecological integrity is usually done by arguing that integrity is focusing on more pristine, self-organized systems, whereas health is referring rather to systems under human use (Burkhard et al. 2008). However, ecosystem health and ecological integrity are very closely linked concepts.

Following the concept of self-organization (Jørgensen 1996, Müller 1997, Jørgensen and Müller 2000, Ulanowicz 2000), the order of ecological systems emerges from spontaneous processes which operate without consciously regulating influences from the system's environment. The consequences have been condensed within the “orientor” approach (Bossel 1998, 2000, Müller and Leupelt 1998), a systems-based theory about ecosystem development, which is founded on the general ideas of non-equilibrium thermodynamics (Jørgensen 1996, 2000, Schneider and Kay 1994, Kay 2000) and network development (Fath and Patten 1998) on the one hand and succession theory on the other (e.g. Odum 1969, Dierssen 2000).

These theories state that self-organized systems are capable of creating structures and gradients if they receive a flow-through of exergy (usable energy, or the energy fraction of a system which can be transferred into mechanical work, see Jørgensen 2000). This “high quality” energy fraction is transformed within metabolic reactions, producing non-convertible energy fractions (entropy), which have to be exported into the environment of the system. As a result of these energy conversion processes, gradients (structures) are built up and maintained, leading to ordered structures and storages of the imported exergy within biomass, detritus and information (e.g. genetic information) as well as a growing degradation of the applied gradients, which is necessary for the maintenance of the system (Schneider and Kay 1994).

Hence, throughout an undisturbed development of an ecosystem (i.e. a succession), there are certain characteristics which are increasing steadily and slowly, developing towards a state which is restricted by the specific site conditions and the prevailing ecological processes. These basic thermodynamic principles have many consequences on other ecosystem features. For instance, heterogeneity, species richness and connectedness will rise, the food web will become more complex and many other attributes will follow a similar long-term trajectory (Müller & Burkhard 2007).

Unfortunately, many of these orientors cannot be easily measured or even modeled under usual circumstances. Some orientors can only be calculated on the base of very comprehensive data sets which are measured on a very small number of sites only. Other orientors can only be quantified by model applications. Therefore, the selected indicators have to be represented by parameters which are accessible by traditional methods of ecosystem quantification. Consequently, the next step of indicator derivation is a "translation" of the theoretical items into ecosystem analytical variables. Within this step, it has to be reflected that the number of indicators should be reduced as far as possible. Thus, many ecosystem variables cannot be taken into account for practical reasons. Instead, a small set consisting of the most important items which can be calculated or measured in many local instances is what we have to look for. This set should be based on the focal parameters of ecosystem research which can be made accessible in comprehensive monitoring networks (Müller et al. 2000) such as LTER.

When working with ecological indicators and complex ecosystems, it is important to be aware of the focal target of the indication. Indicators are used for the indirect comprehension of complex, not direct approachable phenomena (indicanda). By correlations with parameters (in the sense of measurable variables)[1]it is possible to describe the state and development of the indicandum quantitatively (Baumann 2001). Indicators help to assess environmental conditions, referring to the biotic, abiotic or process components of the investigated system. A hierarchical understanding of the indicator system, including the following components, is useful:

- (ecological) **Orientor**: Goal function of ecosystem development/succession considering specific environmental conditions.
- **Indicandum**: the (complex) phenomenon for which comprehension is desired.
- **Indicator**: a variable which provides aggregated information on a certain phenomenon.
- **Parameter**: data/numbers used to quantify the respective indicator. Parameters can originate directly from measurements, from modeling or they can be calculated based on further parameters (e.g. efficiency measures).

Depending on the topics to address, indicandum-indicator hierarchies might change. Therefore, one indicandum can become an indicator itself when the indicandum's hierarchical level is changed (for example, "flora diversity" is an indicator for the indicandum "biotic diversity" which again is an

[1] The terms *variable* and *parameter* are used differently (respectively synonymously) in different scientific disciplines. In order to avoid confusion, we used *parameter* throughout the whole text as defined above and as mentioned in the subproject's objectives. We are not referring to *parameters* as description of driving forces or constant values in ecological modeling.

indicator for the indicandum "ecosystem structures" which again is an indicator for our overall indicandum "ecological integrity").

The focal components which should be taken into account to represent ecosystem integrity are **ecosystem structures** (biotic diversity, abiotic heterogeneity, habitat diversity) and **ecosystem processes** (ecosystem energy balance, water balance, matter balance). For a detailed justification see Müller & Burkhard (2010). On the base of the features mentioned above, a general indicator set to describe ecosystem or landscape states of integrity has been derived. It is shown in Table 3.

The basic hypothesis concerning this set is that a holistic representation of the degree and the capacity for increasing the complexity of ecological processes on the base of a feasible number of indicators can be fulfilled by these parameters. These parameters also indicate the basic trends of ecosystem or landscape development. As a whole, this indicator set represents the degree of self-organization in the investigated system and it can be postulated that (with the exception of mature stages which are in fact very seldom in our cultural landscape) also the potential for future self-organization can be depicted with this indicator set.

Table 3: Set of "optimum" indicators to represent ecological integrity (after Müller & Burkhard (2007) and Müller (2005))

Orientor group	**Indicandum**	**Potential key parameters**
Biotic structures	Biotic diversity	e.g. number and identity of selected species
Abiotic structures	Abiotic heterogeneity	e.g. index of heterogeneity; habitat diversity
Energy balance	Exergy capture Entropy production Metabolic efficiency	Gross or net primary production Entropy production after Aoki Entropy production after Svirezhev and Steinborn Output by evapotranspiration and respiration Respiration per biomass
Water balance	Biotic water flows	Transpiration per evapotranspiration
Matter balance	Nutrient loss Storage capacity	Leaching, e.g. of Nitrate Soil organic carbon Intrabiotic nitrogen

Baumann (2001) provided an overview of indicators to quantify the self-organizing capacity of ecosystems (ecological integrity) based on monitoring data from different spatial scales (Table 4). Thus, the example indicators presented in Table 4 provide an overview on potential variables from monitoring which can be used to describe and quantify the integrity components.

Table 4: Indicators to quantify the self-organizing capacity of ecosystems (ecological integrity) (after Baumann 2001)

Indicandum	**Example indicators** - monitoring at local scales	**Example indicators** - monitoring at landscape scales
Exergy capture	gross primary production	leaf area index
Entropy production	entropy balance after Aoki (1987)	simplified entropy balance
Biotic diversity	numbers of selected species (guilds)	numbers of selected species (less species groups)
Abiotic heterogeneity	heterogeneity index (local scale)	heterogeneity index (landscape scale)
Storage capacity	biomass; stored intrabiotic N and P	biomass; stored intrabiotic N and P
Nutrient loss	Nitrogen loss (atmospheric and infiltration)	Nitrogen loss (infiltration)
Biotic water flows	transpiration / total evaporation	surface phytomass
Metabolic efficiency	respiration loss / biomass (energy usage)	soil respiration per soil biomass (qCO_2 destruents)

4.1 Compilation of useful indicators suitable for LTER-Europe sites

According to the ecosystem integrity based indicator concept, the main components to describe the **state of ecosystems** (according to the "State" component within the DPSIR model; chapter 3) are their **structures** and **processes**.

Structures have so far been described by biotic diversity (flora and fauna) and abiotic heterogeneity (soils, water, air - forming the habitats). Biotic diversity includes several components. Basically it starts with the number and identity of species, followed by numbers of individuals per species and it may end up with the genetic diversity at the population level. Additionally, biotic diversity has something to do with species traits, which is reflected in functional groups resulting in process-diversity. In order to be able also to address biotic habitat components (such as e.g. forest canopy layers), a further category "habitat structure" covering the physical structure of the biotic component is included in the "biotic diversity" indicator group (corresponding to "habitat heterogeneity" in the abiotic heterogeneity indicator group). Moreover, an ancillary "additional variables" section is included for all indicator topics. There, relevant data such as on invasive species within the biotic diversity indicator group or genetic diversity can be integrated if available. These data can provide important information on the state of the ecosystem but also about pressures on the ecosystem (e.g. by invasive species, pollutants etc.). More comprehensive information about invasive species and how to indicate their role for ecosystem functioning can be found from the SEBI initiative (EEA 2007 & 2009).

Processes in ecosystems (cycling of energy, matter and water), are characterized by indicators of inputs, storages and outputs. In order to avoid-double counting of energy components, for practical reasons a distinction has been defined between:

a) free physical energy (e.g. light, heat, hydrodynamics) as a component of the energy budget and
b) chemically bound energy (e.g. stored in biomass, nutrients in the soil) which is seen to be part of the matter budget.
Even though this distinction might be too static and perhaps too pragmatic in some cases, it seems to facilitate the work with the data from the different LTER sites (pers. comm. ENVEurope workshop Halle, Dec 2010). Based on the values for indicators of processes mentioned before and additional ecosystem state variables (if available), efficiency measures can be calculated (e.g. metabolic efficiency=respiration/biomass).

Trans-domain indication, meaning to make terrestrial, freshwater and marine sites comparable and to find suitable indicator-parameter sets from all sites, will be one major challenge for ENVEurope and for the LTER network. Some processes are perhaps very different in the particular systems, e.g. input-output balances, biomass production in fast flowing river ecosystems, biotic water flows might be difficult to be indicated in freshwater and marine ecosystems. However, structural indicators like habitat diversity which can be historically linked to land use changes have a higher potential to be suitable for trans-domain indication.

Table 5 provides an overview of the hierarchical framework for the ecological integrity indicators for the different ENVEurope/LTER ecosystem types.

Table 5: Hierarchical overview of ecological integrity indicator system for different LTER ecosystem types. Indicators/parameters have to be selected and agreed upon by the ENVEurope / LTER community.

Indicandum				**LTER ecosystem type**		
				terrestrial ecosystems	**freshwater ecosystems**	**marine ecosystems**
ecosystem structures	**biotic diversity**		flora diversity	*Indicator*	*indicator*	*indicator*
			fauna diversity	*Indicator*	*indicator*	*indicator*
			habitat structure	*Indicator*	*indicator*	*indicator*
			additional variables	*Indicator*	*indicator*	*indicator*
	abiotic heterogeneity		soil heterogeneity	*Indicator*	*indicator*	*indicator*
			water heterogeneity	*Indicator*	*indicator*	*indicator*
			air heterogeneity	*Indicator*	*indicator*	*indicator*
			habitat heterogeneity	*Indicator*	*indicator*	*indicator*
			additional variables	*Indicator*	*indicator*	*indicator*
ecosystem process	**energy budget**	*input*	exergy capture	*Indicator*	*indicator*	*indicator*
		storage	exergy storage	*Indicator*	*indicator*	*indicator*
		output	entropy production	*Indicator*	*indicator*	*indicator*
		additional state variables	meteorology	*Indicator*	*indicator*	*indicator*

		efficiency measures	metabolic efficiency	*Indicator*	*indicator*	*indicator*
	matter budget	*input*	matter input	*Indicator*	*indicator*	*indicator*
		storage	matter storage	*Indicator*	*indicator*	*indicator*
		output	matter loss	*Indicator*	*indicator*	*indicator*
		additional state variables	element concentrations	*Indicator*	*indicator*	*indicator*
		efficiency measures	nutrient cycling	*Indicator*	*indicator*	*indicator*
	water budget	*input*	water input	*Indicator*	*indicator*	*indicator*
		storage	water storage	*Indicator*	*indicator*	*indicator*
		output	water output	*Indicator*	*indicator*	*indicator*
		additional state variables	element concentrations	*Indicator*	*indicator*	*indicator*
		efficiency measures	biotic water flow	*Indicator*	*indicator*	*indicator*

4.2 Synthesis of identified indicators and parameters already measured at LTER sites: Evaluation and importance

A huge amount of data related to a high variety of themes is collected at the LTER sites. One of the main challenges in ENVEurope is to identify appropriate indicator-parameter (observation data) relationships. They have to (i) be commonly measured at many sites, (ii) regarded as important for the monitored ecosystem, (iii) enable a trans-domain indication and comparison of the sites and (iv) reflect the peculiarity of each individual site and its monitoring program.

In order to test the indicator framework's applicability as well as the data availability, a quick survey was carried out with the participants of the ENVEurope action A2 workshop in Halle 2010, December 02nd-03rd. The 27 participants of the workshop were representing different LTER sites from all over Europe (Italy, Spain, Finland, Bulgaria, Lithuania, Romania, Poland, Portugal, Hungary, Austria, Germany). All three ENVEurope ecosystem domains (terrestrial, freshwater, marine) were represented but a clear dominance of terrestrial site managers compared to marine and freshwater sites was obvious.

In this quick survey, the site managers were asked to identify, which data are available from "their" sites as parameters for the quantification of the particular ecological integrity indicators. As the structure indicators within the ecological integrity concept are indispensable and have to be measured anyway at each site, the survey focused on prioritization of process indicators. The minimum target was to define at least one parameter for each of the five ecological integrity indicanda (biotic diversity, abiotic heterogeneity, energy budget, matter budget, water budget). The second question in this quick survey was concerning parameters which were assessed to be most important to be addressed.

Each site manager was asked to chart the data availability at her/his site and to state at the same time, whether this parameter is/would be important to be measured at the site. As a result, counts of (a) data available at the sites for the individual ecological integrity indicators, and (b) their importance to be measured were derived. By adding up the individual statements and by calculating the differences between the sums of the data availabilities and their importance, data coverage and gaps can be identified. If the difference between a parameter's importance and its availability is positive, a gap within the measured parameters is likely. Table 6 shows the results of the workshop survey.

Table 6: Results from the survey at the ENVEurope workshop 2010 in Halle regarding the availability and importance of parameters monitored at LTER sites for the quantification of the ecological integrity indicators. (Note: the ranking was done on flipcharts by workshop participants, separately for "solid" and "liquid" work groups: each person was allowed to distribute 5 votes for a ranking across ecosystem processes; values in green and red have highest numbers).

			Data availability					**Parameters most important to address**					**Difference (importance-availability)**	
Ecological integrity indicators			rivers & streams	lake ecosystems	marine ecosystems	Sum aquatic ecosystems	Sum terrestrial ecosystems	rivers & streams	lake ecosystems	marine ecosystems	Sum aquatic ecosystems	Sum terrestrial ecosystems	Δ aquatic ecosystems	Δ terrestrial ecosystems
ecosystem processes	energy budget	*input*	2	4	2	**8**	**9**	2	3	2	**7**	**6**	-1	-3
		storage	1	3	2	**6**	**6**		1		**1**	**6**	-5	0
		output	1			**1**	**8**		1	1	**2**	**1**	1	-7
		other state variables		4	2	**6**	**9**				**0**	**3**	-6	-6
		efficiency measures	1	3	2	**6**	**4**	2	1	1	**4**	**5**	-2	1
	matter budget	*input*	1	2	1	**4**	**11**	2	3	1	**6**	**5**	2	-6
		storage	2	4	2	**8**	**9**	1	3	1	**5**	**7**	-3	-2
		output		4	1	**5**	**7**	1		2	**3**	**5**	-2	-2
		other state variables	1	3		**4**	**9**				**0**	**2**	-4	-7
		efficiency measures		1		**1**	**7**		2	1	**3**	**7**	2	0
	water budget	*input*	2	4	2	**8**	**9**		3	1	**4**	**6**	-4	-3
		storage	1	2	1	**4**	**4**	1	1		**2**	**2**	-2	-2
		output	1	3	1	**5**	**4**		2		**2**	**2**	-3	-2
		other state variables	1	2	1	**4**	**11**	1			**1**	**4**	-3	-7
		efficiency measures				**0**	**2**				**0**	**4**	0	2

A lot of parameters are available for estimating “other state variables” (energy, matter, and water budget), although they were not rated particularly essential for indicating ecological integrity. On the other side, energy, matter, and water efficiency were ranked as very important indicators, but there are not enough reliable parameters available to estimate them. In general, indicators of water budget were considered less important than those of energy and matter budget, perhaps because forest sites with no water deficiency was well represented in ENVEurope.

Regarding ecosystem structures (which were not surveyed here), some relevant remarks were provided during the workshop:

- β-diversity was regarded to be more important than α-diversity.
- Birds and butterflies are a good starting point for the indication of fauna diversity.

- All sites should provide EUNIS (European Nature Information System) classification values.
- In general, a priority listing and ranking by importance is needed for the biodiversity components
- Expert groups for certain animal groups should be established.
- Invasive species and their role as pressure or state indicator within the DPSIR scheme (chapter 3). It was decided to include invasive species data within the "other state variables" group, as they provide aggregated / surrogate information about potentially degraded integrity of an ecosystem.
- The scale-dependence of several indicators was mentioned as a problem several times and no satisfying solution was found yet.

For the identification of parameters currently measured at all European LTER sites, a questionnaire that was send to all European LTER site managers as part of the ENVEurope Action A2 in 2010 was used. Thereby, site specific parameters and themes were identified.

The following list of parameters was used for the query from the LTER sites:

Meteorological measurements on the site (according to WMO standards):

1. PAR
2. Wind direction (mean and gust)
3. speed (mean and gust)
4. humidity
5. temperature
6. Precipitation
7. Rainfall Chemical analysis (NO2-, NO3-, NH4+, DOC…)
8. global radiation
9. global radiation
10. Sky temperature
11. temperature
12. Albedo
13. Net sol radiation
14. Net far radiation
15. Net radiation
16. Diffuse sol radiation
17. Sunshine duration
18. Heat flux
19. Temperature soil at 5cm
20. Atmospheric pressure
21. Wet/Dry Deposition Collector
22. UV radiation
23. Others, please specify

Soil properties

1. Soil chemical characteristics (pH, CEC, EC, C and N content, …)
2. Isotopes measurements (Delta 13C measurement, Delta 15N measurement, 14C age, specify)
3. Soil bulk density
4. Soil physical characteristic
5. Potential matriciel
6. Soil contamination (N deposition, ash deposition, heavy metal, …, specify)

Soil array measurement:

1. Soil moisture with depth
2. Soil temperature with depth
3. CO2 surface flux
4. CO2 flux per soil horizon
5. N2O flux
6. Soil solution sampling and measurements: DOC, DON, P, K, Ca, Mg, Na, Cl…(specify)

Water properties

1. chemical properties (nutrients, pH, O2,….etc.)
2. physical properties (temperature, conductivity etc.)
3. Optical properties
4. Circulation and residence time
5. Ground water quantity / quality / recharge time
6. Others

Sediments properties (aquatic ecosystems)

1. Physical characteristics (water content porosity, granulometry….)
2. Chemical characteristics (pH, CEC, EC, C, N and P content, …)
3. Isotopes measurements (Delta 13C measurement, Delta 15N measurement, 14C age, specify)
4. Potential matriciel
5. Contamination (N deposition, ash deposition, heavy metal, …, specify)

Autotrophic compartment. Please indicate organism group!

1.Abundance
2.Biomass
3.Phenology
4. Biodiversity
5. Production
6. LAI
7. C and N content
8. C, N, Mg, K, P, Na, content...
9. Other

Heterotrophic compartment (procaryotic and eucaryotic) Please indicate organism group!

1.Abundance
2.Biomass
3.Phenology
4. Biodiversity (incl. species richness, dominance structure, composition)
5. C and N content
4. DNA storage
6. Other

Biodiversity: For each taxonomic group, how many plots/stations and which area do they cover/represent? Inventory of entire site? Population biology parameters (mortality, germination, individual based tree data, etc.)? Frequency of observations? Length of time series? Do habitat maps exist (relevant for catchments)? Please add any other measurements being done and which are important for your group

1. Procariots
2. Microalgae
3. Macroalgae
4. Vascular plants / Aquatic macrophytes
5. Lichens
6. Mosses
7. Fungi
8. Annelida
9. Molluscs
10. Crustaceans
11. Insects
12. Spiders
13. Other Arthropods
14. Amphibians
15. Reptiles
16. Mammals: small mammals
17. mammals: ungulates
18. Birds
19. Fish
20. Others
21. Other categories: Zooplankton, Meiofauna, Benthic macroinvertebrates
22. Paleolimnological samples (diatoms, ostracods, chironomid headcapsules, chaoborus mandibles, fish scales etc.) Lake sediment are integrating information on the environmental change (e.g. climate change

Many of the data monitored fit well with the concept of ecological integrity and respective indicators presented above. Tables 7/1-7/3 link the ecological integrity components and indicators (from Table 5) to the parameters from the LTER questionnaire. Note that this is just a qualitative assignment, neither considering the availability and frequency of parameters nor the quality measured at the sites.

Table 7/1 -7/3: Linking ecological integrity indicators (as shown in Table 5) and parameters measured at LTER sites.

				Parameters from ENVEurope questionnaire (2010): Meteorological measurements on the site																						
Ecological integrity indicators				1. PAR	2. Wind direction (mean and gust)	3. Wind speed (mean and gust)	4. Air humidity	5. Air temperature	6. Precipitation	7. Rainfall Chemical analysis (NO2-	8. global radiation	9. reflected global radiation	10. Sky temperature	11. Ground temperature	12. Albedo	13. Net sol radiation	14. Net far radiation	15. Net radiation	16. Diffuse sol radiation	17. Sunshine duration	18. Heat flux	19. Temperature soil at 5cm	20. Atmospheric pressure	21. Wet/Dry Deposition Collector	22. UV radiation	23. Others, please specify
ecosystem structures	biotic diversity		flora diversity																							
			fauna diversity																							
			habitat diversity																							
			additional variables																							
	abiotic heterogeneity		soil heterogeneity											x								x				
			water heterogeneity																							
			air heterogeneity		x	x	x	x					x										x			
			habitat heterogeneity																							
			additional variables																							x
ecosystem processes	energy budget	*input*	exergy capture	x							x			x	x	x	x	x	x	x		x			x	
		storage	exergy storage																		x	x				
		output	entropy production					x				x	x		x											
		other state variables	meteorology	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x		x	
		efficiency measures	metabolic efficiency																							
	matter budget	*input*	matter input							x														x		
		storage	matter storage																							
		output	matter loss																							
		other state variables	element concentrations																					x		
		efficiency measures	nutrient cycling																							
	water budget	*input*	water input				x		x																	
		storage	water storage																							
		output	water output																							
		other state variables	element concentrations				x			x																
		efficiency measures	biotic water flow																							

Parameters from questionnaire for ENVEurope LTER-sites (2010):

Ecological integrity indicators				Soil properties: 1. Soil chemical characteristics (pH, CE	2. Isotopes measurements	3. Soil bulk density	4. Soil physical characteristic	5. Potential matriciel	6. Soil contamination (N deposition, as	Soil array measurement: 1. Soil moisture with depth	2. Soil temperature with depth	3. CO2 surface flux	4. CO2 flux per soil horizon	5. N2O flux	6. Soil solution sampling and measurer	Water properties: 1. chemical properties (nutrients, pH, C	2. physical properties (temperature, c	3. Optical properties	4. Circulation and residence time	5. Ground water quantity / quality / re	6. Others	Sediment properties (aquatic): 1. Physical characteristics (water conte	2. Chemical characteristics (pH, CEC, E	3. Isotopes measurements	4. Potential matriciel	5. Contamination (N deposition, ash de	Autotrophic compartment. incl.organism group: 1.Abundance	2.Biomass	3.Phenology	4. Biodiversity	5. Production	6. LAI	7. C and N content	8. C, N, Mg, K, P, Na, content…	9. Other
ecosystem structures	biotic diversity		flora diversity																								x			x					
ecosystem structures	biotic diversity		fauna diversity																																
ecosystem structures	biotic diversity		habitat diversity																								x	x	x	x					x
ecosystem structures	biotic diversity		additional variables																																x
ecosystem structures	abiotic heterogeneity		soil heterogeneity	x	x	x	x			x	x				x							x	x	x											
ecosystem structures	abiotic heterogeneity		water heterogeneity													x	x	x																	
ecosystem structures	abiotic heterogeneity		air heterogeneity																																
ecosystem structures	abiotic heterogeneity		habitat heterogeneity																																
ecosystem structures	abiotic heterogeneity		additional variables																		x														
ecosystem processes	energy budget	*input*	exergy capture																										x		x	x			
ecosystem processes	energy budget	*storage*	exergy storage								x																	x					x	x	
ecosystem processes	energy budget	*output*	entropy production									x	x																						
ecosystem processes	energy budget	*other state variables*	meteorology																										x						
ecosystem processes	energy budget	*efficiency measures*	metabolic efficiency																												x				
ecosystem processes	matter budget	*input*	matter input																																
ecosystem processes	matter budget	*storage*	matter storage	x		x	x								x							x	x	x									x	x	
ecosystem processes	matter budget	*output*	matter loss		x							x	x	x	x	x																			
ecosystem processes	matter budget	*other state variables*	element concentrations	x	x	x									x				x					x		x									
ecosystem processes	matter budget	*efficiency measures*	nutrient cycling	x																															
ecosystem processes	water budget	*input*	water input																x	x															
ecosystem processes	water budget	*storage*	water storage							x									x	x															
ecosystem processes	water budget	*output*	water output																x	x															
ecosystem processes	water budget	*other state variables*	element concentrations													x		x		x			x												
ecosystem processes	water budget	*efficiency measures*	biotic water flow																																

Parameters from questionnaire for ENVEurope LTER-sites (2010):

Ecological integrity indicators				Heterotrophic compartment: 1.Abundance	2.Biomass	3.Phenology	4. Biodiversity (incl. species richness, d	5. C and N content	4. DNA storage	6. Other	Biodiversity: 1. Procariots	2. Microalgae	3. Macroalgae	4. Vascular plants / Aquatic macrophyt	5. Lichens	6. Mosses	7. Fungi	8. Annelida	9. Molluscs	10. Crustaceans	11. Insects	12. Spiders	13. Other Arthropods	14. Amphibians	15. Reptiles	16. Mammals: small mammals	17. mammals: ungulates	18. Birds	19. Fish	20. Others	21 .Other categories: Zooplancton, Me
ecosystem structures	biotic diversity		flora diversity									x	x	x	x	x	x														
ecosystem structures	biotic diversity		fauna diversity	x			x		x		x							x	x	x	x	x	x	x	x	x	x	x	x		x
ecosystem structures	biotic diversity		habitat diversity	x	x	x	x			x			x	x		x										x	x	x	x	x	x
ecosystem structures	biotic diversity		additional variables							x																				x	x
ecosystem structures	abiotic heterogeneity		soil heterogeneity																												
ecosystem structures	abiotic heterogeneity		water heterogeneity																												
ecosystem structures	abiotic heterogeneity		air heterogeneity																												
ecosystem structures	abiotic heterogeneity		habitat heterogeneity																												
ecosystem structures	abiotic heterogeneity		additional variables																												
ecosystem processes	energy budget	*input*	exergy capture			x																									
ecosystem processes	energy budget	*storage*	exergy storage		x			x																							
ecosystem processes	energy budget	*output*	entropy production																												
ecosystem processes	energy budget	*other state variables*	meteorology			x																									
ecosystem processes	energy budget	*efficiency measures*	metabolic efficiency																												
ecosystem processes	matter budget	*input*	matter input																												
ecosystem processes	matter budget	*storage*	matter storage					x																							
ecosystem processes	matter budget	*output*	matter loss																												
ecosystem processes	matter budget	*other state variables*	element concentrations																												
ecosystem processes	matter budget	*efficiency measures*	nutrient cycling																												
ecosystem processes	water budget	*input*	water input																												
ecosystem processes	water budget	*storage*	water storage																												
ecosystem processes	water budget	*output*	water output																												
ecosystem processes	water budget	*other state variables*	element concentrations																												
ecosystem processes	water budget	*efficiency measures*	biotic water flow																												

As tables 7/1-3 illustrate, most of the parameters monitored at the 65 example LTER sites with metadata available until November 19th 2010 can be linked to the ecological integrity indicators. Looking at ENVEurope LTER sites, for almost all ecological integrity components data are available somewhere, but not consistently for many sites. For example, a lot of biodiversity and energy budget (from meteorological measurements) related data seem to be available. However, it becomes obvious that it is easy to establish a clear link between ecological integrity indicators and data collected at the LTER sites. Figure 3 gives an overview on the potential roles of the different data sources within the DPSIR framework presented in chapter 3.

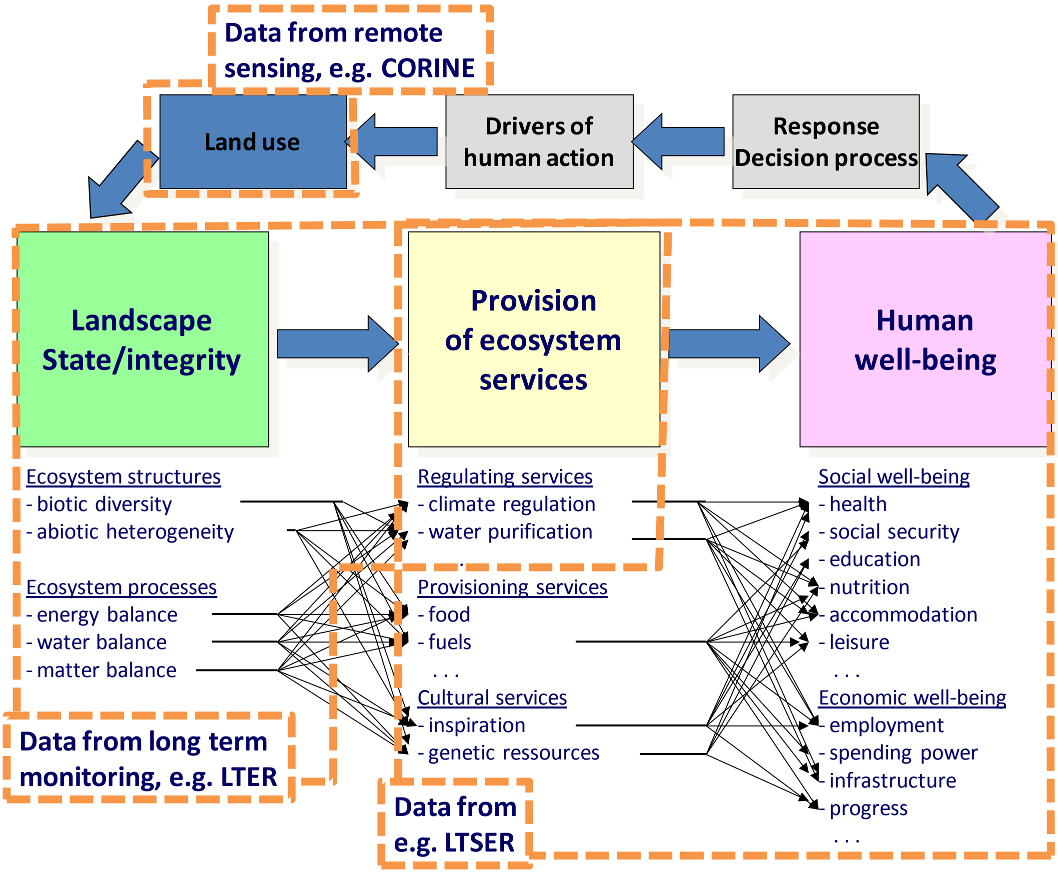

Figure 3: Potential roles of available data sources within the DPSIR framework (Figure 2).

This argues for the concept of ecological integrity as a suitable framework for designing of a common indicator/parameter framework for LTER Europe. A first step identifying suitable indicator-parameter relations has been done (see Tables 7/1-3), but the final identification of these relations will demand for some more efforts. Additionally, questions of different spatial and temporal scales, varying data qualities and quantities have to be solved. But a common framework and a European strategy for a joint environmental monitoring would add much value to the current monitoring systems. Relevant problems in current human-environmental systems, like for example the impact of alien species on ecological integrity and ecosystem services (see Vilà et al. 2010), can be analyzed in detail within such a framework.

4.3 Identification of over-arching indicators and indicators specific for LTER ecosystems

Referring to the ecological integrity indicator components presented before, we suggest the development of a core set of environmental themes and indicators for the different LTER ecosystem types. These core set indicators are supplemented by relevant site-specific parameters from monitoring (Figure 4).

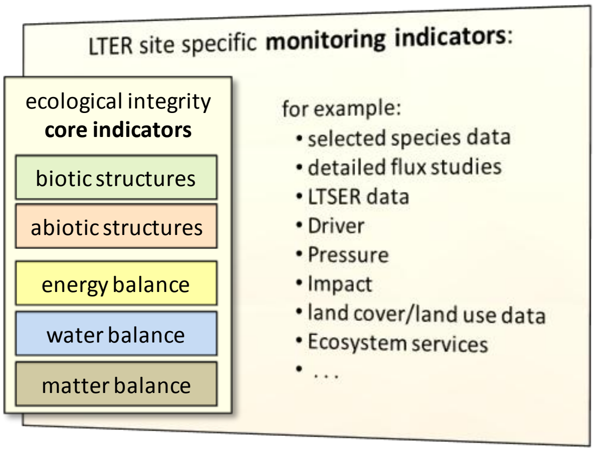

Figure 4: The role of core indicators within the LTER monitoring framework.

In a next step, the answers from 65 sites to the questionnaire until 2010 November 19th, were analyzed. Tables 8/1 and 8/2 provide an overview of the parameters currently monitored at 65 exemplary LTER sites in 10 different European countries. As the tables show, there is a high amount of meteorological data collected at almost all sites. Regarding the other topics, the amount of monitoring sites and measured parameters is highly varying. This emphasizes the importance of detailed metadata about the measurements carried out, as this will be the decisive tool to select subgroups of sites suitable for common analysis of parameters. We are aware that the introduction of new parameters for LTER sites is limited by the resources available and thus only very few “cheap” new parameters might be proposed. The biggest resource is the intelligent combination of what is already there and pay attention to close the most important gaps.

Table 8/1 & 8/2: Overview of parameters monitored at exemplary LTER sites (65 LTER who has filled the questionnaire until Novembr,19th, 2010)

Parameters from questionnaire for ENVEurope LTER-sites (2010):

			Meteorological measurements on the site																							Soil properties						Soil array measurement						Water properties					
Country	Name	ID	1. PAR	2. Wind direction (mean and gust)	3. Wind speed (mean and gust)	4. Air humidity	5. Air temperature	6. Precipitation	7. Rainfall Chemical analysis (NO2-, NO3-, NH4+,	8. global radiation	9. reflected global radiation	10. Sky temperature	11. Ground temperature	12. Albedo	13. Net sol radiation	14. Net far radiation	15. Net radiation	16. Diffuse sol radiation	17. Sunshine duration	18. Heat flux	19. Temperature soil at 5cm	20. Atmospheric pressure	21. Wet/Dry Deposition Collector	22. UV radiation	23. Others, please specify	1. Soil chemical characteristics (pH, CEC, EC, C and N	2. Isotopes measurements	3. Soil bulk density	4. Soil physical characteristic	5. Potential matriciel	6. Soil contamination (N deposition, ash deposition, h	1. Soil moisture with depth	2. Soil temperature with depth	3. CO2 surface flux	4. CO2 flux per soil horizon	5. N2O flux	6. Soil solution sampling and measurements: DOC, DO	1. chemical properties (nutrients, pH, O2,....ecc.)	2. physical properties (temperature, conductivity etc	3. Optical properties	4. Circulation and residence time	5. Ground water quantity / quality / recharge time	6. Others
Austria	Zöbelboden	SI000049		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x			x	x	x	x		x	x	x	x			x	x	x	x	x	x	
Germany	Darss-Zingst Bodden	SI000315	x	x	x		x	x	x	x														x														x	x	x	x		x
Italy	Golfo di Venezia	SI001242	x	x	x	x	x	x		x			x									x		x														x	x	x			
Italy	Golfo di Trieste	SI001243		x	x	x	x																															x	x	x			
Italy	Staz. MareChiara	SI001247											x																									x	x	x			
Italy	Lacco Ameno	SI001248											x																									x	x	x			
Sweden	Gårdsjön	SI000902	?	x	x	x	x	x	x	x			x								x		x			x		x	x		x	x	x				x	x	x			x	
Sweden	Aneboda	SI000898	?	x	x	x	x	x	x	x			x								x		x			x		x	x		x	x	x				x	x	x			x	
Sweden	Kindla	SI001007	?	x	x	x	x	x	x	x			x								x		x			x		x	x		x	x	x				x	x	x			x	
Sweden	Gammtratten	SI000901	?	x	x	x	x	x	x	x			x								x		x			x		x	x		x	x	x				x	x	x			x	
Germany	Rhein-Main-Observatorium	SI001513				x	x	x																														x	x				x
Lithuania		SI001489	x	x	x	x	x	x	x	x		x	x										x	x		x		x	x		x	x	x				x	x	x		x	x	
Lithuania		SI001468	x	x	x	x	x	x	x	x		x	x		x	x	x		x		x		x	x		x		x	x		x	x	x				x	x	x		x	x	
Lithuania		SI001457	x	x	x	x	x	x	x	x		x	x		x	x	x		x		x		x	x		x		x	x		x	x	x				x	x	x		x	x	
Hungary	Sikfokut LTER	SI000360	x	x	x	x	x	x	x	x	x			x	x		x	x	x	x	x	x				x			x			x	x	x			x						
Hungary	KISKUN LTER	SI001305																																									
Germany	NP Eifel	SI000321	x	x	x	x	x	x	x	x	x			x	x	x	x			x	x	x	x			x		x	x	x	x	x	x	x				x	x	x		x	
Hungary	Balaton	SI001302		x	x	x	x	x	x	x				x					x			x		x														x	x	x			
Italy	Apennines	SI001230					x	x	x														x		x													x	x	x	x		
Romania	RO01 Bucegi P. Craialui NP	SI000706		x	x	x	x	x	x	x			x						x		x	x	x			x			x								x						
Italy	Bosco Fontana	SI001223		x	x	x	x	x		x		x					x					x																					
Italy	Monum.Nat.Torre Flavia	SI001497			x																					x			x			x					x						
Italy	Foce Trigno Marina di Petacciato	SI001498			x																					x			x			x					x						
Italy	Biferno litorale di Campo Marino	SI001499			x																					x			x			x					x						
Italy	Foce Saccione Bonifica Ramitelli	SI001500			x																					x			x			x					x						
Italy	Punta Aderci	SI001501			x																					x			x			x					x						
Italy	Marina di Vasto	SI001502			x																					x			x			x					x						
Finland	02 Lake Paijanne	SI001186	x	x	x	x	x	x		x					x							x		x														x	x		x		
Italy	08 Southern Alpine Lakes	SI001228	x	x	x	x	x	x	x													x	x															x	x	x	x		
Italy	10 Lake Sardinia	SI001231					x	x														x																x	x		x		
Germany	Uckermark	SI000328	x	x	x	x	x	x		x			x								x				x	x		x	x			x	x			x	x	x	x	x	x	x	
Spain	Sierra Nevada	SI001345	x	x	x	x	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x													x	x	x				
Spain	Ordesa	SI001355		x	x	x	x	x		x																																	
Spain	Aigüestortes	SI001347	x	x	x	x	x	x	x	x	x				x							x				x		x	x		x							x	x	x	x		
Spain	Doñana	SI001346	x	x	x	x	x	x		x	x	x		x	x	x	x	x		x	x	x										x	x					x	x				
Italy	TOS1	SI001118		x	x	x	x	x	x	x	x		x								x	x	x			x		x	x	x	x	x	x				x						
Italy	LAZ1	SI001113		x	x	x	x	x	x	x	x		x								x	x	x			x		x	x	x	x	x	x				x						
Italy	SIC1	SI001117							x																	x		x	x	x	x	x	x										
Poland	Pilica	SI001473		x	x	x	x	x														x		x	x	x			x								x	x	x	x		x	
Italy	Gran Sasso	SI001135					x	x													x					x			x					x	x		x						
Italy	Monte Velino	SI001136					x	x													x					x			x					x	x		x						
Italy	Majella	SI001219					x	x													x					x			x					x	x		x						
Italy	Appenino settentrionale	SI001221					x	x													x					x			x					x	x		x						
Italy	Matese	SI001220					x	x													x					x			x					x	x		x						
Italy	BOL1	SI001102		x	x	x	x	x	x	x	x		x								x	x				x		x	x	x	x	x	x				x						
Italy	TRE1	SI001119		x	x	x	x	x	x	x	x		x								x	x				x		x	x	x	x	x	x				x						
Italy	FRI2	SI001112		x	x	x	x	x	x	x	x		x								x	x				x		x	x	x	x	x	x				x						
Italy	Valbona	???		x	x	x	x	x	x	x																x			x								x						
Italy	Lagoon of Venice	SI001258	x	x	x	x	x	x		x												x		x														x	x	x			
Italy	Po di Goro	SI001244	x	x	x	x	x	x		x			x									x		x														x	x	x			
Italy	Transetto Senigallia-Susak	SI001245	x	x	x	x	x	x		x			x									x		x														x	x	x			
Germany	LH-Wanzleben	SI001295		x	x	x	x	x					x								x				x																		
Germany	LH-Schafstaedt	SI001297		x	x	x	x	x					x																														
Germany	LH-Greifenhagen	SI001296		x	x	x	x	x					x								x				x																		
Germany	LH-Friedeburg	SI001294		x	x	x	x	x					x								x				x																		x
Spain	Illas Atlánticas	SI001349		x	x	x	x	x		x									x			x																x	x		x		
Spain	Collserola / Barcelona (ES-SNE)	SI001350		x	x	x	x	x	x	x													x			x		x	x		x												
Romania	Braila Islands	SI000726		x	x		x	x							x						x	x	x	x		x		x				x	x					x	x	x	x	x	
Romania	Neajlov catchment	SI000724			x		x	x																														x	x				
Bulgaria	Mesta river	SI001481																																				x	x			x	
Bulgaria	Sozopol	SI001483	x																																			x	x	x			
Bulgaria	Srebarna	SI001482				x	x	x														x																x	x	x			x
Bulgaria	Yundola	SI001488		x	x		x	x																		x	x		x														
Bulgaria	Petrohan (BG02)	SI001486						x	x																	x		x			x						x	x					
Germany	Bornhoeved	SI000314	x	x	x	x	x	x	x	x									x		x		x			x		x	x	x	x		x	x									

			Parameters from questionnaire for ENVEurope LTER-sites (2010):																																									
			Sediments properties (aquatic ecosystems)					**Autotrophic compartment. incl.organism group**									**Heterotrophic compartment (procaryotic and eucaryotic)**							**Biodiversity**																				
Country	**Name**	**ID**	1. Physical characteristics (water content porosity, gr	2. Chemical characteristics (pH, CEC, EC, C, N and P c	3. Isotopes measurements	4. Potential matriciel	5. Contamination (N deposition, ash deposition, heav	1.Abundance	2.Biomass	3.Phenology	4. Biodiversity	5. Production	6. LAI	7. C and N content	8. C, N, Mg, K, P, Na, content…	9. Other	1.Abundance	2.Biomass	3.Phenology	4. Biodiversity (incl. species richness, dominance stru	5. C and N content	4. DNA storage	6. Other	Procariots	Microalgae	Macroalgae	Vascular plants / Aquatic macrophytes	Lichens	Mosses	Fungi	Annelida	Molluscs	Crustaceans	Insects	Spiders	Other Arthropods	Amphibians	Reptiles	Mammals: small mammals	mammals: ungulates	Birds	Fish	Others	Other categories: Zooplancton, Meiofauna, Benthic m
Austria	Zöbelboden	SI000049						x	x		x	x	x	x	x												x	x	x												x			
Germany	Darss-Zingst Bodden	SI000315						x	x		x	x		x			x	x		x				x	x																			x
Italy	Golfo di Venezia	SI001242						x	x	x	x	x		x			x	x							x																			x
Italy	Golfo di Trieste	SI001243	x	x				x	x	x	x			x			x	x																										
Italy	Staz. MareChiara	SI001247						x	x	x	x	x					x	x	x	x		x			x								x											x
Italy	Lacco Ameno	SI001248						x	x	x	x	x					x	x	x	x		x			x								x											x
Sweden	Gårdsjön	SI000902																																										
Sweden	Aneboda	SI000898																																										
Sweden	Kindla	SI001007																																										
Sweden	Gammtratten	SI000901																																										
Germany	Rhein-Main-Observatorium	SI001513						x			x						x			x							x				x	x	x	x										x
Lithuania		SI001489																																										
Lithuania		SI001468																																										
Lithuania		SI001457																																										
Hungary	Sikfokut LTER	SI000360						x	x	x	x	x	x	x	x		x										x		x					x					x		x			
Hungary	KISKUN LTER	SI001305							x		x	x	x																															
Germany	NP Eifel	SI000321							x																							x			x					x				x
Hungary	Balaton	SI001302	x	x				x	x	x	x	x	x			x	x	x	x	x			x		x	x	x						x	x							x	x	x	x
Italy	Apennines	SI001230	x	x				x	x	x	x	x					x	x	x	x													x									x		x
Romania	RO01 Bucegi P. Craialui NP	SI000706						x	x		x																																	
Italy	Bosco Fontana	SI001223									x			x	x							x					x			x	x	x	x	x	x	x	x	x	x		x	x		x
Italy	Monum.Nat.Torre Flavia	SI001497						x			x						x		x	x							x											x			x			
Italy	Foce Trigno Marina di Petacciato	SI001498						x			x						x		x	x							x											x			x			
Italy	Biferno litorale di Campo Marino	SI001499						x			x						x		x	x							x											x			x			
Italy	Foce Saccione Bonifica Ramitelli	SI001500						x			x						x		x	x							x											x			x			
Italy	Punta Aderci	SI001501						x			x						x		x	x							x											x			x			
Italy	Marina di Vasto	SI001502						x			x						x		x	x							x											x			x			
Finland	02 Lake Paijanne	SI001186						x	x								x	x		x																						x		x
Italy	08 Southern Alpine Lakes	SI001228	x	x				x	x	x	x	x					x	x	x	x				x	x		x						x											x
Italy	10 Lake Sardinia	SI001231						x	x	x	x														x																			
Germany	Uckermark	SI000328						x	x			x	x		x	x		x									x			x				x	x				x		x			
Spain	Sierra Nevada	SI001345																							x		x							x			x		x	x	x	x		
Spain	Ordesa	SI001355									x																x									x	x		x		x			
Spain	Aigüestortes	SI001347	x	x	x		x	x	x	x	x	x		x			x			x				x	x		x					x		x					x	x	x			x
Spain	Doñana	SI001346						x	x	x	x	x					x		x								x							x		x	x	x		x	x	x		
Italy	TOS1	SI001118							x	x	x	x			x								x				x	x	x					x										
Italy	LAZ1	SI001113								x	x	x			x	x							x				x							x					x		x			
Italy	SIC1	SI001117								x	x	x			x	x							x				x	x	x					x										
Poland	Pilica	SI001473	x	x			x		x		x				x		x	x		x				x			x															x		x
Italy	Gran Sasso	SI001135						x			x											x					x																	
Italy	Monte Velino	SI001136						x			x											x					x																	
Italy	Majella	SI001219						x			x											x					x																	
Italy	Appenino settentrionale	SI001221						x			x											x					x																	
Italy	Matese	SI001220						x			x											x					x																	
Italy	BOL1	SI001102								x					x												x	x	x					x										
Italy	TRE1	SI001119								x					x												x	x	x					x										
Italy	FRI2	SI001112								x					x												x	x	x					x										
Italy	Valbona	???																x												x					x	x			x					x
Italy	Lagoon of Venice	SI001258						x	x	x	x	x		x			x	x							x																			x
Italy	Po di Goro	SI001244						x	x	x	x	x		x			x	x							x																			x
Italy	Transetto Senigallia-Susak	SI001245						x	x	x	x	x		x			x	x							x																			
Germany	LH-Wanzleben	SI001295						x			x					x	x			x							x							x							x			
Germany	LH-Schafstaedt	SI001297						x			x						x			x							x							x							x			
Germany	LH-Greifenhagen	SI001296						x			x					x	x			x							x							x							x			
Germany	LH-Friedeburg	SI001294						x			x					x	x			x			x				x							x							x			
Spain	Illas Atlánticas	SI001349						x			x														x		x	x				x	x				x		x		x	x		
Spain	Collserola / Barcelona (ES-SNE)	SI001350								x		x																x				x		x					x	x	x	x		
Romania	Braila Islands	SI000726		x			x	x	x		x	x		x			x	x		x	x																x					x		
Romania	Neajlov catchment	SI000724																																										
Bulgaria	Mesta river	SI001481	x	x			x	x	x		x						x	x	x	x					x						x											x		x
Bulgaria	Sozopol	SI001483	x	x			x	x	x		x	x		x						x		x				x																		
Bulgaria	Srebarna	SI001482					x	x	x	x	x	x					x	x	x	x					x						x	x	x			x					x	x		x
Bulgaria	Yundola	SI001488							x		x	x	x																															
Bulgaria	Petrohan (BG02)	SI001486																																										
Germany	Bornhoeved	SI000314						x	x	x	x																x		x															

4.4 Example application

In Table 9 an example is given of how measured values from the exemplary LTER and IPC Forest LEVEL II site "Bornhöveder Lake District" in northern Germany (SI000314) can be applied to practically quantify the ecological integrity indicators. The site and the area were part of the interdisciplinary research and development project "Long term research in the Bornhöved Lake District", which started in 1988 and covered a primary observation period of 12 years (Fränzle et al. 2009). The main aims of the project were the analysis and modeling of ecosystem structures, dynamics and stability conditions and the assessment of environmental strains and related resilience mechanisms (Tavares et al. 2010). Today the site is part of the European forest monitoring program LEVEL II and of LTER Europe. As Table 9 illustrates, the current monitoring focuses on matter budget (especially deposition inputs) and forest conditions (for the LEVEL II network).

Table 9: Example from the LTER site Bornhöved lakes district on how to link monitoring data to the ecological integrity indicator concept.

Indicandum			Example: Bornhöved forest ecosystem (Level II and LTER site)			
			Indicator	unit / classification	resolution of records	comment
biotic diversity		flora diversity*	ground vegetation survey	e.g.shannon-wiener-index	annual	
		fauna diversity*	*			
		additional variables	circumference and height of trees	m	6 weeks	
			discoloration	0,1,2,3,4	annual	see ICP manual (http://www.futmon.org/submission.htm); 2009 & 2010 version
			foliage loss	0,5,10……95,100	annual	see ICP manual (http://www.futmon.org/submission.htm); 2009 & 2010 version
			visibility	1,2,3,4	annual	see ICP manual (http://www.futmon.org/submission.htm); 2009 & 2010 version
			crown shading	1,2,3,4,5,6	annual	see ICP manual (http://www.futmon.org/submission.htm); 2009 & 2010 version
			social status (Kraftsche Klasse)	1,2,3,4,5	annual	see ICP manual (http://www.futmon.org/submission.htm); 2009 & 2010 version
			fruiting	sparse, moderate, abundant, mast	annual	
abiotic heterogeneity		soil heterogeneity*	Water availability	(insufficient = 1, sufficient = 2, excessive = 3)	5 years interval	see ICP manual (http://www.futmon.org/submission.htm); 2009 & 2010 version
				(Mull = 1, Moder = 2, etc.)	5 years interval	see ICP manual (http://www.futmon.org/submission.htm); 2009 & 2010 version
			Code of the WRB Reference Soil Group (2006)		5 years interval	see ICP manual (http://www.futmon.org/submission.htm); 2009 & 2010 version
			Code of the WRB Qualifier, e.g. Gleyic		5 years interval	see ICP manual (http://www.futmon.org/submission.htm); 2009 & 2010 version
			Code for Parent Material		5 years interval	see ICP manual (http://www.futmon.org/submission.htm); 2009 & 2010 version
		water heterogeneity*	*			
		air heterogeneity	wind speed in different heights (2m,6m,16m)			
energy budget	*input*	exergy capture	solar radiation	$W \cdot m^{-2}$	subhour	mean values
	storage	exergy storage	biomass (NPP)	$J \cdot m^{-3}$	annual	
	output	entropy production	terrestrial radiation	$W \cdot m^{-2}$	subhour	
	additional state variables	meteorology	wind direction	°; 0° = North, 270°= West		
			air temperature	°C	day	mean, min and max value
			relative humidity	%	day	mean, min and max value
			wind speed	$m \cdot s^{-1}$	day	mean and max value
			UV b radiation	W/m²		mean values
	efficiency measures	metabolic efficiency*	*			
matter budget	*input*	matter input	Deposition of DOC	$mg \cdot l^{-1}$	~weekly	
			Deposition of c(Ca^{2+}), c(Mg^{2+}), c(K^{+}), c(Na^{+}), c(Ca2+), c(Mg2+), c(K+), c(Na+), c(Mn2+), c(SO42-), c(PO43-), c(Cl-), c(N-NH4), c(N-NO3), c(TDN)	$mg \cdot l^{-1}$	~weekly	
	storage	matter storage*	*			
	output	matter loss	Soil solution (5cm, 12cm, 50cm, 150cm, 400cm)			same parameters as for deposition
	additional state variables	element concentrations	pH; alkalinity	$mg \cdot l^{-1}$		
			DOC, Ca,Mg, K, Na, Mn, SO, PO, Cl, N (NH4), N (NO3)	$mg \cdot l^{-1}$		same parameters as for deposition
	efficiency measures	nutrient cycling*	*			modelling
water budget	*input*	water input	precipitation, stemflow, throughfall	mm-d-1	day	modelling
	storage	water storage	water content (5cm, 12cm, 50cm, 150cm)	$m^3 \cdot m^{-3}$	minute/hour	mean, min and max value
	output	water output	interception		weekly	
			seepage (400cm)		weekly	
	additional state variables	model results*	*			modelling
	efficiency measures	biotic water flow	Transpiration/evapotranspiration			modelling

In Figure 5, a graphical presentation of selected ecological integrity parameters from the LTER site Bornhöved (beech forest) for the four different seasons is shown (Tavares et al. 2010). The following indicators from Table 8 are included:

- matter input: Nitrogen deposition (kg/ha season): DEP_N_NO3, DEP_N_NH4, DEP_N_total, Carbon deposition (kg/ha season): DEP_DOC
- matter loss: soil solution in 150 cm depth in kg/ha season: N_NO3, DOC
- element concentrations: pH in soil solution in 150 cm depth
- energy budget: air Temperature (°C average)
- biotic water flow: transpiration/evapotranspiration (T/Et_average)
- exergy capture: global radiation (J cm^{-2})
- water input: precipitation (mm/season)

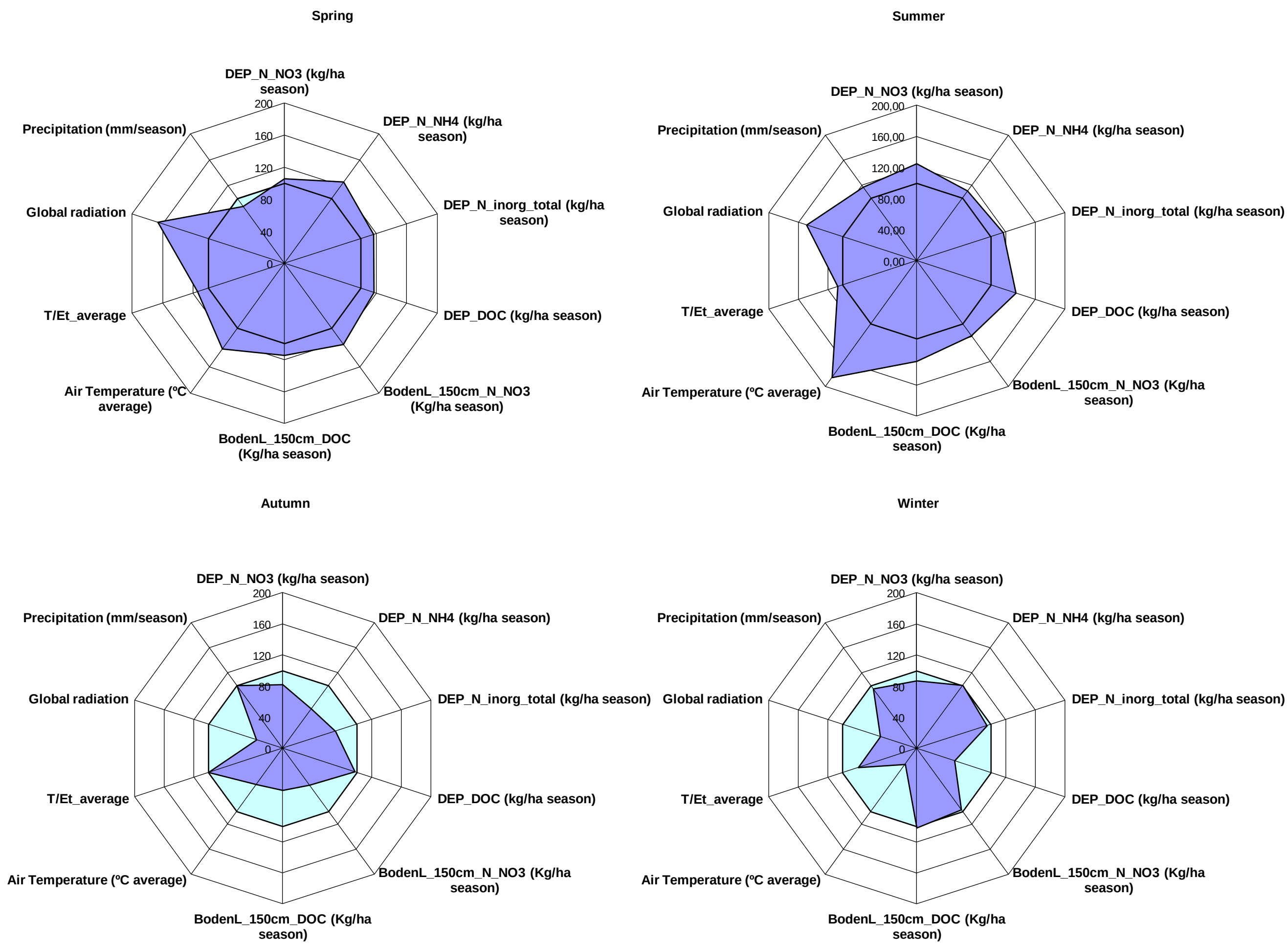

Figure 5: Seasonal variations of selected ecological integrity parameters at the Bornhöved beech forest. All values are normalized to 100 %, representing the long-term average of the respective parameter in the reference period 1989-2005 (after Tavares et al. 2010).

5 The concept of ecosystem goods and services as a base for societal indicators

For the integration of information from environmental monitoring with socio-economic monitoring and assessment, the concept of ecosystem goods and services provides a useful framework. The environment provides space to live for humans and other organisms and supports us with products and processes which are the base for life on earth. Classifications of ecosystem goods and services are linking structures and processes (means) for achieving goods and services and the goods and services themselves (end products, benefits) within different classification categories. The base of these relationships is built by processes like soil formation, photosynthesis of autotrophic plants or cycling of energy, matter and water. These processes were named supporting ecosystem services (MA 2005) although they do not only support the other forms of ecosystem services, but actually they are prerequisites for their performance. Looking at the different supporting services it becomes obvious that distinctive ecosystem structures and processes are needed for their operation. Cycling of energy, matter and water, a specific diversity of functional key species and suitable abiotic conditions are key components for the description of ecosystem functioning (de Groot et al. 2010).

Similar factors are mentioned in the concept of ecosystem integrity (see chapter 4) which aims at preserving those structures and functions that are necessary for the maintenance of the self-organizing capacity of ecological systems (Barkmann et al. 2001). Hence, ecosystems with a high integrity provide a high degree of materials and functions necessary for the availability of provisioning, regulating and cultural ecosystem goods and services. They again are indispensable prerequisites for human well-being (Figure 2).

Hence, the dependence of ecosystem services which include the supply of products that can be consumed or used by people directly or indirectly, e.g. food, water, fiber, fuel or building material, on the integrity of ecosystems can be depicted in a rather straight line (Figure 6).

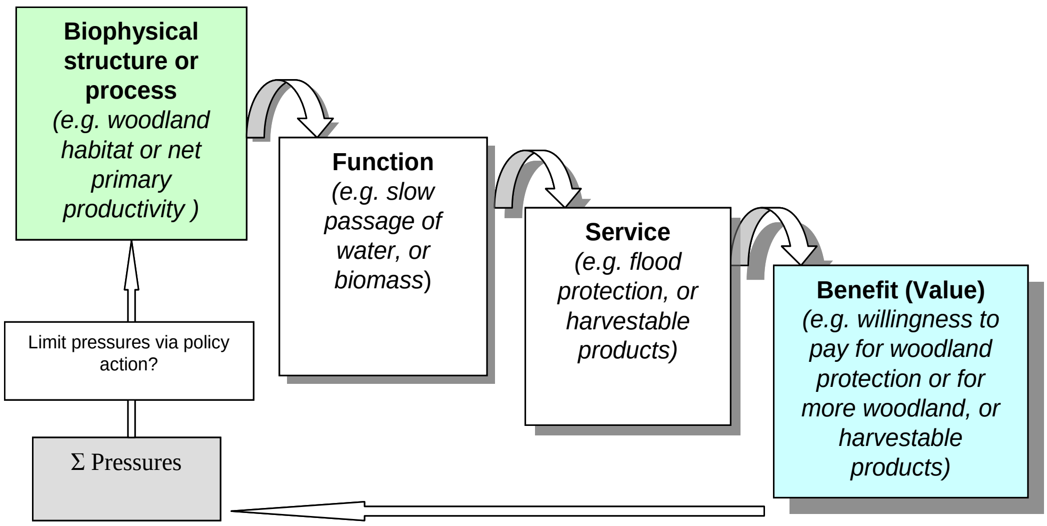

Figure 6: Ecosystem service "cascade", from ecosystem structures and processes to human benefits (adapted from Haines-Young et al. 2006 in de Groot et al. 2010)

Regulating services, including for example water and air purification, climate regulation or disease control, can be utilized by humankind directly, or they include important components of ecosystem processes and functioning. Thus, there are mutual relationships with human well-being but also with provisioning services, cultural services and with the integrity of ecosystems reversely too. The cultural services consist of certain rather subjective components such as inspiration, spiritual experience, recreation, education and information. The last one includes genetic information also and might therefore be easier to quantify than the former ones.

5.1 Ecosystem service indicators

The quantification and operationalization of ecosystem goods and services have been among the biggest challenges of current ecosystem science (Burkhard et al 2010). Monetary approaches like cost-benefit analyses, contingent valuations or willingness-to-pay assessments are useful attempts but they often disappoint due to their economic focus and the lack of appropriate pricing methods for non-marketed goods and services.

Ecosystem integrity – as the base for the provision of all other ecosystem services – and respective indicators have been described above. Regulating ecosystem services include further ecosystem functions and are difficult to quantify in real systems. Thus, most assessments are based on model calculations. Moreover, some components of regulating services are overlapping with ecological integrity processes; for example processes related to nutrient or water regulation. Therefore, a high risk of merging and double-counting of ecological integrity processes and regulating ecosystem services is inherent. Figure 7 shows the concept of supply and demand of ecosystem services by linking ecological integrity with ecosystem services and human well being as a slight modification of the "ecosystem service cascade" presented in Figure 6.

Figure 7: Conceptual model of ecosystem services' supply and demand in human-environmental systems.

As indicators for provisioning services production and trade numbers, market prices of products and further economic parameters are appropriate. Hence, they seem to be most easy to quantify but, changing markets and supplies, resource scarcity or altering production and trade patterns have to be considered. Assessments of cultural ecosystem services are very subjective and value-laden as each individual or group of individuals have different value systems and demands. Nevertheless, quantifications based on interviews, questionnaires or additional information sources can provide useful results. For certain cultural ecosystem services, for example recreation, tourist numbers or the numbers of overnight stays at particular locations are applied.

In the beginning of each ecosystem service assessment, a selection and specification of relevant services must take place. Table 10 provides a list of ecosystem services including definitions and potential indicators for the quantification. The list has been derived from most recent literature.

Table 10: List of ecological integrity and ecosystem service components with definitions and potential indicators (based on de Groot et al. 2010, Burkhard et al. 2009, Müller & Burkhard 2007, MA 2005).

	Definition	**Potential indicators**
Ecological integrity		
Abiotic heterogeneity	The provision of suitable habitats for different species, for functional groups of species and for processes is essential for the functioning of ecosystems.	habitat diversity indices heterogeneity indices, e.g. humus contents in the soil number/area of habitats
Biodiversity	The presence or absence of selected species, (functional) groups of species or species composition.	Indicator species representative for a certain phenomenon or sensitive to distinct changes.
Biotic water flows	Referring to the water cycling affected by plant processes in the system.	transpiration / total evapotranspiration
Metabolic efficiency	Referring to the amount of energy necessary to maintain a specific biomass, also serving as a stress indicator for the system.	respiration / biomass (metabolic quotient)
Exergy capture	The capability of ecosystems to enhance the input of usable energy. Exergy is derived from thermodynamics and measures the energy fraction that can be transformed into mechanical work. In ecosystems, the captured exergy is used to build up biomass (e.g. by primary production) and structures.	Net primary production Leaf area index LAI
Reduction of nutrient loss	Referring to the irreversible output of elements from the system, the nutrient budget and matter flows.	Leaching of nutrients e.g. N, P
Storage capacity	Is referring to the nutrient, energy and water budgets of the system and the capacity of the system to store them when available and to release them when needed.	Solved organic matter N, C_{org} in the soil N, C in biomass
Provisioning ecosystem services		
Crops	Cultivation of edible plants.	Plants / ha kJ / ha
Livestock	Keeping of edible animals.	Animals / ha kJ / ha
Fodder	Cultivation and harvest of animal fodder.	Fodder plants / ha kJ / ha
Capture fisheries	Catch of commercially interesting fish species, which are accessible for fishermen.	Fishes available for catch / ha kJ / ha
Aquaculture	Animals kept in terrestrial or marine aquaculture.	Number of animals / ha kJ / ha
Wild foods	Harvest of e.g. berries, mushrooms, wild animal hunting or fishing.	Plant biomass / ha Animals available / ha kJ / ha
Timber	Presence of trees or plants with potential use for timber.	Wood / ha kJ / ha
Wood fuel	Presence of trees or plants with potential use as fuel.	Wood or plant biomass / ha

		kJ / ha
Energy (biomass)	Presence of trees or plants with potential use as energy source.	Wood or plant biomass / ha kJ / ha
Biochemicals / medicine	Production of biochemicals, medicines.	Amount or number of products kg / ha
Freshwater	Presence of freshwater.	l or m³ / ha
Regulating ecosystem services		
Local climate regulation	Changes in land cover can locally affect temperature, wind, radiation and precipitation.	Temperature, albedo, precipitation, wind Temperature amplitudes Evapotranspiration
Global climate regulation	Ecosystems play an important role in climate by either sequestering or emitting greenhouse gases.	Source-sink of water vapour, methane, CO_2
Flood protection	Natural elements dampening extreme flood events	Number of floods causing damages
Groundwater recharge	The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in land cover, including, in particular, alterations that change the water storage potential of the system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.	Groundwater recharge rates
Air quality regulation	The capacity of ecosystems to remove toxic and other elements from the atmosphere.	Leaf area index Air quality amplitudes
Erosion regulation	Vegetative cover plays an important role in soil retention and the prevention of landslides.	loss of soil particles by wind or water vegetation cover
Nutrient regulation	The capacity of ecosystems to carry out (re)cycling of e.g. N, P or others.	N, P or other nutrient turnover rates
Water purification	Ecosystems have the capacity to purify water but can also be a source of impurities in fresh water.	Water quality and quantity
Pollination	Ecosystem changes affect the distribution, abundance, and effectiveness of pollinators. Wind and bees are in charge of the reproduction of a lot of culture plants.	amount of plant products distribution of plants availability of pollinators
Cultural ecosystem services (*selection*)		
Recreation & aesthetic values	Refers specifically to landscape and visual qualities of the resp. case study area (scenery, scenic beauty). The benefit is the sense of beauty people get from looking at the landscape and related recreational benefits.	Number of visitors or facilities Questionnaires on personal preferences
Intrinsic value of biodiversity	The value of nature and species themselves, beyond economic or human benefits.	number of endangered, protected or rare species or habitats
+ further case study specific indictors		

5.2 Assessments of ecosystem services supply

Different ecosystems have different functions based on their structures and processes. Therefore, the capacity to supply particular services varies between different ecosystems. The individual capacities are strongly linked to:

a) natural conditions, e. g. land cover (vegetation foremost), hydrology, soil conditions, fauna, elevation, slope and climate as well as
b) human impacts (mainly land use but also emissions, pollution etc.).

One main problem in almost all ecosystem service studies is the generation of appropriate data to quantify the broad range of ecosystem services (Wallace 2007). One solution can be to make use of expert evaluations in order to gain an overview and see trends for ecosystem service assessments (Burkhard et al. 2009). Based on these expert evaluations, hypotheses about capacities of different ecosystem to supply ecosystem services can be derived. In the following steps, expert evaluations can successively be replaced by data from monitoring, measurements, modeling, targeted interviews or statistics.

The integration of data from LTER monitoring in the different European biomes would provide a very useful data base for more quantitative ecosystem service assessments. As the ecosystem service concept is very holistic and comprehensive, as much relevant information as possible has to be taken into account. Information should be as detailed as possible and needed, in a relevant resolution and at an appropriate scale. Land cover information from e. g. remote sensing, simulation models, GIS and statistical data is an appropriate starting point. By integrating these features with further data, the state of ecosystems and their capacities to supply ecosystem services can be assessed and transferred to maps of different spatial and temporal scales. The results reveal patterns of natural conditions and human activities over time and the capacities of different ecosystems to provide ecosystem services considering changes in land use.

One approach to give an overview on ecosystem service capacities is based on an expert assessment matrix linking ecological integrity and ecosystem services (on the x-axis) to different land cover types (on the y-axis) (Burkhard et al. 2009). At intersections of land cover types and ecological integrity/ecosystem services, different capacities of land cover types to support ecological integrity and to provide particular services were assessed. The initial assessments can take place qualitatively on a scale consisting of for example: 0 = no relevant capacity, 1 = low relevant capacity, 2 = relevant capacity, 3 = medium relevant capacity, 4 = high relevant capacity and 5 = very high relevant capacity (see Figure 8).

	Ecological Integrity Σ	Abiotic heterogeneity	Biodiversity	Biotic waterflows	Metabolic efficiency	Exergy Capture (Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	Regulating services Σ	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	Provisioning services Σ	Crops	Livestock	Fodder	Capture Fisheries	Acquaculture	Wild Foods	Timber	Wood Fuel	Energy	Biochemicals / Medicine	Freshwater	Cultural services Σ	Recreation& Aesthetic Values	Intrinsic Value of Biodiversity
Continuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Discontinuous urban fabric	7	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	3	1	0	1	0	0	1	0	0	1	0	0	0	0	0
Industrial or commercial units	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Road and rail networks	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Port areas	2	1	1	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Airports	7	1	1	1	1	1	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Mineral extraction sites	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
Dump sites	8	2	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Construction sites	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green urban areas	18	3	3	2	1	4	3	2	11	2	1	0	2	1	2	1	1	1	2	0	0	0	0	0	1	0	1	0	0	0	3	3	0
Sport and leasure facilities	16	2	2	2	1	4	3	2	9	1	1	0	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0
Non-irrigated arable land	22	3	2	3	4	5	1	4	5	2	1	1	1	0	0	0	0	0	21	5	5	5	0	0	0	0	0	2	1	0	1	1	0
Permanently irrigated land	21	3	2	5	2	5	1	3	5	3	1	1	0	0	0	0	0	0	18	5	5	2	0	0	0	0	0	1	1	0	1	1	0
Ricefields	20	3	2	5	1	5	1	3	4	2	0	0	2	0	0	0	0	0	7	5	0	2	0	0	0	0	0	0	0	0	1	1	0
Vineyards	14	3	2	3	1	3	0	2	3	1	1	0	1	0	0	0	0	0	5	4	0	0	0	0	0	0	1	1	0	0	5	5	0
Fruit trees and berries	21	4	3	4	2	3	2	3	19	2	2	2	2	2	2	1	1	5	13	5	0	0	0	0	0	4	4	1	0	0	5	5	0
Olive groves	17	3	2	3	2	3	1	3	7	1	1	0	1	1	1	1	1	0	12	4	0	0	0	0	0	4	4	1	0	0	5	5	0
Pastures	24	2	2	4	5	5	2	4	8	1	1	1	1	0	4	0	0	0	10	0	5	5	0	0	0	0	0	1	0	0	3	3	0
Annual and permanent crops	18	2	2	3	2	4	2	3	7	2	1	1	1	1	1	0	0	0	20	5	5	5	0	0	0	0	0	1	1	0	1	1	0
Complex cultivation patterns	20	4	3	3	2	4	1	3	5	2	1	1	1	0	0	0	0	0	9	4	0	3	0	0	0	0	0	1	2	0	2	2	0
Agriculture& natural vegetation	19	3	3	3	2	3	2	3	13	3	2	1	2	1	3	0	1	0	21	3	3	2	0	0	3	3	3	2	1	0	5	2	3
Agro-forestry areas	27	4	4	4	3	4	4	4	13	2	1	1	1	1	2	1	1	3	14	3	3	2	0	0	0	3	3	2	0	0	3	3	0
Broad-leaved forest	31	3	4	5	4	5	5	5	39	5	4	3	2	5	5	5	5	5	21	0	0	1	0	0	5	5	5	1	5	0	10	5	5
Coniferous forest	30	3	4	4	4	5	5	5	39	5	4	3	2	5	5	5	5	5	21	0	0	1	0	0	5	5	5	1	5	0	10	5	5
Mixed forest	32	3	5	5	4	5	5	5	39	5	4	3	2	5	5	5	5	5	21	0	0	1	0	0	5	5	5	1	5	0	10	5	5
Natural grassland	30	3	5	4	4	4	5	5	22	2	3	1	1	0	5	5	5	0	5	0	3	0	0	0	2	0	0	0	0	0	6	3	3
Moors and heathland	30	3	4	4	5	4	5	5	20	4	3	2	2	0	0	3	4	2	10	0	2	0	0	0	1	0	2	2	0	0	10	5	5
Sclerophyllous vegetation	21	3	4	2	3	3	4	2	7	2	1	1	1	0	0	0	0	2	8	0	2	0	0	0	1	0	2	0	3	0	6	2	4
Transitional woodland shrub	21	3	4	2	3	3	4	2	3	1	0	0	0	0	0	0	0	2	5	0	2	0	0	0	1	0	2	1	0	0	4	2	2
Beaches, dunes and sand plains	10	3	3	1	1	1	0	1	6	0	0	5	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	7	5	2
Bare rock	6	3	3	0	0	0	0	0	3	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0
Sparsely vegetated areas	9	2	3	1	0	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burnt areas	6	2	1	0	0	0	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glaciers and perpetual snow	3	2	1	0	0	0	0	0	10	3	3	0	4	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	5	5	5	0
Inland marshes	25	3	2	4	4	4	3	5	14	2	2	4	2	0	0	4	0	0	7	0	2	5	0	0	0	0	0	0	0	0	0	0	0
Peatbogs	29	3	4	4	4	4	5	5	24	4	5	3	3	0	0	3	4	2	5	0	0	0	0	0	0	0	0	2	0	0	8	4	4
Salt marshes	23	2	3	4	3	3	3	5	8	1	0	5	0	0	0	2	0	0	2	0	2	0	0	0	0	0	0	0	0	0	3	3	0
Salines	2	1	1	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0
Intertidal flats	13	2	3	0	2	1	4	1	7	1	0	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4	4	0
Water courses	18	4	4	0	3	3	3	1	10	1	0	2	1	0	0	3	3	0	12	0	0	0	3	0	4	0	0	3	0	5	10	5	5
Water bodies	23	4	4	0	4	4	3	4	7	2	1	1	2	0	0	1	0	0	12	0	0	0	3	0	4	0	0	0	0	5	9	5	4
Coastal lagoons	25	4	4	0	5	5	3	4	5	1	0	4	0	0	0	0	0	0	16	0	0	0	4	5	4	0	0	1	0	0	9	5	4
Estuaries	21	3	3	0	5	5	3	2	9	0	0	3	0	0	0	3	3	0	17	0	0	0	5	5	4	0	0	2	0	0	7	4	3
Sea and ocean	15	2	2	0	3	3	4	1	13	3	5	0	0	0	0	5	0	0	11	0	0	1	5	5	0	0	0	3	0	0	6	4	2

Figure 8: Matrix for the assessment of the different CORINE land cover types' capacities to support ecological integrity and to provide ecosystem services (from Burkhard et al. 2009). The assessment scale reaches from 0 = rosy color = no relevant capacity of the land cover type to provide this particular ecosystem service, 1 = grey green = low relevant capacity, 2 = light green = relevant capacity, 3 = yellow green = medium relevant capacity, 4 = blue green = high relevant capacity and 5 = dark green = very high relevant capacity. In the rows between the assessments (yellow color), sums for the individual ecosystem services groups were calculated (without weighting them).

6. Gap analysis

The evaluations of the available **indicator-parameter base** from the quick workshop survey (Table 6) and the metadata questionnaire in Tables 7/1-3 give an overview about what is already there (without the frequency of measurements) and where are major gaps in data. The following step will be the closer look at the parameters behind (later with a focus on the methods), the potential for harmonization of parameters and at the gaps that need to be filled by additional parameters.

In this respect we will consider the initiatives mentioned in chapter 2.2 and look for data which can be gained without much effort or data which are already available, e.g. by **Remote Sensing** (RS). RS offers various options for the LTER-sites which have to be assessed more in detail in practice. However, the GMES Directive needs to be considered by ENVEurope anyway as it is one focal point for remote sensing tools in ENVEurope. One main problem in the practical application at the LTER sites is perhaps that experts are needed which can process and interpret RS data and images appropriately. Nevertheless, some spatially explicit derived products (e.g. CORINE), which are partially validated, are ready to be used. Thus, the ability to handle RS products has to be checked at the LTER sites. Additional ground truth validation might be needed to be carried out at each site. The subsequent analyses should be done centralized or by a respective core group.

A proposal of structural (aggregative) indicators that might reveal details on ecological food and interaction webs and report on the role of engineering species inside the ecosystem may be important, but is missing. Same for functional groups and energy compartments which were originally proposed as indicanda in ENVEurope.

However, there is a high degree of **uncertainty** when working with heterogeneous data sets and different degrees of documentation of these data and methods. Nevertheless, there are methods to deal with this kind of uncertainties and to use long-term environmental data successfully (Magurran et al. 2010). We are aware of the issue that procedures need to be available to ensure the comparability of data when methods of measuring the same parameters change (e.g. by harmonization of parameters and methods).

Two major issues remaining with regard to data harmonization and comparability are (i) the question of defining **appropriate scales** (in space and time) and (ii) suitable **baselines** or reference conditions to which the individual sites' ecological integrity parameters can be compared to. So far, no solution that suits all sites could be found. The future work to be carried out in ENVEurope, especially the practical implementation of the conceptual framework, will show whether a harmonization in the two points mentioned above is possible and to which degree it is definitely needed. LTER sites are often rather small portions of the landscape and their size range should be considered as a factor to take into account for indicator and indicandum selection. Moreover, spatial scale identification will provide a minimum sampling size for measurements and might eventually help to extrapolate captured information to equivalent spatial units across the landscape and upscale processes and functions.

Another important point not addressed sufficiently up to now is the **data storage and management** in LTER. A central data management using standardized methods, software tools and user interfaces is mandatory in order to improve the coordination and management of the data and for a better communication regarding data requests. One idea could be to offer aggregated raw data for ecological integrity core indicators (Figure 4) with a coarse temporal resolution (e.g. average annual values) as a kind of "quick view" for public use. More detailed information would then be available on request in co-operation with the particular site manager.

7. Implementation

The implementation of this conceptual framework will be done in Action 5 of ENVEurope (Field Testing). It is proposed to do this with the following steps taking most advantage of the constellation of LTER sites:

1. Clustering of sites that can provide certain EI indicators due to their specific focus. This will be done based on Table 7/1-3, but with more detailed information
2. Priorty list of indicators: (a) High priority / core indicators, (b) medium priority indicators and (c) optional indicators (to exclude nothing). The selection of indicators should be driven by their sensitivity concerning the indicandum.
3. Parameter-based identification of suitable spatial scales. Perhaps measurements are scale-related in this way: EI processes < EI structures < ESS
4. Parameter-based identification of suitable temporal scales and frequencies. Again, the ranking will reveal the same sequence in terms of frequency measurements: EI processes > EI structures > ESS
5. Potential for harmonization of methods (ensuring comparability of data *a priori*)
6. Potential for temporal and spatial aggregation of parameters for common analysis (comparability of data *ex post*)
7. Remote sensing products to generate unified data sets at different points in time for all LTER sites (e.g. CORINE)

The **application** of the theoretical concepts in practice is one major challenge and chance of ENVEurope. Therefore, **harmonization of methods** and the development of common **manuals** are mandatory. To test the indicator sets and systems ecological theories with data from long-term monitoring at different sites will reveal how a harmonization of international monitoring activities should take place in order to get optimum results regarding staff and financial effort invested. Moreover, to take the step from long term ecological monitoring ("LTEM") to a real long term ecological *research* (LTER), the link to scientifically relevant questions should be improved. There are numerous relevant questions and hypotheses which could be addressed by using long-term ecological data:

Potential research questions:

- Which are the impacts of global changes (climate change, invasive species, land use change, pollutants) on ecological integrity and the provision of ecosystem services?
- Can we find resilience and adaptability in ecosystems' dynamics related to these global changes?
- Which spatial scales are needed to appropriately address structures and processes at heterogeneous sites?
- Which information can be obtained from remote sensing at which spatio-temporal resolution?
- How can we achieve trans-domain indication and comparability?
- Which measurement frequencies are needed in order to cope with long-, medium- and short-term dynamics in the different ecosystems?
- . . .

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Annex

Table 1A: SEBI 2010 indicators within CBD focal areas and headline indicators (EEA 2007 & 2009).

CBD focal area	Headline indicator	SEBI 2010 specific indicator
Status and trends of the components of biological diversity	Trends in the abundance and distribution of selected species	1. Abundance and distribution of selected species a. birds b. butterflies
	Change in status of threatened and/or protected species	2. Red List Index for European species
		3. Species of European interest
	Trends in extent of selected biomes, ecosystems and habitats	4. Ecosystem coverage
		5. Habitats of European interest
	Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socio-economic importance	6. Livestock genetic diversity
	Coverage of protected areas	7. Nationally designated protected areas
		8. Sites designated under the EU Habitats and Birds Directives
Threats to biodiversity	Nitrogen deposition	9. Critical load exceedance for nitrogen
	Trends in invasive alien species (numbers and costs of invasive alien species)	10. Invasive alien species in Europe
	Impact of climate change on biodiversity	11. Impact of climatic change on bird populations
Ecosystem integrity and ecosystem goods and services	Marine Trophic Index	12. Marine Trophic Index of European seas
	Connectivity/fragmentation of ecosystems	13. Fragmentation of natural and semi-natural areas
		14. Fragmentation of river systems
	Water quality in aquatic ecosystems	15. Nutrients in transitional, coastal and marine waters
		16. Freshwater quality
Sustainable use	Area of forest, agricultural, fishery and aquaculture ecosystems under sustainable management	17. Forest: growing stock, increment and fellings
		18. Forest: deadwood
		19. Agriculture: nitrogen balance
		20. Agriculture: area under management practices potentially supporting biodiversity
		21. Fisheries: European commercial fish stocks
		22. Aquaculture: effluent water quality from finfish farms
	Ecological Footprint of European countries	23. Ecological Footprint of European countries
Status of access and benefits sharing	Percentage of European patent applications for inventions based on genetic resources	24. Patent applications based on genetic resources
Status of resource transfers	Funding to biodiversity	25. Financing biodiversity management
Public opinion (additional EU focal Area)	Public awareness and participation	26. Public awareness

Table 2A: Overview of the ongoing and planned international indicator initiatives most relevant to biodiversity in Europe (from EEA 2002).

Name	Topic	Lead organisation	Aim	Level of development	Status	Linkages
Core set of biodiversity indicators	Biodiversity	EEA and ETC/NPB	EEA assessment and reporting	Intergovernmental	Development (ready mid 2002)	Other ETCs, CBD, EFI, BirdLife Int., Wetlands Int., ECNC, OECD, MCPFE
Biodiversity headline indicators	Biodiversity	EEA and ETC/NPB	EU Council Spring meetings	Intergovernmental	Development (ready by Apr. 2002)	Other ETCs, EC
IBAs, threatened birds, common birds	Biodiversity based on bird data	BirdLife International	Reporting and assessment	NGO	Development/ implementing	EEA, OECD, ...
Wetland indicators	Biodiversity of wetlands	Wetlands International	Reporting	NGO/Convention	Development	EEA, Ramsar
Forest biodiversity indicators	Forest biodiversity, sustainable forestry	MCPFE	MCPFE meetings	Intergovernmental	Development, ready by 2003	EEA, EFI, CBD
Core set of biodiversity indicators	Biodiversity	CBD, SBSTTA	CBD/COP, national reporting	Intergovernmental	Development, ready by COP7	EEA, MCPFE
ELISA Agri-environmental indicators	Agri-environment	ECNC (for EC DG Research)	Assessment agricultural policies	Intergovernmental	Testing in ENRISK project	OECD, EEA, FAO, EUROSTAT
Integration indicators	Agri-environment	EC DG Agriculture	Reporting on integration of environment in agriculture	Intergovernmental	Proposed	EEA, OECD, ELISA, FAO, EUROSTAT
Sustainability indicators	Sustainable development	EC	EU Council Spring meetings	Intergovernmental	Proposed	EEA, UNCSD
Agri-biodiversity indicators	Agri-biodiversity	OECD	National reporting	Governmental	Testing, implementing	ELISA, EEA, EUROSTAT, FAO, EC
Living Planet Index	Biodiversity	WWF	Global reporting	NGO	Implementing	UNEP-WCMC
Sustainable development indicators	Sustainable development	UNCSD	Global reporting	Intergovernmental	Implementing	EEA, EC
Index development	Biodiversity, based on red lists	IUCN	National reporting	NGO	Proposed	CBD
TEPI environmental pressure indicators	Environmental pressure	EUROSTAT	National reporting, sectorial assessment	Intergovernmental	Implementing	EEA, EC
World Resources	Environment, inc. biodiversity	WRI	Global reporting	NGO	Implementing	UNDP, UNEP, World Bank

Table 3A: Examples of ecological indicators within different ecological levels (from Niemi & McDonald 2004).

Type		Example	References
Compositional	Genes	Species differentiation	Rudi et al. 2000
	Cell and subcellular	Immune response	Anderson et al. 1989
	Tissue	Metal concentration	Pérez-Lopéz et al. 2003
	Species	Butterflies	MacNally & Fleischman 2002
	Populations	Birds	Browder et al. 2002
	Communities	Floristic quality	Lopez & Fennessy 2002
	Ecosystems	Lakes	Whittier et al. 2002
	Landscape types	Land use/cover	Lausch & Herzog 2002
Functional	Genetic processes	Mutation rates	Ames et al. 1973
	Behavior	Feeding rate	Sierszen & Frost 1990
	Life history	Species traits	Hausner et al. 2003
	Demographic processes	Productivity	Underwood & Roth 2002
	Ecosystem processes	Growth	Marwood et al. 2001
	Landscape processes	Diatoms	Dixit et al. 1992
Structural	Genetic structure	Zooplankton genotypic differentiation	Baird et al. 1990
	Population structure	Bird guilds	Croonquist & Brooks 1991
	Habitat physiognomy	Forest structure	Lindenmayer et al. 2000
	Landscape patterns	Fragmentation	O'Neill et al. 1988
Integrative	Index of biotic integrity	Fish	Karr 1981
	AMOEBA	Multiple taxa	ten Brink et al. 1991
	Multivariate	Biomarkers	Cormier & Racine 1992
	Species assemblages	Beetles	Dufréne & Legendre 1997
	Index of environmental integrity	Multiple indices	Paul 2003