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Literature data base of indicators of ecosystem functioning and biodiversity

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EndNote database. Filename – D511.enl

Executive Summary

Information about ecosystem functioning and biodiversity indices is spread over a variety of literature sources. The concept of ecological indicators is developing rapidly and the therefore the list of literature sources is changing literally on a daily bases.

Here we focus on regular scientific journal articles, which are rigorously peer reviewed and relatively well accessible. Many examples of indicators can be found in journals such as *Ecosystem Health*, *Ecological Economics, Conservation Biology, Ecological Modelling* and particularly in the recently founded journal *Ecological Indicators*.

In this document we present an EndNote[1] database on the literature sources, mostly regular articles in scientific journals. This document is conceptually linked to deliverable 5.1.2, which provides a thematic catalogue of ecosystem functioning and biodiversity indices.

[1] http://www.endnote.com

1. Introduction

The body of literature dealing with indicators of biodiversity and ecosystem functioning is vast and growing rapidly, literally on a daily basis. It is thus impossible (with the given resources) and perhaps not meaningful (for the Thresholds project) to compile all what is available. The first selection of literature sources was done during the search and browsing phase. Naturally, the result (i.e. the selected sources) are biased towards biology and marine ecosystems, even though a few papers use landscapes or terrestrial organisms as objects and some papers fall to the border of ecology and economics.

Thus the reader should not treat the literature database as a comprehensive list. We attempted to keep the length of the list manageable, within the range of 200 to 300 titles, with the hope that project partners will find articles of their interest, choosing from a variety of themes and subjects. An additional source is always the reference list of the particular articles. In this way the amount of literature sources will grow almost exponentially.

Most of the regular journal articles are available in pdf format, but these files are not part of the formal deliverable (due to size and copyright constraints). If we could not access a particular paper in pdf format, we have attempted to add a full abstract in the database.

The database format is EndNote, which is a widely used and common database management application. If a partner does not have access to EndNote, an alternative suitable format can be requested.

During compilation of the database a combination of key-words and expressions was used to search public, as well as proprietary databases (ASFA, ISI, Google). The reference lists of key papers served as an additional source. Certain key journals were browsed manually for relevant titles.

1.1. The layout of the document

The main part of the Deliverable is the literature database in EndNote format. The text below should be treated as an introduction to some papers and themes what we considered more influential. Needless to say, the borders between the categories are not sharp, but rather arbitrary.

A number of papers deal with methods of developing and/or selecting ecological indicators. This section will be followed by an introduction to more general, holistic review or overview papers. More promising recent developments deal with information theory, exergy and Fisher information introduced in section 4. Finally we introduce a few useful special issues of journals. There are more special issues dealing with indicators, but we opted to exclude strongly terrestrial treatments.

2. Method papers

A category of papers is devoted to construction of indices or selection of indices from the plethora of existing ones. In the following examples of two types are provided – (i) methods to detect regime shifts in oceanographic data sets and (ii) various approaches and methods to develop indicators.

2.1. Detecting regime shifts

Beaugrand and co-workers have discussed and presented analysis methods of inherently univariate Continuous Plankton Recorder (CPR) data. Four types of recently developed plankton indicator, based on the CPR survey, are summarized by Beaugrand (2005): indicators based on individual taxa; indicators based on functional attributes of the ecosystem (diversity); species assemblage indicators; and indicators of larval fish survival. All provide information on the state of a pelagic ecosystem, but have different limitations. In most of the examples described, statistical analyses help to identify major spatial and temporal patterns, and may allow future ecosystem changes to be anticipated. A dedicated overview paper on up-to-date analysis methods of CPR data is Beaugrand et al. (2003). Special attention is devoted to an elegant method, where monthly mean univariate CPR variables are tabulated into a 12 months (rows) times years (columns) data matrix and then subjected to a multivariate analysis to extract information. Results obtained from recently applied geostatistical methods on CPR data are then considered. An example of a time series decomposition by the use of eigenvector filtering is presented to illustrate time-series analysis.

In the *Progress in Oceanography* 2004 special issue Mantua (2004) explores methods dedicated to detecting regime shifts in time series data. The methods discussed are: (i) principal component analysis, (ii) compositing average standard deviates, (iii) autoregressive moving average and intervention analysis modelling, (iv) vector autoregressive process modelling, and (v) Fisher information. The methods are demonstrated on a collection of 100 data sets containing annual observations of 31 abiotic and 69 biotic (fishery and survey) time series for 1965–1997 primarily for the North Pacific and Bering Sea regions.

Following the same lines Solow and Beet (2005) describe a formal statistical approach of testing for regime shifts based on population time series. The problem was formulated as detecting a change-point in a vector autoregressive process. A regime shift is said to occur if the system switches abruptly from varying around one locally stable steady state to varying around another. The method is illustrated using data from the North Sea for the period 1963 – 97.

2.2. Indicator development methods

This paper by Manoliadis (2002) describes efforts to develop an ecological indicator based on information routinely collected during irrigation systems operation from projects in Greece. Compromise programming, described as employing a normalised hierarchical distance from the ideal solution, is used for the development of ecological indicators.

In a paper by Merkle and Kaupenjohann (2000), the authors state that the derivation of ecosystem indicators is often unclear and non-transparent, without a sound theoretical basis. The authors present the idea of ecosystematic effect indicators (EEI) and propose a conceptual approach to deduce these indicators. A set of indicators can be derived that is tailored to the needs of the indicator user, but remains rooted firmly in the principle of ecosystem functioning. The EEI provide information about the cause-effect relationship between (agricultural) production processes and their effects on the affected ecosystems.

The starting point of a paper by Hoag et al. (2002) is statement that while indices facilitate simultaneous comparison of two or more complex, multifaceted systems, by reducing information about each system into a single number, the reductionism enhances understandability, but works contrary to both the complex nature of the system and potentially disparate values that might be held by system users. The authors propose to adopt the use of a payoff matrix – a common tool from decision theory, to develop a comparable framework for ecosystem risk. They call it the Impact Matrix. As the authors claim, the impact matrix allows flexibility in developing indices of complex, multifaceted systems so that many disparate value systems may be easily represented.

The paper by Hajkowicz (2006) presents a framework for constructing multi-attributed indices to measure welfare derived by a region's citizenry from environmental resources. The framework provides a procedure for integrated regional accounting. The index shows how scientific information can be merged with societal preferences for competing water services to attain an overall measure of performance. Results report regional welfare resulting from alternative policy scenarios and the impact of individual indicators on whole-of-system performance. According to the authors, the process for index construction developed by them could be applied for a multitude of environmental issues. It can provide a single unifying measure of performance when an environmental resource delivers numerous services measured in multiple monetary and non-monetary units.

3. Review and holistic papers

Duelli and Obrist (2003) propose three indices of biodiversity evaluation in agricultural landscapes, each consisting of a basket of concordant indicators. The indices represent the three value systems "conservation" (protection and enhancement of rare and threatened species), "ecology" (ecological resilience, ecosystem functioning, based on species diversity), and "biological control" (diversity of antagonists of potential pest organisms). Discussed are questions like values system, how to select indicators for the three main motivations, effort and cost, indicators for what aspect of biodiversity, alfa-diversity and contribution to higher scale biodiversity. The authors conclude that there is no single indicator for biodiversity. The choice of indicators depends on the aspect of entity of biodiversity to be evaluated and is guided by a value system base on personal and/or professional motivation. Each biodiversity index for a particular value system should consist of a basket of methods with one to several concordant indicators.

The article by Turnhout et al (2006) approaches the concept of ecological indicators from a social science perspective. By applying theoretical concepts from policy analysis and social the authors aim to contribute to our understanding of the actual use of ecological indicators in policy processes and the importance of political context. The focus is on those ecological indicators that attempt to measure the ecological quality of ecosystems and are specifically developed to be used as instruments to evaluate the effects of policies on nature. The authors claim that these indicators, although they are highly dependent on scientific knowledge, cannot be solely science-based, due to the complexity of ecosystems and the normative aspects involved in assessing ecosystem quality. As a result, they situate ecological indicators in a fuzzy area between science and policy and between the production and the use of scientific knowledge.

Hughes et al (2005) highlight the emergence of a complex system approach for sustaining and repairing marine ecosystems, linking ecological resilience to governance structures, economics and society. They conclude that the developing concept of adaptive governance, informed by a clearer understanding of resources and ecosystem dynamics, provides a new paradigm for responding multi-scale environmental feedbacks and from managing resilience to ensure sustainable resources. The authors find that adaptive governance of linked social-ecological systems provides a new framework for developing an ecosystem-based approach to management of the world's oceans.

Partly the same set of authors review the evidence of regime shifts in terrestrial and aquatic environments in relation to resilience of complex adaptive ecosystems and the functional roles of biological diversity in this context (Folke et al. 2004). The evidence that the likelihood of regime shifts may increase when humans reduce resilience by such actions as removing response diversity, removing whole functional groups of species, or removing whole trophic levels. The combined and often synergistic effects of those pressures can make ecosystems more vulnerable to changes that previously could be absorbed. As a consequence, ecosystems may suddenly shift from desired to less desired states in their capacity to generate ecosystem services.

In a recent minireview by Groffman et al (2006) revisit the concept of ecological thresholds, definitions, methods for analysis, the diverse spatial and temporal scales by 'adding humans into the equation'. They conclude that the lack of general principles is a major inhibiting factor for the use of ecological thresholds concepts in environmental management.

In an overview paper by Lindmayer and Luck (2005) the authors discuss (i) whether threshold relationships are common and widespread, (ii) the potential for large variations in the use and application of the threshold concept to lead to adverse conservation outcomes, (iii) The inherent multi-variate nature of landscape processes and responses of individual species and assemblages that creates variability in datasets.

Muradian (2001) reviews some theoretical developments and empirical studies dealing with ecological phenomena involving non-linear dynamics. The author concludes that ecological discontinuities as the consequence of human impacts are not uncommon in nature. However, difficulties rise mainly because the definition of alternative stable states is highly dependent on the chosen temporal and spatial scales, as well as on the adopted notion of attractor.

Scheffer and Carpenter (2003) review ways how to link theory to observations. They revisit (often graphically) basic theory and the concepts like feedback and alternative attractors, hysteries, resilience, stability landscape, etc. They conclude that although field observations can provide hints of alternative stable states, experiments and models are essential for good diagnosis. Scheffer and van Nes (2004) re-visit the subject (with much the same schematic graphics) in the *Progress in Oceanography* special issue (see below).

Walker et al (2004) open the concepts of resilience, adaptability, and transformability in the context of social-ecological systems (SES). Resilience (the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks) has four components—latitude, resistance, precariousness, and panarchy—most readily portrayed using the metaphor of a stability landscape. Adaptability is the capacity of actors in the system to influence resilience (in a SES, essentially to manage it). Transformability is the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable. They conclude that strategies for sustainability must take many forms and there is no 'one size fits all' approach to the future. The authors also discuss adaptive management and adaptive governance.

4. Thermodynamics and information theory

A number of papers are devoted to what is believed to be a measurable holistic parameter reflecting the ecosystem health and allowing to estimate the strength of anthropogenic damage. A variety of ecosystem goal functions have been proposed: ascendancy, emergy, energy flow maximization, entropy minimisation, etc. Among them exergy is shown to have good theoretical basis in thermodynamics, close relation to information theory, high correlation with other goal functions and relative easiness of computation (Jørgensen and Bendoricchio 2001).

Jørgensen (2006) propose three holistic thermodynamic indicators: eco-exergy, specific exergy and buffer capacity, to cover essential ecosystem health properties. The paper provides comparison with earlier thermodynamic ecosystem indicators and some theoretical background.

Silow and In-Hye (2004) give practical examples of exergy use to assess the ecosystem health and resistance to pollution based on meso- and microcosm studies in Lake Baikal. They emphasize the ease of calculation of exergy and advocate the use of structural exergy goal function in environmental monitoring as a holistic and quantitative parameter, reflecting the ecosystem state and its anthropogenic changes.

Papers by Ludovisi and co-authors (Ludovisi et al. 2005; Ludovisi 2006) are devoted to the theoretical basis and application of thermodynamic indices.

Cabezas and Fath (2002) combine information theory and ecological models to explore the fundamentals of sustainability. They use Fisher information as a function of the variability of the observations and conclude that low variability leads to high Fisher information and high variability leads to low Fisher information. Systems in stable dynamic states have constant Fisher information. Systems losing organization migrate toward higher variability and lose Fisher information. These considerations lead us to propose a sustainability hypothesis: "sustainable systems do not lose or gain Fisher information over time." The theory is further developed in Cabezas et al (2005). They develop a novel application of Fisher Information to time-series data of dynamic systems. The same lines are followed by Fath et al. (Fath et al. 2003; Fath and Gabazas 2004).

5. Special issues

5.1. Regime shifts in the ocean. Reconciling observations and theory

Progress in Oceanography, 2004: vol 60, issues 2 – 4. made up from contributions of a Workshop hosted at the Laboratoire Oceanographique, Villefranche, 16–19 April, 2003.The volume consists of 14 review articles and an introductory editorial by John H. Steele. The volume focuses on the term *regime shifts* (and is thus highly relevant to the Thresholds project) and on spatial and temporal correspondences between climatic indices and population abundance mostly in fisheries oceanography. Considerable attention is devoted to time-series analysis (deYoung et al. 2004; Mantua 2004). The external pressures considered in this volume are mostly climatic, but also over-fishing in different marine regimes.

Observations from the ocean have served as a stronghold for the concept of regime shifts. Usually it stems from the fisheries statistics, which enjoys long time series of fish landings (Beamish et al. 2004; Rothschild and Shannon 2004). In this volume the rapid physical and biological changes in the North Pacific Ocean between 1976 and 1980 are in the focal point (Wooster and Zhang 2004).

Mathematical ecologists have developed relatively simple models to detect regime shifts based on univariate data such as zooplankton abundance or cod recruitment (Beaugrand 2004). The paper by Mantua (2004) is completely dedicated to methods for detecting regime shifts. However, there are also words of warning that question the appropriateness of the statistical techniques used, which show punctuated equilibrium also in randomly generated red noise time series (Steele 2004).

5.2. Theoretical fundamentals of consistent applications in environmental management

Ecological Indicators, 2006: vol 6, issue 1. In September 2003, 37 scientists from Australia, Denmark, Germany, Italy, Portugal, Slovenia and the USA came together at the Villa Vigoni in Northern Italy to discuss the recent development in the area of ecological indicators and indications. The focal point-of-interest was the potential linkages between theory and practice in environmental indication: “What can we learn from ecosystem theory for the derivation and the practical application of ecological indicators?”

Indicators seem to be useful tools to bridge that gap between complex demands and methodologies of ecological theories and the practical requirements of environmental assessment. This is because the main characteristics of indicators represent attempts to reduce complexity, to avoid too complicated measurements and to select “simple” methods, which nevertheless can lead to a satisfying representation of a complex relationship (Müller and Lenz 2006). Therefore, indicators are also well-suited instruments to apply the results of ecosystem research to a broader field of utilisation.

This collection of articles shows the broad bandwidth of approaches between very theoretical concepts and applied methodologies in environmental indication. It is also visible that up to now a couple of fundamental rules in ecological systems have not been widely used in environmental management. Although integrative and holistic approaches in assessment and application have to be intrinsically based on systems theoretical concepts.

The recent state of ecosystem theory can be characterised by an accentuation of developmental processes of ecological entities in a combination with systems analytical concepts from thermodynamics (e.g.Jørgensen 2006; Ludovisi 2006; Patricio et al. 2006), network theory (e.g. Patten 2006) and synergetics. Although these approaches seem to be far away from 'real' environmental objects, they can offer a lot of ideas for the derivation of consistent indicator sets.

Patten (2006) discusses the indicator problem from the viewpoint of network models, environmental theory and network enfolding, and provides a case study from wildlife management.

Jørgensen (2006) demonstrates the principle of eco-exergy optimisation. His approach is based on the dynamics of exergy storage, and he suggests that the exergy measures are good indicators for ecosystem health.

Ludovisi (2006) introduces a ratio of the entropy produced and the exergy stored. From his point-of-view, the minimisation of this ratio is another orientor of ecosystem development. His concept is illustrated by case studies from different shallow lakes.

Patricio et al (2006) have observed the structural and functional dynamics after the re-colonisation of intertidal rocky ecosystems at the coast of Portugal. Their results show that the indicator eco-exergy provides useful information about the structural development of the community. In addition, the authors stress the significance of spatial scales, referring to the specific disturbance and the disturbed area.

Bastianoni et al (2006) introduce the indicator empower in comparison with the maximum exergy principle, from a practical viewpoint. They found that there is a temporal sequence, starting with a maximisation of empower, which is followed by exergy optimisation.

As a result of these contributions it becomes clear that there is a high correlation between the different thermodynamic variables. Furthermore, the paper shows that the thermodynamic indicators can be distinguished due to their suitability to depict different states of ecosystem development.

The rest of the sections in this volume ask, and attempt to answer the questions: Which community features can serve as objects of ecological indication? How can theoretical ideas be used to represent the impacts of specific disturbances? How can we use indicators for a better environmental management?

5.3. Biotic indicators for biodiversity and sustainable agriculture—introduction and background

Agriculture, Ecosystems & Environment, 2003: vol. 98, issues 1-3. This volume comprises of 45 contributions on the development of biotic indicators for sustainable land use and biodiversity. The volume is divided into sections "Requirements", "Biodiversity and Habitat" (including "Soil" as a subsection), "Biodiversity and Landscape", "Experiences and Application" and "Economy". The volume is strongly biased towards agroecology and to the best of our understanding, not all sections are equally important for the Thersholds project and a selection was done when including the papers into the literature database. The majority of publications within this special issue originate from contributions presented at a 4-day meeting in a monastery at Freising, Germany, organized by the working group "Agroecology" of the international "Society for Ecology" in Germany, and devoted to finding indicators for a sustainable land use in the areas landscape and biodiversity. One goal of the special issue was to contribute to the development of a strategy on how the assessment of biotic aspects in agro-ecosystems with the help of indicators can be handled and how these findings can be transferred to national as well as international panels and finally into practice.

Biodiversity and habitat. A survey on the understanding of biotic indicators is presented including aspects of nomenclature, categorisation and definitions as well as preconditions and rules for their use. Requirements for different taxa (mostly invertebrates) to act as biotic indicators are summarised and several attempts to use animals on the population and/or community level as biotic indicators for biodiversity are discussed critically as well as their replacement by surrogate indicators. Other fundamental problems regarding the development of biotic indicators as baselines, sample size, frequency of surveys, mutual neutralisation of indicators, double assessments, selection of taxa, etc. are addressed. Finally, an assessment of the practicality, the power of indication statements and the remaining work required to validate indicators will be provided for discussion, as well as suggestions for a simplification of indicator systems in order to minimise the input needed for data recording.

Biodiversity and landscape. In this section the complexity of biodiversity, its levels of aggregation and its specific relations to ‘natural’ and ‘anthropogenic’ environmental conditions depending on spatio-temporal scales are emphasized. Especially, the following questions are addressed: (i) how far scientific research on indication of landscape biodiversity considers landscape complexity and dynamics (ii) whether the indicators found, allow valid conclusions on landscape biodiversity.

Economy. These articles deals with the interrelation of ecological and economic aspects through the use of indicators. Two aspects are painted out: the first being the measurement of the economic value of ecological services, and the second being the integration of economic aspects into comprehensive indicator systems.

6. Conclusions

We present a literature database on indicators of ecosystem functioning and biodiversity in EndNote format. The database is based on searches in the internet and critical evaluation of the search results. As the subject is hot and the list of papers is increasing continuously, the database will be outdated within a short period of time and should thus not be considered comprehensive. Most of the papers are available in pdf format; those which we could not access electronically are supplemented with a full abstract.

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