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ALTER-Net

A Long-Term Biodiversity, Ecosystem and Awareness Research Network

Modelling and Forecasting

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Modelling and Forecasting

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1 Introduction

The intention of this report is to accomplish the first objective of Research Area 6, namely to "review existing modelling techniques that relate to the DPSIR framework and identify gaps in the modelling effort where models are either clearly needed or may have long-term potential". The report contains five chapters:

- Introduction and background
- Model vocabulary - what is modelling?
- The role of modelling in ALTER-net
- An overview of existing model expertise in ALTER-net
- Perspectives and new directions

A main aim of ALTER-net is to forecast changes in biodiversity based on the combined impacts of main natural and socio-economic drivers and pressures.
The development of tools for forecasting is an iterative process and requires sound understanding of biodiversity and its underlying causality. The construction of models is intended to help focus the research in all activities and is thus a major instrument to integrate research in ALTER-net. Another important goal is to make sure that both researchers and end-users understand what models and forecasting can be used for and – equally important – what their limits are.

Modelling in ALTER-net will focus on biodiversity in the context of the driver-pressure-state-impact-response-policy (DPSIR) framework. This framework is well suited to encompass the integrated impacts on biodiversity of the main natural and human-induced drivers. Due to their importance, an extended definition of these two concepts follows here:

1.1 The DPSIR concept

The widely used DPSIR framework implies the integration of socio-economic and ecological processes to understand the forces that drive patterns of biodiversity change. For this reason, it was agreed that the DPSIR framework provides a convenient approach to fulfil the objectives described in the previous paragraph.

Figure 1 presents a conceptual model that is a simplified version of a DPSIR framework to illustrate how socio-economic and biophysical drivers of change are brought together to understand biodiversity changes. In this conceptual model, socio-economic drivers (demographic, economic, or political) or biophysical forces (e.g. physical geography or climatic conditions) cause the emergence of observable patterns. These patterns relate to the spatial and temporal distributions of socio-economic or biophysical drivers. Additionally, the interactions among the drivers set in motion processes that affect ecological conditions, which in turn cause changes not only in biodiversity but also socio-economic circumstances (human welfare) which finally affect the main drivers themselves. Hence the process can be seen as an iterative cycle.

The key point here is that this conceptual framework may enable modellers to have a common approach in incorporating various drivers in more or less uniform manner while autonomously developing models for different aspects of biodiversity at different spatial scales. The uniform approach would facilitate the groundwork for synthesising results from different models.

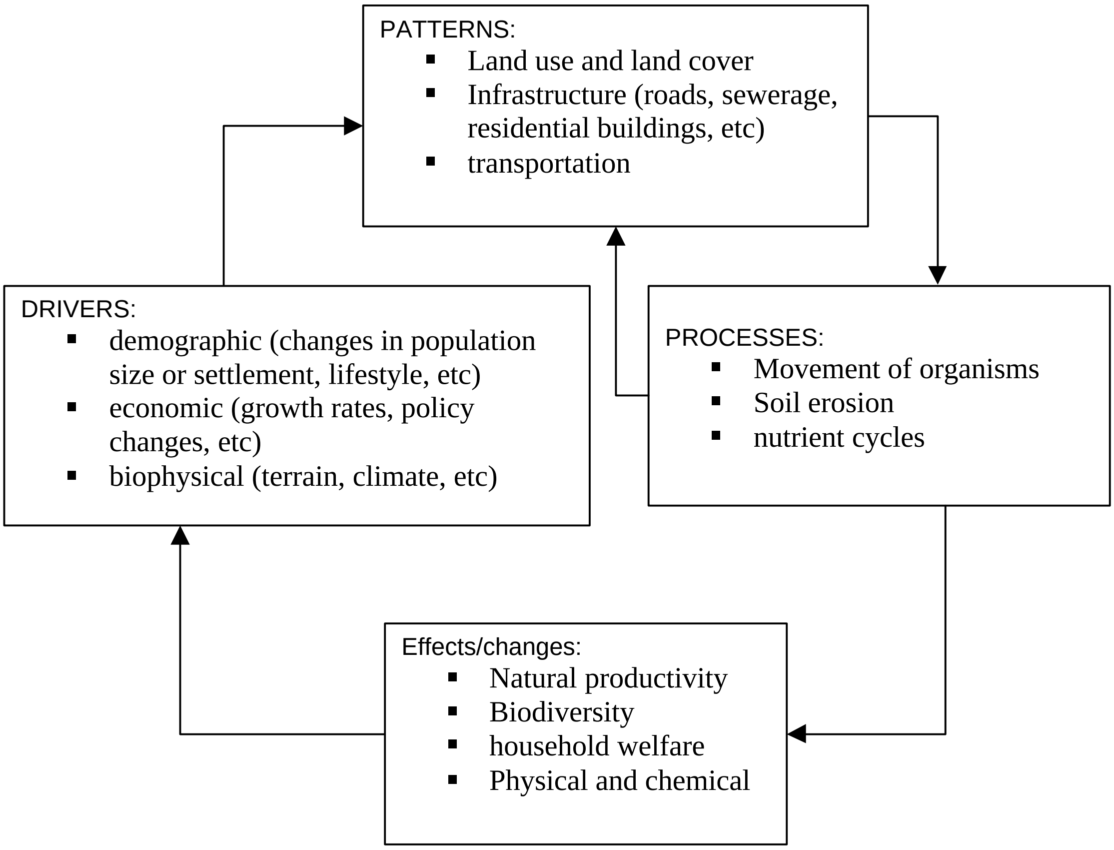

Figure 1: A conceptual model for modelling biodiversity changes Source: adapted from The Impact of Urban Patterns on Ecosystem Dynamics, http://www.urbaneco.washington.edu/

1.2 What is biodiversity?

The biodiversity concept is a central theme in the ALTER-Net project. All work packages deal with different aspects of biodiversity. Despite the wide use of the term, it has different meaning to different people. To a majority of the lay public it probably means the number of species. For scientists, the biodiversity concept has a wider meaning including genetic, species and ecosystem diversity. The latter definition is adopted from the Rio convention on biological biodiversity. Using this definition, biodiversity becomes divided into two parts. The first part is the living organisms, and the second is processes created by the living organisms. Together these two parts widen the biodiversity concept to encompass interactions between ecosystem composition, structure and function.

1.2.1 Use of biodiversity

Arguments for preservation of biological diversity can be divided into two groups, **anthropocentric** and **biocentric**. The former puts humans and mankind in the centre and focuses on how high biodiversity is beneficial for our present and future survival. The biocentric arguments are based on the preservation of biodiversity for its own sake. A third set of arguments that are closely related to the anthropocentric are economic values and costs linked with biodiversity.

The anthropocentric arguments can be divided into four main categories or arguments.

- The first argument may be called "the **utilisation argument**". We (the humans) need to preserve the biodiversity as we utilise or will utilise it. This applies directly to agriculture, forestry and fishery. This argument may also be applied to the preservation of genetic diversity, as the genes are codes for the production of millions of substances that may be utilised by us.
- Another argument concerns the **ecological services** that the ecosystems provide to us. Examples are micro-organisms that mediate the nutrient cycles, or pollination performed by insects.
- A third argument is based on the **aesthetic values** that flourishing and variable ecosystems provide.

- The final group of arguments involves **ethical motives**. The biological diversity is the result of billions years of evolution. According to the ethical motives, we have no right to extinguish a major part of the species within a few human generations.

Effects on ecosystems by decreased biodiversity have been subject to substantial research. Yet, there is no single theory on the relationship between diversity and ecosystem functions (Chapin et al., 2000). Ideally, hypotheses with subsequent experiments should test this relationship. However, large-scale scientific experiments on biodiversity are impossible, as we cannot manipulate whole ecosystems. The more or less anthropocentric arguments for preservation of diversity mentioned above do not include any functional relationships. Thus, they cannot serve as a basis for scientific hypotheses for testing the importance of biological diversity from a functional or ecological point of view. However, a number of theoretical hypotheses have been formulated for hypothetical or small-scale testing of the importance of biological diversity. The first is generally known as "The rivet popper hypothesis" (Ehrlich and Ehrlich, 1981). In this hypothesis species are seen as rivets in a flying aircraft, and the aircraft is seen as an ecosystem. Removing (popping) one randomly selected rivet will probably not cause any trouble, neither popping a second or third rivet. Eventually, a critical number of rivets have been popped and the aircraft will fall into pieces if another rivet is removed. The second hypothesis is called "The Redundancy hypothesis" (Walker, 1992). This hypothesis is based on the assumption that an ecological function is maintained as long as at least one species in a functional group is preserved. A third hypothesis is based on "Mutual losses" (Naeem et al., 1995), saying that loss of species is directly related to reduced ecosystem function.

1.2.2 Species richness and ecosystem functions and stability

The relationship between biodiversity and ecosystem function is one of the fundamental assumptions in the argumentation for preservation of biodiversity. However, this assumption is questioned by some of the theoretical hypotheses noted above, and there has been a debate on both the relationships between species richness and ecosystem function, and the underlying mechanisms. If all species in a community contributes in a unique way to an ecosystem process, the relationship between species richness and process stability will increase linearly. An increasing niche overlap or species redundancy at higher species densities will lead to an asymptotic behaviour of the relationship. This asymptotic, or nonlinear, behaviour of the relationship may make it difficult to find statistical relationships between species richness and ecosystem functions. In such cases, the mechanisms behind the relationship must be determined by studies of food webs to find important interactions between producers and consumers (McCann, 2000).

It has been suggested that weakly interacting species stabilizes communities by levelling out community oscillations caused by strong predator-pray interactions (Odum, 1971). It is hypothesised that the diversity per se is not the driver of this relationship. Instead, the stability depends on the ability for communities to contain species or functional groups that are capable of different responses to competition, stress and predation. Empirical data have shown that weak trophic interactions in communities are stabilizing the food webs (McCann, 2000). Any removal, or addition, of species may lead to altered interactions, which in turn may lead to increased oscillations and instability. Thus, both reduced diversity as well as addition of alien species may be destabilizing factors. Some studies have shown that decreasing naturalness of the environment causes greater sensitivity to invasion of alien species and extinction of the natural flora and fauna (Moyle, 1976).

1.2.3 Biodiversity assessment within the DPSIR framework

If we agree that biodiversity is more than the number of species, an assessment of biodiversity becomes complex. By counting species numbers, lot of important information on system complexity and function is excluded. Wider information is included if number of genera and families are included. Combining data on number of species and their abundance in an index gives us a somewhat more complex figure on diversity, but far form complete. Even more information is included if data on endemism and naturalness is given.

The quality of data on species richness may be insufficient (Nilsson and Nilsson, 1985). Many taxa are difficult both to find and to determine in the field. No studies can include all taxa in survey protocols. Since species are also commonly overlooked in the field, Chao & Shen (2003) have suggested a method for estimating true species diversity from incomplete species lists. If detailed surveys are not practical, an indirect way to assess the diversity is to use indicator taxa or surrogate measures of biodiversity. These include either taxa that are more easily surveyed than others, or physical structures that indicates a high probability of high biodiversity.

1.2.4 Biodiversity within the DPSIR framework

The ALTER-Net framework assumes cause-effect relationships between interacting components of social, economic, and environmental systems. The DPSIR model is used to evaluate and visualize relevant and important relationships between drivers and pressures, and state of biological diversity. Driving forces that may affect the biological diversity are: human demographics, economic growth, urbanization, technological advances, culture and transports. These drivers may cause pressures such as: climatic change, pollution, altered land use, and species introductions. Assumed impacts by decreased biodiversity are more fragile ecosystems, and loss of functional redundancy. Societal responses to mitigate these effects may be protected areas and national and international legislation.

2 Model vocabulary – what is modelling?

The purpose of this chapter is to introduce the reader to a number of terms and concepts that are useful when dealing with modelling and models used in biodiversity research. One of the most important criteria for models to be applicable in ALTER-net is that they must fit into the DPSIR concept. Most ecological models inform us about States and Impacts only a few integrate socio- or economic aspects. To be part of the DPSIR framework ecological models must at minimum be able to accept input from Pressure models and give output applicable to Response models. This gives restrictions on in- and output-parameters especially related to dimensions (space and time), but can sometimes be overcome by the linking of models such that one model (socio-economic) provides data input for ecological models to address aspects of biodiversity.

Models are tools used to represent reality in a simplified state. The type of model chosen will depend upon the problem to be addressed, i.e. there is no need to use a sledgehammer to crack a walnut. No single best model exists to describe all possible ecological problems, however to decide what model should be applied some criteria and definitions need to be considered.

2.1 Criteria

There are a number of issues that are important to consider when creating or using a model. Some of these are considered below:

Model scope:	System/species level; ecological/socio-economic/integrated? The scope refers to the purposes of the model for scientific and policy aims. Furthermore, it should be noted to what extent the model is accepted for scientific and policy purposes.
Model type:	Qualitative/Statistic/Mechanistic/Dynamic? Has the model an empirical (i.e. statistical) or theoretical (mechanistic) basis? What are the main assumptions? Is the model based on relevant processes? Which processes and mechanism are ignored in the model?
Model scale:	What are the time and spatial scales for which a model can be applied? Is the model restricted to a certain time or spatial scale? Can the model be extrapolated to other time or spatial scales?

Model feasibility:	Is the model comprehensible? Is good documentation available? Model complexity and comprehensibility of underlying mechanisms may influence the usefulness of a model if users are not able to run the model without advanced programming or modelling knowledge. Good documentation of the model or setting up courses for novice users may aid potential users.
Model input:	Data requirements? Are input parameters measurable? Does the model give reliable output for the whole range of input data?
Model output:	Generality/predictability? Are the model results analytically tractable and/or can they be verified against real-world data.
Alternative models:	Are there alternative models? What are the differences? If the model was compared with alternative models, the outcome of this comparison may also be presented.
Model references:	What are the most important resources about these models is presented. These sources may consist of model descriptions, examples of model use, discussions on calibration and validation methods, etc.

2.2 A model classification

When communicating models and model results it is important to have a grasp of the basic types of model and their properties. This classification is an attempt to present the major modelling styles usually encountered in modelling of different aspects of biodiversity.

Models can be categorised on the basis of their unit of study and spatial resolution. This method of classification follows and extends Munns et al (subm.)'s classification of population models (Figure 2). It is important to note that although there is a spatial axis, this does not relate to spatial scale extent but to spatial resolution (or grain). The five model types of Munns et al (subm.) have been extended with a further two types (Community & Distribution models) to represent those kinds of models most commonly used in biodiversity studies.

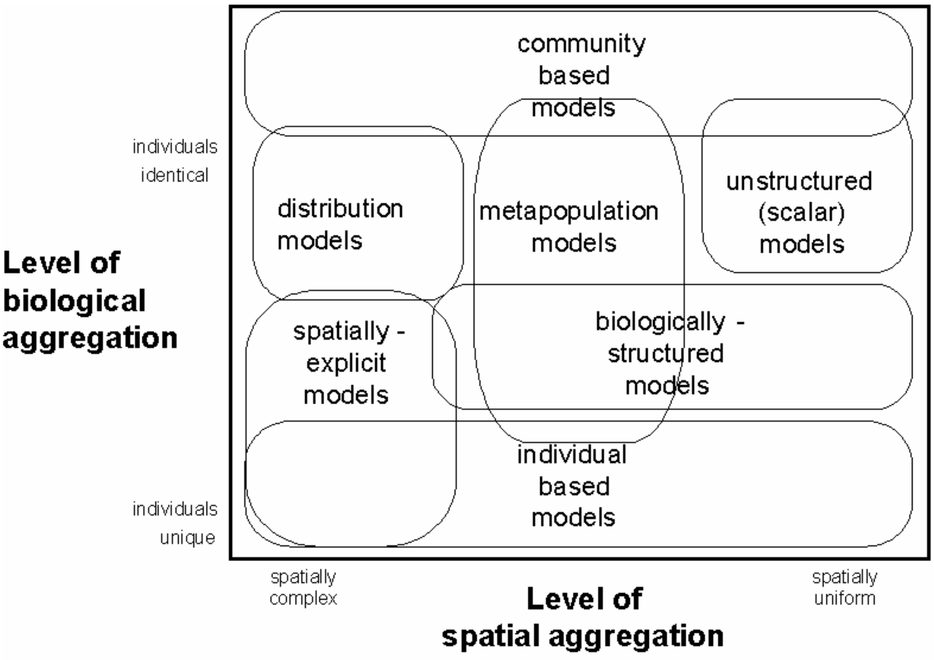

Figure 2: A proposed classification of models typically used for biodiversity research (after Munns et al, subm.).

Scalar models - Probably the simplest form is that suggested by Malthus in 1798: $dN/dt=rN$ (where N is population size, t is time and r is birth-death rate). Assumptions are that the population can be represented as a single uniform entity, no demographic or environmental structure, and usually few variables describing specific properties. Their uncomplicated and aggregated nature emphasises generality at the expense of realism and accuracy.

Biologically-structured models - These models assign demographic characteristics or vital rates to unique classes of individuals in the population. These models begin to incorporate a higher degree of realism and are useful where biological structure is important. Typical implementations involve the use of projection matrix representations such as the Leslie model. This type of formulation can incorporate discrete time and can include time-dependent variation in vital rates. Other implementations include a variety of differential equation based models.

Metapopulation models - Takes into account the disjunctive spatial distribution of many natural populations by simulating these as a set of interacting sub-populations. The level of biological aggregation can encompass all three of the preceding types. This modelling format has been extensively used in the past but is beginning to fall out of favour following the recognition that the assumption of discrete sub-population is not valid for the majority of species. For those systems compatible with the assumptions of the model, metapopulation models represent a relatively easy approach to implement and parameterise. Levels of realism can be scaled according to the data availability and aims.

Individual-based models (IBMs) - IBMs consider individuals as the unit of study. Their data needs are very specific to the species modelled and they tend toward a high degree of realism (and hopefully accuracy) at the expense of generality. Two classes of IBMs are recognised: i-state distribution (based on partial differential equations to manage the activities of individuals) and i-state configuration (characterised as summing the activities of all individuals as they are modelled separately). IBMs require higher volumes of data and longer development times than the previous model types.

Spatially-explicit models – From simple spatial representations to the extreme of spatial disaggregation. These models consider the characteristics of the environment, habitat quality, types, arrangements, as well as the spatial arrangement of environmental stressors. These models strongly emphasise ecological realism and accuracy over generality and are often parameterised for specific cases. Like IBMs they are generally employed for specific case studies where their realism is necessitated by the decisions or detailed research they support. Development cycles are long, and the data volume required is high.

Community Models - Differ from the preceding models in that the community not the population is the unit of focus. Community models come in all degrees of spatial aggregation. Typical model types include GIS based systems and multivariate statistical models.

Distribution models - refer to the prediction of occurrence of a species in space. Typically GIS based information models. These models pre-suppose a spatial element.

When considering genetics as a biodiversity trait a range of models can be used, but these are based upon a type of model construct represented here and therefore do not require a special model definition.

2.3 A note on integration

When developing models that integrate knowledge from different disciplines or sub-disciplines it is important to be aware of different modelling cultures. This is likely to be critical especially when knowledge from natural and social sciences is to be integrated. Such differences may substantially complicate the co-operation between scientists from the different disciplines. At UFZ (Drechsler et al. 2005) such differences were investigated between ecological and economic modelling with regard to problems of biodiversity conservation. Sixty models that address issues relevant to biodiversity conservation were selected randomly from eight international economic and ecological journals. The models were compared according to a number of criteria including the level of generality the models are aiming at, the mathematical technique employed for the formulation and solution of the model, the level of complexity and the consideration of real world phenomena such as time, space and uncertainty. As a result, the economic models sampled are formulated and analysed analytically, tend to be relatively simple and to be used for the investigation of general questions, however often ignoring space, dynamics and uncertainty. Some of the ecological models sampled have similar properties, however, there are also many other ecological models that are relatively complex and analysed by simulation. These models tend to be rather specific and often explicitly consider dynamics, space and uncertainty. With regard to model integration it is also interesting to know how ecological-economic models that contain aspects from both disciplines behave in this context. These models were observed to lie in the middle between ecological and economic models, an important result being that they are not more complex than ecological and economic models (as one could have expected from naive “merger”), but have an intermediate complexity!

3 The role of modelling in ALTER-net

ALTER-net should be viewed not only as a consortium of more or less linked organisations across Europe, having different, although sometimes convergent, experiences in identifying, describing and dealing with ecological problems. The extent of the network, which covers a broad range of cultures, traditions, socio-economic conditions and biodiversity levels provides excellent background for developing communication tools (also those based on modelling). The first tests for such tools are provided by ALTER-net team itself. Making sure that we are able to describe processes and links between them, produce scenarios and visualise predictions in a way acceptable and easy understood by all partners is a first step for developing common communication systems. Systems focused on propagation of long-term biodiversity, ecosystem and awareness research.

3.1 Models to help relate socio-economic factors to biodiversity change.

It is expected that modelling will enable us to bring together disparate issues surrounding biodiversity changes. As noted in the project proposal, one important component of the modelling task would be identifying important socio-economic drivers of biodiversity change and analysing their political and economic dynamics, as well as identifying policy options to mitigate the negative impacts of these drivers. It is believed that this approach will lead to a better understanding of the role of socio-economic drivers in ecosystem dynamics and thus to improve our capability to anticipate the impacts of socio-environmental trends to allow the European Union to make well-founded decisions about its own sustainable development. This overall objective was further elaborated and five specific objectives were formulated:

1. To identify the gaps in our understanding of the main socio-economic drivers and anthropogenic pressures on biodiversity and conservation policies related to these drivers and pressures.
2. To deliver an adequate vocabulary and methodology to describe, analyse and understand the integrated dynamics of socio-economic and natural environmental systems, henceforth referred to as socio-environmental dynamics.

3. To have defined key research hypotheses on the role of main drivers for biodiversity change in a socio-environmental context at different spatial and temporal scales.
4. To have analysed the political and economic processes behind these drivers.
5. To develop [in co-operation with Research Activities 3 and 6, below] models characterising the main components and functions of the socio-environmental systems and the relationships between them and biodiversity.

3.2 Models as a basis for data analysis and design of LTER network

An emerging assumption is that experimental and monitoring data extend to larger scales and crosscut disciplines facilitating an improved forecasting capability (Clark et al. 2001, Osmond et al. 2004). May (1999) noted that "many of the most intellectually challenging and practically important problems of contemporary ecological science are on much longer time-scales and much larger spatial scales" than are currently being investigated.

ALTER-Net's Multifunctional long-term research platforms (MFRP) provide a solution to this problem. Fully integrated landscape sites or regions like UNESCO Biosphere reserves, Zones Atelier in France or Multifunctional Research Platforms in Austria operate at a scale required to measure combined socio-environmental processes (see relevant documents of Integrating Activity 3). These sites should be designed to provide appropriate information for modellers to develop and test process-based integrated models able to predict biodiversity change and change in ecosystem functions driven by anthropogenic and natural drivers and pressures (Figure 3). The focus on modelling the processes and mechanisms involved is certainly the core area of fully integrated LTER sites and contrasts with correlative empirical (descriptive) models, which describe patterns in space and time with no explicit need to understand the underlying processes (see Chapter 2 for different types of models)

Several research questions need solving in order to achieve this goal:

1. What might be a common framework for this multidisciplinary modelling approach?
2. Do we have models that provide appropriate exchange parameters, allowing model integration/linking?

3. How do we scale-up and –down (in space and time) ecological and socio-economic parameters to be applicable in a unifying model?
4. How can we handle multiple sources of stochasticity, non-linearity and uncertainty?

At least some approaches have been under intensive debate, which tackle the above questions. The principles of DPSIR have been widely applied for the purpose of environmental assessment. However, how this framework can be used to model the consequences of environmental change for biodiversity is not fully explored (Petit et al. 2001). If such a model is to capture cause-effect chains then appropriate exchange parameters, particularly between the societal and the ecological compartments, have to be defined. One such link is between land-use and/or land-cover change and socio-economic changes. This principle is underlying the SENSOR IP where outcomes of socio-economic models are being used to predict future land use, and in turn evaluate the impacts of such changes on sustainability.

Most often ecological and social processes operate at a wide variety of scales and levels and cross-scale/level interactions are rather typical (Giampietro 2004). Interfaces of submodels need to take different spatial and temporal scales into account (Millennium Ecosystem Assessment Advisory Board 2003).

Finally, many sources of uncertainty exist in predicting biodiversity change due to anthropogenic and natural impacts. These uncertainties include human responses to environmental changes but also system inherent uncertainty (e.g. extinction risk of species). Many approaches for handling uncertainty are currently being developed including model averaging or hierarchy-models (Clark et al. 2001).

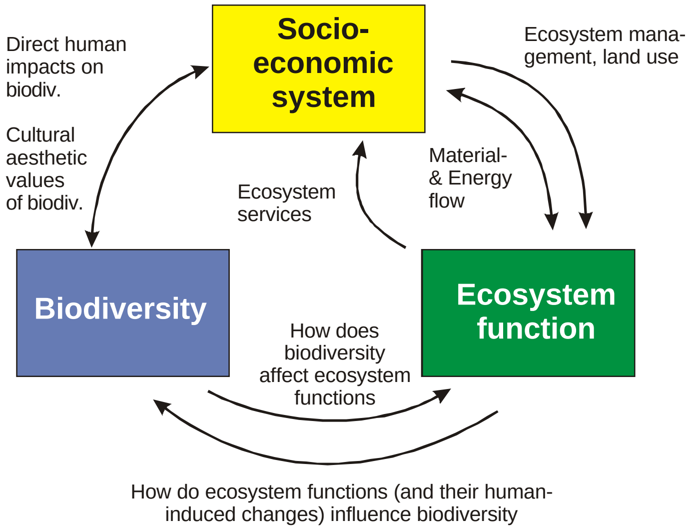

Figure 3: Processes to be modelled in order to link socio-economic systems with biodiversity and ecosystem function (source: Haberl, H. Sing, S.; Research activity 3; Workshop Halle; 21.-22.10.2004) .

3.3 *Models as scenario tools*

Scenarios are imaginative pictures of potential futures. The objective of scenarios is not to forecast or predict the future development of landscapes, but to imagine a variety of possible and plausible futures (Penker & Wytrzens, 2005, Mohren 2003). Scenarios are hypothetical, describing alternative future pathways, and elements are judged with respect to importance, desirability and/or probability (EEA 2000). Scenarios describe processes representing sequences of events over a certain period of time. Alternative policies can be evaluated in light of contrasting scenarios and their robustness to possible futures can be compared.

While scenarios are often based on qualitative stories (narratives), computer models are tools to explore future consequences of assumptions and consistency of the developed scenarios in a quantitative way. Besides advising the decision-making process a key function of scenarios is its power for combining both qualitative (expert knowledge) and quantitative (data and model based) output (Rotmans & van Asselt 1996; Penker & Wytrzens, 2005). Models and scenario analysis can provide a very powerful tool for explorative studies, provided they use reliable input data, and are based on thorough understanding of ecosystem functioning as well as of needs and demands from society (Mohren 2003).Scenarios are now developing towards integrated assessment, which is a relatively new field of decision support paying attention to the harsh complexity of major social and environmental problems (Rotmans & van Asselt 1996).

Usually forecasting biodiversity change is based on existing scenarios of one (Kopácek et al. 2003; Kovács-Láng et al. 2000; Pontius et al. 2001; Skov & Svenning 2004; Virkkala et al. 2004) some (Dirnböck et al. 2003; Dullinger et al. 2004; Klok et al. 1997), or multiple pressures (Petit et al. 2001; Topping, 2005). The explicit incorporation of socio-economic drivers in one model remains a rarity and was done particularly at the regional scale (Tasser & Tappeiner 2002). Furthermore, integrating several scales in developing scenarios, which means being developed at one scale (e.g. continental) but including trends at other scales (global, regional), is still a rarity.

The most elaborate biodiversity change scenario exercise at the global scale so far has been carried out by the Millemium Ecosystem Assessment (Millennium Ecosystem Assessment 2003). Terrestrial biodiversity was modelled via the IMAGE land cover change scenario and the species-area relationship, the potential biome and species shift due to climate change, and the critical loads concept for nitrogen deposition. Other approaches were adopted for freshwater and marine environments. In addition to biodiversity loss itself related ecosystem services were assessed. Although uncertainty is still unsatisfactorily high, the approach employed relies on ecological theory and is of high scientific quality.

Clark et al. (2001) point out that scenarios can be uncertain as long as they are as consistent as possible with current scientific understanding and that uncertainty is communicated transparently. Much more crucial for scenarios to be successful is that priorities for ecological forecasting must come from dialogue that ensures active participation by policy-makers, managers and the general public. A first step in scenario building would thus focus on the definition of forecasting priorities via user needs. IPCC Scenarios have been influential because they respond to a request from governments.

The use of alternative scenarios is becoming increasingly popular in environmental decision making, because scenarios combine assumptions and values in coherent packages that are easier to understand than are complex models with innumerable premutations of parameters (Kareiva 2001). In landscape ecology, scenarios are usually applied to understand more about landscape development, to support decisions for policy interventions in landscapes, and to support participation processes in landscape and regional planning. For these purposes, the scenario technique is considered to be a useful means of gathering and structuring diverse expert knowledge (Penker et Wytrzens, 2005). The spatially detailed modelling tools can be successfully used in definition and assessment of scenarios. Premises behind scenario set up and the related outcomes are made accessible for all stakeholders, such as political decision-makers, farmers or the general public (Münier et al. 2004). Despite some methodological limitations, scenarios can deal with uncertainty concerning the socio-economic driving forces of landscape change and therefore can be used as a preliminary step in formulating robust strategies for landscape management (Penker & Wytrzens, 2005).

3.4 Models as a tool for communication with the public

Science and society is linked in many different ways and conveying information between stakeholders has become crucial. Simultaneously, our knowledge has expanded and become rooted in huge data bases and its translation into policy has become more and more dependent on problem understanding and good will of people not dealing with scientific issues. Finally the policy implementation has become dependent on common acceptance by users and therefore effective exchange of information through direct or indirect contact with people is crucial.

3.4.1 Communication tools

Communication between science, technology and the public may be based on a variety of tools such as papers and books, brochures, films, Internet and models. However, among those, only models have the potential to get people directly involved in some processes and translate complicated problems into relatively simple language of signs. This is the case for four important reasons:

1. models allow (or even force) scientists and scientific organisations to communicate directly with their audience;
2. models allow the use and combination of very complex data bases, provide summarised information, detect relations between different variables, and allow forecasting and scenario building;
3. they have a demonstration power not comparable to any other communication tool in that they allow both visualisation of present data and future scenarios.

3.4.2 Communication to decision makers

Decision makers make comparative judgements about the hierarchy of importance of different issues while the attentive public (other scientists, lecturers, land owners and land users, NGOs) requires to understand basic processes, relations and model elements. These two groups are involved in designing strategies in conservation and management of biodiversity and such issues have to be incorporated into models, which use and generate specialised and precise information, forecasting and simulation of impacts of certain management options on the ecosystem properties. They should also be aimed at the creation of policy assessment instruments useful in spatial and temporal planning of human activities and conflict solving. By presenting information in a recognizable and understandable format, models can stimulate meaningful discussions and dialogue between groups traditionally associated with conflicting opinions.

3.4.3 Communication with the public public

The attentive public expect models describing and presenting processes, and here visualisation allows models to communicate, educate, inform and involve public and stakeholder groups in management decisions. The non-attentive public ignores ecological and environmental information, but as in many countries they constitute over 50% of audience; it is important to attract their attention using nice-looking, pictorial, game models (communication for education). The interested public requires the same kind of communication as, despite an interest in the issues, it lacks understanding of the processes involved.

Education requires mathematical models to be presented as graphs, equations, or algorithms. By using simulations, students can understand environmental processes playing important roles in whole complex and dynamic systems and they have an opportunity to view an ecosystem as an integral part of the natural and socio-economic environment. This creates public sensitivity to biodiversity-related issues.

3.4.4 Conclusions and conceptual model of communication process

Models are a very valuable tool to ensure good quality communication between different groups of interest – scientists, authorities, decision makers, NGOs, environmental protection agencies, foundations, stakeholders and the public. Expectations, knowledge constraints, level of interest and data available, strictly determine the structure of a model, its predictive power and accuracy. What is unquestioned is the fact that modelling, like no other tool, requires and ensures communication between: ‘information sources’ (education, management, science), modellers and scientists working directly on approach and a model (at every step of model elaboration) and end-users, who consciously or not incorporate results into learning activities, policy and investment.

Along the process of model elaboration, communication takes different forms - simple information transfer necessary for proper tasks identification, then problem assessment for identification the optimal approach, translation of scientific approach into proper modelling approach and adjustment of that approach and deciding about model structure and properties. Finally results in required form – ecosystem state assessment, scenario, educational game, management suggestions - are transferred directly to the publics in synthetic, focused and visualised form; the ”Story and Simulation (SAS)” approach taken by IPCC and further elaborated by the Millenium Ecosystem Assessment providing narratives of model results that are understandable by a broader public.

3.5 Improving access to data for models

Work package R6 has to co-operate with work package I6 (a framework for distributed data, information and knowledge management system) in order to establish an IT framework for ALTER-Net that sufficiently supports the needs of establishing, tuning and applying different biodiversity models. Although preferred models exist (e.g. niche models) as well as a unifying metamodel framework (DPSIR) in order to forecast biodiversity change, it is necessary that the IT strategy allows for implementing a wide range of ecological models.

It is assumed that I6 establishes a network for distributed data, distributed applications and distributed datamining based on grid technology (http://public.eu-egee.org/) so that e.g. a member in Poland will be able to work with a model of Denmark on data of Scandinavia and Poland.
R6 needs to work out metadata standards and ontologies (semantics and structures) together with I6 which will allow:

- mapping of existing data to the standard ontologies

- establishment of semantic interfaces of (modelling-) applications (e.g. defining that a forecast model is only valid for certain species) (http://www.sys-con.com/xml/article.cfm?id=776)
- a seamless access to data and applications

It is crucial that existing standards for metadata, ontologies and process- and service definition (especially IEEE [http://standards.ieee.org/], ISO [http://www.iso.org/iso/en/ISOOnline.openerpage], W3C [http://www.w3c.org/], EN), existing software developed by others (SEEK [http://seek.ecoinformatics.org/] , e-science, e-health, biodiversity modeller), existing know how, and existing concepts are taken into account.

4 An overview of existing model expertise in ALTER-net

This chapter is not intended to be a complete overview of all types of modelling developed by the participating institutions of ALTER-net. Rather, the purpose is to identify and describe some major model 'trends' within the following six areas:

1. Forest ecosystems
2. Freshwater ecosystems
3. Agro-ecosystems
4. Broad-scale distribution modelling
5. Land use change modelling
6. Integrated impact modelling

4.1 Models of forest ecosystems

A number of forestry models are available that predict how environmental conditions affect biodiversity. Some of those models use a static approach to identify the influence of climatic variables on tree species distribution, the influence of environmental conditions (climate, soil) and forest stand structure on forest biodiversity. There are also examples of dynamic models used to assess forest diversity changes over time, in relation to vegetation succession, climate change, disturbance, and management strategies.

Most forestry models developed in the network have a small resolution, as they predict species diversity and forest stand dynamics for plots which size varies from a few square meters to a few hectares. Their domain of use is related to the spatial extension of focal species and main environmental drivers. However, there are also probabilistic models of tree distribution at continental (European) scale.

Modelling tree species distribution along climatic gradients, at local, regional and continental scales. At regional scale, probabilistic models have been used to explain the patterns of distribution and abundance of oaks along climatic gradients in Spain (Urbieta et al., 2004).

Modelling forest vegetation biodiversity in relation to environment conditions and stand structure. The relationship between vegetation community composition in Swedish forests and environmental variables is used to forecast the likelihood of a species being present under changing environmental conditions. The methodology is based on the RIVPACS model (Wright et al., 2000).

Modelling forest biodiversity changes over time. The OFM (Oak Forest Model) is a non-statistical verbal model which describes the effect of global climate change on the biodiversity of Hungarian oak forests (based on data from the Síkfokút ILTER Project (Hungary).

SAMSARA. The model SAMSARA (Courbaud et al. 2003) is a spatially-explicit individual based model allowing to simulate the dynamics of mixed forest stands. Competition between trees and between canopy and regeneration is modelled through the explicit calculation of radiation interception by every tree in the stand. The model is currently applied in mixed *Picea-Abies-Fagus* forest stands in the Alps.

The ALCALA forest management model. The ALCALA model (under construction) is a biology based management model aimed to predict changes in forest composition along topographic and disturbance gradients, and within a global change scenario. The model is implemented in southern Spain, but will be applicable to other Mediterranean forests.

Forest tree line models. Dullinger et al. (2004) have developed an individual based model to predict the impact of climate change on the dynamics of mountainous treeline. The model is spatially explicit and handles interactions with resident vegetation.

4.2 Models of freshwater ecosystems

The major drivers affecting the integrity of aquatic ecosystems are overexploitation, nutrient enrichment and organic pollution, acidification and alterations of hydrology and morphology. To address the effects of human-induced stress on aquatic habitats, many European countries have a long history of monitoring (using benthic macroinvertebrates) the biodiversity and ecological integrity of freshwater ecosystems. Methods include relatively simple algorithms or biotic indices, combinations of multiple indices (multimetric approaches), and relatively complex, multivariate approaches for pattern recognition and prediction. All three approaches are commonly used in biomonitoring and assessment studies to detect ecological change.

Another area that shows promise is the use of modelling approaches that utilise ecological relationships to predict community composition in the absence of human-induced stress. Various initiatives are underway within ALTER-net. Among these predictive approaches (RIVPACS-type models), dynamic models to describe structure and dynamics of populations, construction of tools to identify hierarchies of components in aquatic ecosystems, and tools to predict response of biodiversity to stress caused by human impacts.

DALIS (Wojtal et al. in prep) – a model for forecasting influence of natural (mortality, reproduction, predation) and human-driven factors (eutrophication, hydrology) on cladoceras' dynamics and water quality (depending on filtrators density) in Sulejow reservoir in Poland.

FISHEST (Zalewski 1994) estimates fish stock density using only one electrofishing, which is crucial for preservation of fish populations in small streams. Traditional methods based on multiple electrofishing may lead to fish depletion and are not applicable in natural parks or for studying of rare or endangered species.

PROTECH (Reynolds et al. 2001) and **CE-QUAL-W2** (Cole and Wells 2002) are used to predict phytoplankton responses to environmental change in lakes and reservoirs. **MICRO-PEG-RES** (Straskrabova et al. in print) verbally describes seasonal cycles of plankton communities in temperate water bodies and include following pelagic groups: zooplankton (cladocerans, copepods, rotifers), two size groups of phytoplankton, bacteria and protistan grazers, their interactions and an effect of meteorological conditions upon them.

4.3 Models of agro-ecosystems

ALTER-net has a range of expertise within modelling of aspects of biodiversity in agro-ecology. Agro-ecological modelling applications require a range of temporal and spatial scales to be considered dependent upon the spatial unit of study (field, farm or landscape), and upon the biological unit, which may be from soil-dwelling Collembola to migratory birds or large grazing animals. This variety of applications necessitates a variety of models, however many of the more simple applications require the use of simple models such as matrix population models, or metapopulation models (e.g. Grimm et al, 2004). Here ALTER-net has expertise and experience at least as wide as other competent modelling group. However, agricultural systems are highly dynamic both from a biological point of view (succession, spatial dynamics, nutrient dynamics), and from a management perspective (Tappeiner et al. 2003, Tasser & Tappeiner 2002). They therefore often require a multifaceted approach to their modelling. In these cases ALTER-net has considerable expertise to bring to bear. From an information perspective, ALTER-net consists of the many of institutes throughout Europe that most commonly undertake applied conservation projects within agricultural systems; therefore there is good basis from which to build knowledge-based models. Additionally there exists an expertise in construction and application of simulation modelling from relatively simple simulation models of animal movement (e.g. ALTERRA's SmallSteps model (Jepsen et al, 2005)), invasion models (e.g. SEIBS (Higgens et al, 2001)), simulations of plant growth, competition and evolution (e.g. Warren &Topping 2004), to comprehensive simulations of the agri-environment such as the ALMaSS system (e.g. Topping & Odderskær, 2003).

4.4 Broad-scale distribution modelling

Broad-scale distribution modelling of species-environment relationships, i.e. based on various hypotheses as to how environmental factors control the distribution of species is widely used in ecology, biogeography and conservation planning. These models have especially gained importance as tools to assess the impact of accelerated land use and other environmental change, e.g. climate, on the distribution of species. The statistical formulation of the model depends on the type of response variable (for a review, see Guisan and Zimmermann, 2000) and a number of indices and techniques are available to assist the assessment and deconstruction of prediction errors (Fielding and Bell, 1997).

When applied to species distributions, broad-scale distribution modelling and mapping includes three different stages, (i) developing and calibrating a statistical model of the relationship between environmental variables and species distribution, (ii) evaluating the model with an independent data set or other validating techniques, and (iii) applying the model to a geographic data base to create a predictive map.

Predictive species-environment models are powerful tools as they provide a graphical summary of the results, a framework on which a field survey might be planned in order to collect empirical data more efficiently, and tools for inference of properties not directly observed.

Species occurrence and biodiversity patterns are primarily dependent on climate and habitat pattern. A central premise of biogeography is that climate exerts a dominant control over the distribution of biota on large scales. On smaller scales, e.g., landscapes, habitat cover and land use changes are often considered as the main factors affecting biodiversity patterns. Consequently, environmental drivers of species distribution might operate at contrasting scales. The occupancy of any species is thus affected by the spatial distribution of appropriate habitat patches on the landscape scale, whereas climatic factors are usually responsible for the large-scale distribution patterns.

4.4.1 Examples of distribution modelling in the network

Distribution of alpine plants in relation to future climate and land-use. The objective of this study was to assess potential response of alpine plant species distribution to different future climatic and land use scenarios in the North-eastern Calcareous Alps of Austria. The results support earlier hypotheses that alpine plant species on mountain ranges with restricted habitat availability above the treeline will experience severe fragmentation and habitat loss. (Dirnböck et al. 2003). However, an extended dynamic model also revealed that considerable time lags can be anticipated until potential habitat losses will be reached (Dullinger et al. 2004).

Prediction of suitable habitat for priority species. Habitat maps for Crex crex and priority grassland was made in Poloniny Biosphere Reserve, Slovakia. Logistic regression, CART, Discriminant analysis and ENFA (Hirzel et al., 2002) were used in order to build statistical model of the relationship between environmental variables and habitat distribution. The model was also used to predict suitable habitat today and in 2030. Priority species and habitats were used as indicators of agricultural decline in the abandon mountainous region in Eastern Carpathians Mts.

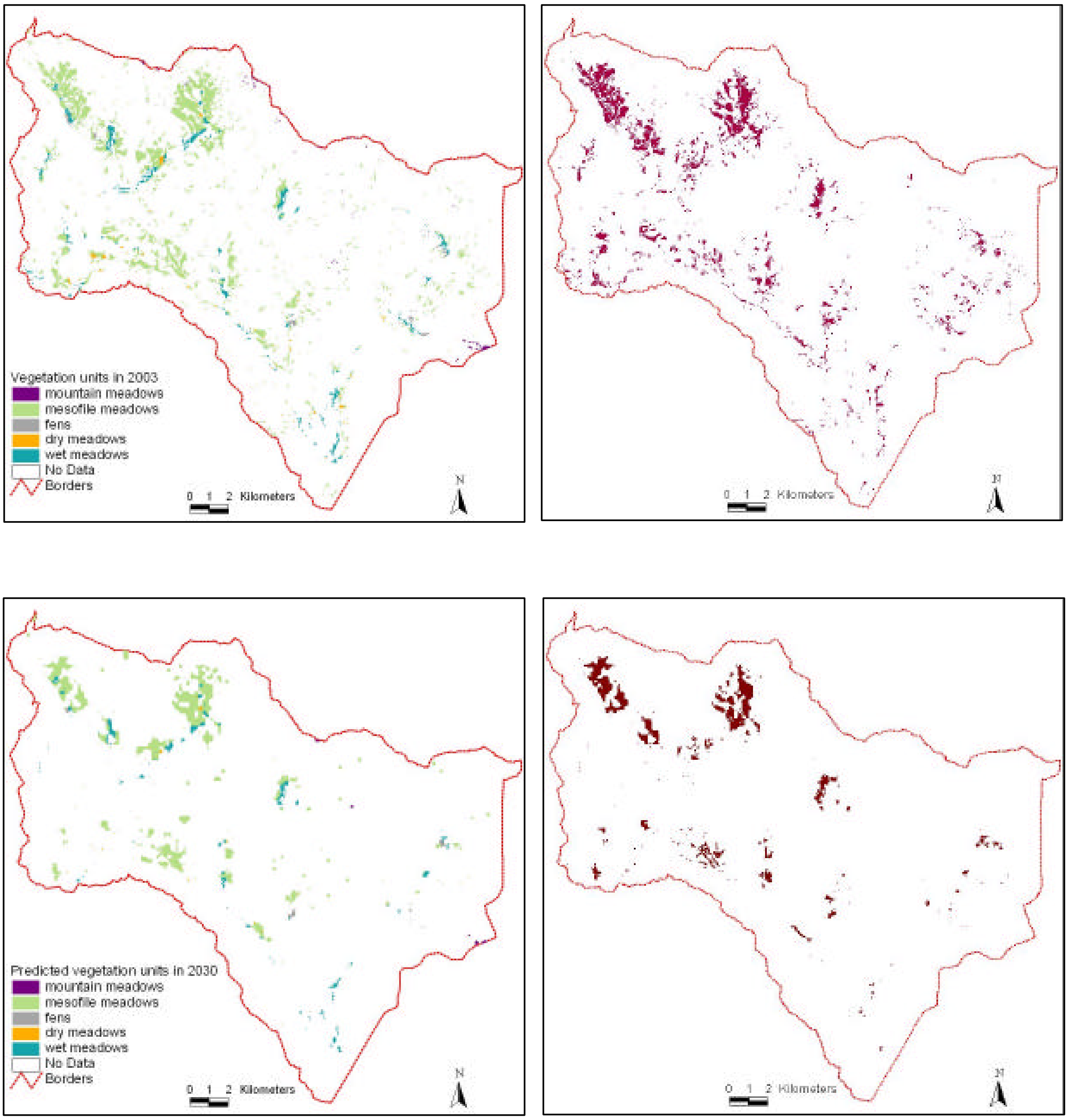

Figure 4: An example of predictive habitat mapping from Slovakia.

Determinants of biogeographical distribution of butterflies in boreal regions. In this study, the main environmental correlates of butterfly distributions in Finland were investigated. Results indicate that the distributional limits of butterfly species in Finland are principally set by climate and were used to see which species are particularly sensitive to forecasted global changes.

Species richness coincidence: conservation strategies based on predictive modelling. Here it was explored whether hot spots of five taxonomic groups (plants, dragonflies, butterflies, herpetofauna and breeding birds) coincide after correcting for differences in mapping intensity. This example illustrates how decisions on the designation of conservation areas may greatly benefit from predictive modelling performed at a regional scale.

Birds as predictors for butterfly distribution. In this study it was demonstrated that distribution data of a very well-surveyed taxonomic group (birds) data can be used to predict the distribution of less well-surveyed species groups (butterflies). In addition, our results indicate that models built in one region could be applied in an adjacent ecologically similar region.

4.4.2 Important future research areas in relation to Alter-net priorities

Recent critiques have questioned the validity of this climatic envelope approach by pointing to the many factors other than climate that also affect species distributions and the rate of distribution changes (Davis et al. 1998, Hampe 2004). The relative importance of habitat factors on the one hand, and factors related to climate on the other hand, are thus essential for understanding the causes of biogeographical distribution patterns. The challenge is to explore the risks to biodiversity caused by the synergy of climate change (at the large scale) and habitat fragmentation (at the regional scale). The assimilation of climate and landscape level processes can improve our understanding of species geographical patterns, future biodiversity research and conservation strategies. Here below are listed some future research aims in relation to Alter-net priorities.

4.5 Land use change modelling

In this section we present as an example a landscape model which was developed in order to analyse landscape-scale changes of biodiversity and carbon pools in relation to historical and current land use, as well as explorative scenarios of future land use. This was achieved by integrating socio-economic drivers and spatially explicit information, scaling up biodiversity as well as C-pools from the ecosystem to the landscape scale.
The approach combines: (i) historical and current land cover, (ii) scenarios of land use as inferred from stakeholder consultations, from a spatially explicit land use change model (transition matrices), from an agro-economic model, and (iii) estimation of biodiversity as well as of C-pools in the phytomass via a geo-statistical model.

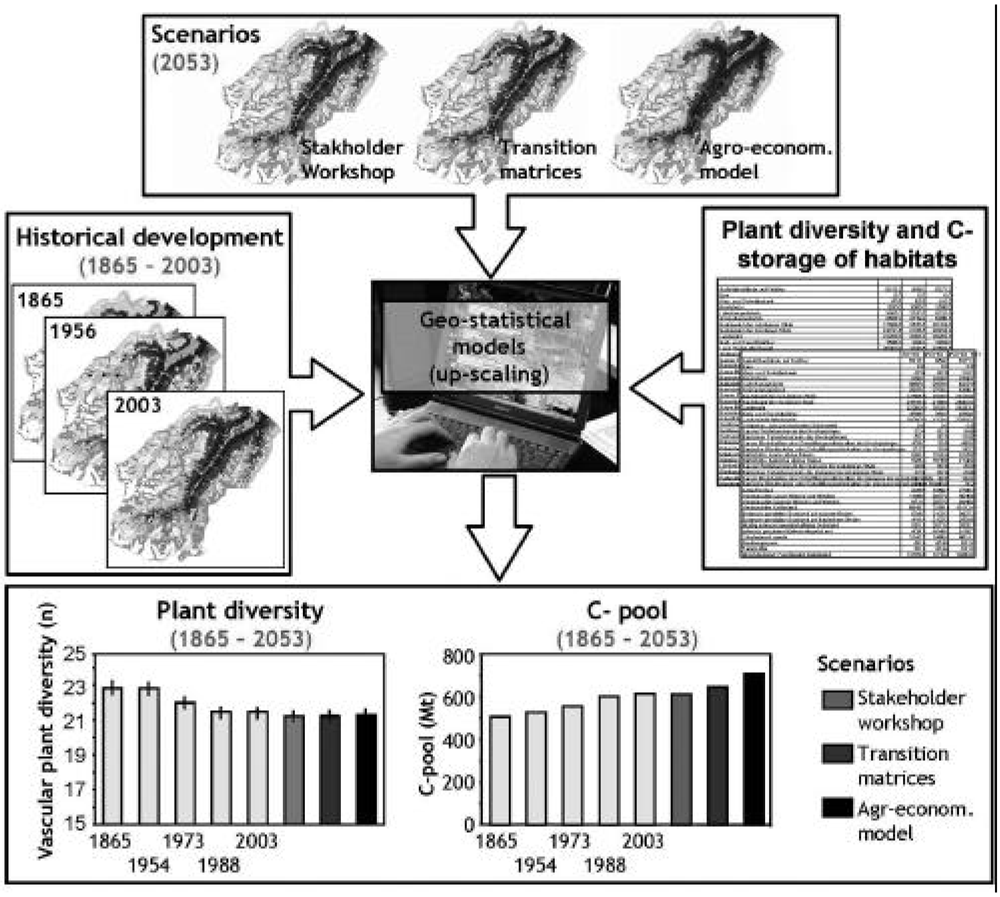

Figure 5: Research approach to analyse landscape-scale changes of biodiversity and carbon pools in relation to historical and current land use, as well as explorative scenarios of future land use on the example of the Stubai Valley in Austria (region Innsbruck Land).

The historical land cover was obtained by digitizing historical maps (Francisco-Josephinian Cartographical Register, M 1:25000, 1869-1887) which depict the different land-use types from forest, to lightly used meadows, pastures, larch meadows, permanent crops, arable land, settlements and others (rocks, moors, rivers). Starting from 1950 up to now, remote sensing data were available in the form of aerial photographs and orthophotos. Consequently, we got information on land cover and land use changes of the last 150 years to 200 years.

The calculation of the scenarios of land use was based on the following methods:

Stakeholder Consultations: The approach examined three contrasting funding scenarios (1) Status quo - gradual reduction of farm income support, continuation of restrictive planning policies; (2) Reduced area-based support - rapid reduction of area-based direct payments in favour of environmental or cultural landscape payments linked to labour, continuation of restrictive planning; (3) Rural Diversification - enhanced rural development policy with positive planning.

On workshops stakeholders such as farmers, foresters, economists, ecologists, and planners made a reasonable judgment of how a possible policy change might affect them and their area and predicted the effects on mountain landscape sites (Bayfield et al. submitted).
Transition Matrices: The transition matrices implied the development of the past 15 years and forecast a continuous development in the same direction (Luijten 2003).
Agro-Economic Model: The agro-economic model focused on the changes resulting from economic aspects (milk price premium, area premium or income from sideline) with the aim to point out the effects of economic changes on the acting of farmers and subsequently on agriculture by responding to agro-environmental policies (Hupfauf et al. submitted).
As input variables we used among others site and topographical factors as well as farm size, cost distance between areas and farm, and accessibility with machines as basis for each farm. The driving variables for our model were the aforementioned economic aspects and their changes.

In a next step, biodiversity as well as C-pools in the phytomass were estimated via a geo-statistical model. The land use classes were combined with detailed phytosociological information (e.g. species) to enable the estimation of biodiversity changes, C-pools and other ecosystem services. The values result from project area relevant literature (approx. 30 publications) and our own findings if data were not available.
The used approach of a comparatively simple geo-statistical modelling of the results proves to be a very suitable measure to consider all principles of DPSIR by assuring simplicity, comprehensibility and clarity (Tappeiner et al. 2001; Tasser & Tappeiner 2005).

4.6 Modelling the integrated impact of pressures on biodiversity at a European scale

MIRABEL (**M**odels for **I**ntegrated **R**eview and **A**ssessment of **B**iodiversity in **E**uropean **L**andscapes) is a conceptual framework that applies the principles of DPSIR and is designed to facilitate analysis of the consequences of environmental change for biodiversity at the scale of Europe (Petit et al. 2001). MIRABEL was developed under contract to the European Environment Agency (EEA) to underpin the assessment of European biodiversity within the EEA successive State of the Environment report. The assessment is based, when possible, on spatially explicit quantitative modelling of the responses of biodiversity to environmental conditions (Fig. 6).

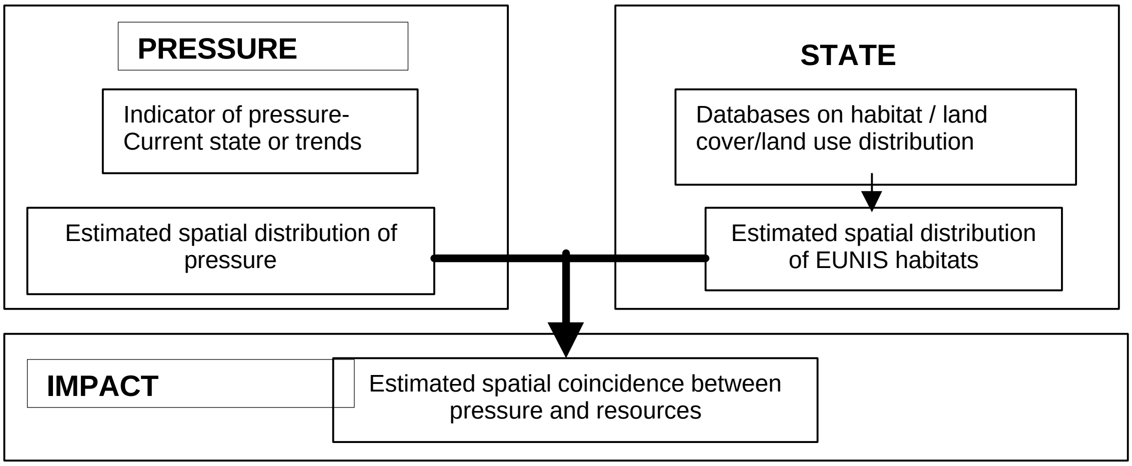

Figure 6: The DPSIR framework in the context of MIRABEL

4.6.1 Assessing the impact of terrestrial eutrophication on Biodiversity

Atmospheric nitrogen (N) deposition has been identified as an increasingly important driver of ecological change in Europe. In Mirabel II, we developed a model to assess risks associated with increased N levels across Europe for 22 EUNIS habitat types present in designated sites and that have been identified as sensitive to N deposition in recent international workshops. The distribution of EUNIS habitat types was derived from the pan-European databases of designated sites (Natura 2000 and CORINE Biotopes). In our model, response of vegetation to N deposition – as estimated by EMEP grid - was affected by variables such as soil pH as it affects the availability of phosphorus, a component which is known to worsen the effect of N; soil moisture, as extreme conditions will impede the response of vegetation to N deposition; the length of the growing season, as again it affects the response of vegetation and finally the surrounding land use, which dictates the availability of sources of propagules of plants typical of eutrophic habitats around sites.

This assessment showed that the amount of habitats at high risk was much less than the total amount of sensitive habitats found in a region and that a substantial proportion of sensitive habitats experiencing N deposition values above their critical load were not at high risk when assessed by our model. The two main factors limiting the impact of N deposition on habitats were phosphorus limitation and the land use surrounding the designated sites.

4.6.2 Assessing the impact of farming intensification on biodiversity

There is now much evidence that the intensification of farming practices that took place after over the last 50 years has been a major driver for the decline in European biodiversity and today, there are still strong ecological signals that the decline of biodiversity in farmland has not been halted.

In Mirabel II, a quantitative spatially explicit model was developed to assess the the impact of farming intensification on ecological resources at risk from this pressure. Indicators of intensification were the stock in 2000 and the change between 1990 and 2000 for (i) nitrogen surplus and (ii) livestock stocking densities and were computed using the ELPEN system (6). Distribution of resources at risk were derived from the pan-European databases of designated sites. Models outputs were interpreted at the Biogeographical level and below in terms of (i) the amount of resources potentially at risk, (ii) the state and trends in pressure and (iii) the foreseen impacts on responsive habitat types. Spatial coincidence of pressures with habitat types in designated sites were assessed across Europe for specific habitat types or for sets of habitat types in specific biogeographical regions.

For Nitrogen surplus, the pressure seems to have decreased between 1990 and 2000 where it used to be very intense (Atlantic region) while it is still increasing in some other areas. Impact on specific habitat types varied, but in most regions, there was always a proportion of habitats that were predicted to be under increasing pressure (especially true for the Mediterranean region). Trends in stocking densities were heterogeneous within all Biogeographical regions, with similar amount of area predicted to have experienced increased and decreased grazing pressures (except in the Alpine region with more areas experiencing increases). Substantial increases in grazing pressure were predicted to impact on xeric grassland in the Mediterranean region and on alpine grassland types in the Alpine region.

This assessment proves that linking agricultural statistics to biodiversity information is possible at a coarse scale. The spatial dimension of the indicators of farming intensification derived from the ELPEN system enabled to make a direct link with the nature and location of natural resources. The development and/or refinement of additional indicators of agricultural trends would provide extremely valuable tools for future integrated assessments at the regional level.

5 Perspectives and new directions

The purpose of this chapter is to discuss some possible ways in which modelling may be further developed in the context of ALTER-net.

5.1 Integrated modelling

Integrated models are relatively new approaches for discussing the issue of sustainability. These models are aimed at bringing together the knowledge of various disciplines in assessing the developments in ecology and economy. Starting in the 1970s, many researchers have attempted to integrate various relevant systems into a comprehensive model. Different concepts and modelling approaches emerged in the 'integrated modelling society'. Among these are system dynamics, environmental economics, biodiversity, industrial ecology, ecological economics, systems ecology and integrated assessment modelling. Despite the different approaches, all models that have been developed share one essential property: the inherent impossibility to make accurate predictions for long-term future developments, no matter the level of detail in the model. This is caused by the complexity of systems involving ecology and human behaviour, which confronts us with the fundamental limits of predicting future system behaviour. Notwithstanding these serious limitations of integrated models, they can help us to show the interdependence of the various activities and their consequences in time, place and scale. In that way models can be used to communicate knowledge on relevant system dynamics from the scientific community to policy makers and stakeholders.

Integrated models are being applied on various issues at different scale levels. They might focus on ecological-economic developments at a regional or local scale. In these models, socio-economic developments and interactions with the environment are simulated in spatial detail and also the development of integrated models of global systems.

The first step in modelling such complex problem is developing a conceptual model of the system and processes involved. We expect that such a model clarify the connection across disciplines, reveal which research questions were better approached within a traditional single discipline, and identify opportunities for constructing mathematical model of biodiversity.

5.2 Conceptual models and Cognitive Maps

The purpose of a conceptual model is basically to capture the scientific understanding of a given system. Conceptual models have proven valuable to help understand how systems work, highlight what we don't know and hence help formulate new research programs. Another important use of conceptual models is to disseminate information to other scientists, to decision-makers and to the public. A conceptual model may be formulated verbally or graphically on a piece of paper, but it is also possible to build dynamic, computerised conceptual models. Various methods are available. In this paper Cognitive Mapping is presented as a simple, yet powerful approach:

The term 'Cognitive map' can be attributed to Axelrod (1976) who used cognitive maps to plot his understanding of a given system as a number of concepts affecting each other. A Cognitive Map is represented as a graph or network where *variable concepts* are represented by nodes and *causal events* (interactions between concepts) by edges or lines connecting the nodes. Connections are usually directional, meaning that the action is from one node to another and represented by an arrow. In other words, a Cognitive Map consists of individual cause-effect relationships tied together in a large network which makes it possible to construct large and relatively complicated models even though only small parts of it is understood at one time.

A Cognitive Map represents a convenient way of visualising a complex scenario or system. A cognitive Map is dynamic and allows for feed-back and may produce simple predictions on how complex situations may evolve if we change some of the initial concept states, e.g. to evaluate what-if implications of a model. System feed-back often results in a dynamic phase where concept values go up and down for then, finally, to converge to an equilibrium. This equilibrium, or hidden pattern, is the outcome or prediction of our model. Cognitive Maps, hence, may provide rich insights in the behaviour of complex systems.

Larks and pesticides – an illustrative example

A useful example of the potential for linking multi-facetted models to decision making in agro-ecology is the evaluation of the impact of different pesticide taxation scenarios on skylark population numbers (Topping, 2005). This problem required the consideration of a number of aspects including the socio-economic impact of taxation scenarios on the farmer and the changes in management that would result. These changes were used as input to ALMaSS (a landscape scale, agent-based simulation model, Topping et al, 2003). ALMaSS models both the ecology and behaviour of the target animal species in detail, but also models the environment in which the animal is placed. This environment includes the spatial arrangement of fields, weather, and most importantly a farm-by-farm, and field-by-field detailed crop management including crop rotations and detailed crop husbandry. Inputs from the socio-economic model resulted in changes in farm management and crop choices, and these changes were translated into changes in skylark abundance.

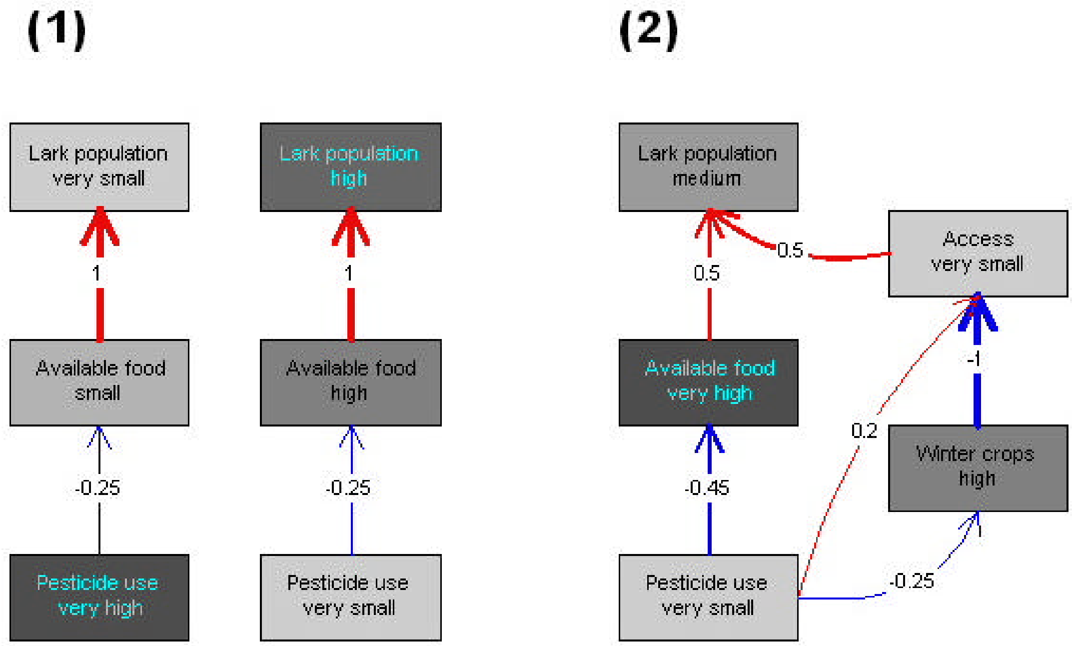

Figure 7: Two cognitive maps showing (1) the ‘expected’ cause-effect relationship between pesticide application and lark population under a high and low pesticide use scenario, respectively and (2) the interpretation of the results from the ALMaSS simulations. Red and blue arrows show positive and negative effects, respectively. The thickness of the arrow indicates the relative strength of the effect (from –1 (strong negative) to 1 (strong positive))

The results indicated that contrary to expectations, direct pesticide taxes were far from being the most positive measure that could be used. Direct taxes led to a change in farmer behaviour and an increase in the area of detrimental crops, as well as a reduction in indirect pesticide effects. The overall result was a balance slightly tipped in favour of negative impacts on skylarks. An alternative strategy of reducing pesticide to the same degree using unsprayed field margins was predicted to have large positive impacts. This work demonstrated that it is important to consider the multifaceted nature of the agricultural system when evaluating the impacts of changes on wildlife, especially since in this case the impacts of the change were smaller than the side-effects caused by the implementation of policy.

5.3 The viability theory and biodiversity management

The viability theory was developed by J.P. Aubin (1991). It is a mathematical theory that offers a precise conceptual framework and practical tools to define and control the evolution of dynamical systems in, e.g., biology, economics, cognitive sciences, and in game theory.

The theory emphasises 3 main common features of these systems :

- A nondeterministic (or contingent) engine of evolution, providing a number of opportunities to explore the environment. These may be interpreted as possible actions on the system
- A set of viability constraints that the system must be kept inside at each instant in order to survive
- An inertia principle stating that the “controls" of the system are changed only when viability is at stake.

Viability theorems provide selection procedures for viable solutions (evolution). They characterise, in other words, the connections between the dynamics and the constraints for guaranteeing the existence of at least one viable solution starting from any initial state. These theorems also provide the regulation processes (feedbacks) that maintain viability, or, even as time goes by, improve the state according to some preference relation.

Contrary to optimal control theory, viability theory does not require any single decision-maker (or actor, or player) to ``guide" the system by optimising an optimality criterion. System settings are very flexible and can be changed anytime to accommodate changes in the system allowing for adaptation in relation to viability constraints.

Viability theory does not require any knowledge of the future. In a nutshell, the main purpose of viability theory is to explain the evolution of a system, determined by given nondeterministic dynamics and viability constraints, to reveal the concealed feedbacks which allow the system to be regulated and provide selection mechanisms for implementing them.

5.3.1 The viability theory in relation to biodiversity management

The viability theory seems particularly adapted to give a conceptual framework to the problem of biodiversity management. We propose to formalise the problem more precisely as follows:

We suppose that the state of the system is described by a set of N species each characterised by a number of attributes. Each species is capable of change as a respond to other species and to a set of environmental conditions (e.g., nutrient supply, humidity, climate). These environmental are also dynamical.

We assume further that the global evolution of the system can be described by a number of equations. These equations also make it possible to include human actions such as modifications of the environment or direct effects on species.

Finally, we suppose that biodiversity conditions are satisfactory when all the attributes of the considered species are neither too low, nor too high. Typically, this constraint means that when the size of a population gets below a threshold, it face an extinction risk. Conversely, if a species becomes too successful or invasive, the equilibrium of the ecosystem may be threatened.

The problem can be therefore stated as: finding an action policy which guarantees that each species remains within these limits, or - at least – will be able to return. Figure 8 illustrates this idea on a simplified example with two species.

Then, viability theory shows that to ensure that the system does not go outside a set of limits or space, it must remain in an even smaller set included herein. This set of viable solutions is defined as the set of states where at least one action policy ensures that the system always remains in a viable. Once this set is identified, the simplest action policy consists in acting whenever the system is close to the boundary of the set of viable solutions. This is illustrated on figure 9.

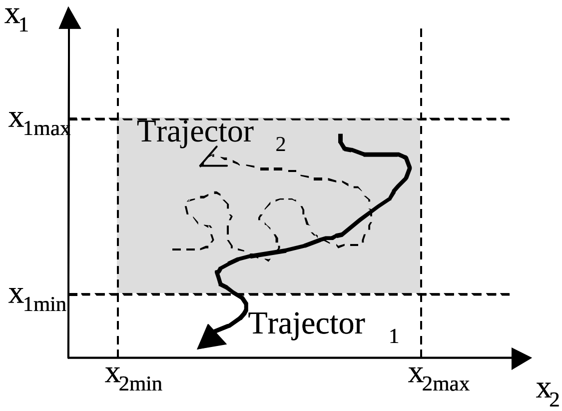

Figure 8: Species 1 and 2 interact and are submitted to some policy of action.
Trajectory 1 goes outside the limits (bad management) whereas trajectory 2 remains inside (good management).

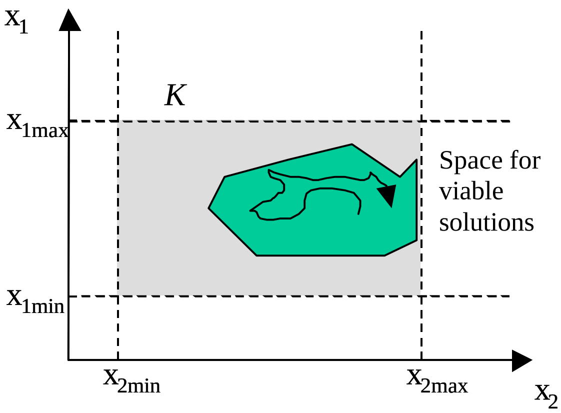

Figure 9: For any point in set of viable solutions, there exists an action which keeps the system in K.
As soon as the system crosses the border no action can prevent the system from getting outside *K*.

In this framework, the biodiversity management would require the following actions:

- identify constraints
- define the dynamics interactions between species, other species and the environment and the impact of different actions
- derive the viability kernel of the system (different techniques are available)

The management of the system requires observation and action as soon as the system moves too to close to the boundary of the viability kernel.

5.3.2 Possible link with the DPSIR framework

In the modelling research task of the ALTER-net network, it seems important to try to interpret the DPSIR notions into a rigorous mathematical framework. The viability framework, as interpreted above offers precious tools to achieve this. We propose here some preliminary reflections, which are open to discussion (especially according to the diverse interpretations of the DPSIR items).

- *Drivers*: Are understood as the main driving forces of the system's evolution. In our view, these driving forces are behind the definition of a driving function which defines the direction changes in the conditions of the system. These driving forces are therefore only implicit in our application of the viability theory on the problem of the biodiversity management. One can imagine different scenarios for these driving forces (for instance one corresponding to a high development of the industry), corresponding to different versions of the driving function.

- *Pressures*: They correspond in this framework to variables, which have direct impact on the species dynamics.

- *State*: In our framework, they correspond to the variable evolving in response to some given pressures.

- *Impact*: This is the result of the function which defines the joint evolution of the variables defined above (state and pressures). This function expresses how the state changes in time from given values of the species number of representatives and environmental conditions.

- *Response*: This is the action that can be taken to try to correct the evolution of the system. In fact, in the viability framework we are considering a policy of actions (a set of action in time).

The main difference of perspective is that the viability theory considers a stochastic dynamical system (given by differential equations or inclusions), whereas this dynamical aspect is not explicit in the DPSIR framework.

6 Conclusion

The main conclusions of this report were presented at a joint workshop in Madrid in June 2005. The workshop was arranged by three ALTER-net work packages: I3 (A network of long-term multi-functional inter-disciplinary, ecosystem research (LTER) sites; RA3 (Impacts of the main natural and anthropogenic drivers and pressures on biodiversity); and RA6 (Forecasting change in biodiversity). The purpose of the workshop was to advance collaboration and exchange of ideas between the work packages.

An outline of the report was presented at the meeting to provide an overview of the modelling expertise within ALTER-net. Furthermore, the two main strategies for further development were introduced.

The first strategy – the development of conceptual models – is a top-down approach often used as a first step in the modelling of complex systems. The purpose of a conceptual model is basically to capture the essence of a given system, its main components and dynamics. A conceptual model may also highlight what we don't know and hence help formulate new research programs. Another important use of conceptual models is to disseminate information to other scientists, to decision-makers and to the public. The approach could also include the construction of a meta-model, i.e. a model of models.

The integrated model approach, on the other hand, is a bottom-up process. In an integrated model, the main aim is to combine explicit and detailed models from various disciplines from ecology to economy. The main objective is to link and combine existing work in order to enhance generality and predictive power.

Both strategies have their pros and cons: The top-down approach provides a quick overview of a problem domain and can be implemented relatively fast. The method is well suited for the presentation of complex problems for decision-makers and the public. The bottom-up approach, on the other hand, is a slower, but much more detailed and accurate process with scientific appeal. A disadvantage is the rather narrow domain and poor generality covered by most existing models.

During the workshop in Madrid, RA6 participants split into two subgroups. One group discussed a top-down approach to develop a modelling framework (on a pan-European scale). The other group tried to apply a bottom-up approach to the same question (case study / LTER site related).

During the following discussions, the groups came to the conclusion that the two approaches should be united in the upcoming work. Ideally, only one framework is needed provided it may be adjusted to and used at different scales and on different problem domains. Furthermore, it was decided that the work should be based on the MIRABEL framework where a matrix links pressures to ecological resources (e.g., habitats, communities, species or populations). Such a framework is well suited to organise information on available models and highlight gaps in our current knowledge.

Theses decisions are reflected in the work plan for the next 12-month period. Many tasks depend on input from and co-ordination with other work packages. In order to identify and rank pressures to build the model matrix, for example, input from R3 is needed and information from I3 on available data from LTER-sites may be very useful for model calibration and evaluation. Generally, model development depends heavily on knowledge and input from all of ALTER-net and collaboration with other work packages will be promoted actively.

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