Vulnerability assessment – analysing the human-environment system in the face of global environmental change[1]

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Introduction

Over the next century society will increasingly be confronted with global changes such as population growth, pollution, climate and land use change. By 2050, the human population will probably be 2 to 4 billion larger than today (Cohen 2003). An increasing number of people, with increasing consumption of food and energy per capita have boosted the emission of nitrogen to the atmosphere, resulting in eutrophication of the environment via deposition (Galloway 2001). In Europe eutrophication is likely to be an important stressor for terrestrial and hydrological systems until at least mid 21st century (Alcamo et al. 2002). Furthermore, within the next century the atmospheric carbon dioxide concentration will at least double compared to pre-industrial times, while the global average surface temperature is projected to increase by 1.4-5.8°C (Houghton et al. 2001). Land use changes will have an immediate and strong effect on agriculture, forestry, rural communities, biodiversity and amenities such as traditional landscapes, especially in a continent as densely populated as Europe (Watson et al. 2000, UNEP 2002). Projections like these have led to a growing awareness of our vulnerability to global change. This paper introduces a spatially explicit vulnerability assessment of Europe. We briefly describe the underlying concepts, describe the methodological steps involved, and highlight some main results and conclude lessons learned.

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The concept of vulnerability – towards an operational definition

In recent years, global change research has worked towards a common definition of vulnerability to move beyond the immediate intuitive understanding and towards an operational concept of vulnerability. We suggest that the following definition emerges from the most recent conceptual developments (Turner et al. 2003, Schröter et al. 2004 (in press)): *Global change vulnerability is the likelihood that a specific coupled human-environment system will experience harm from exposure to stresses associated with alterations of societies and the environment, accounting for the process of adaptation*. In this definition the human-environment system is the vulnerable entity. Multiple global change drivers such as socio-economic change, land use change and climate change are the potential stressors that impact the system. The term 'coupled human-environment system' acknowledges the fact that humans, as users, actors and managers are not external, but integral elements of the studied system. Vulnerability then is the likelihood or probability of harm to the system, such as for example declining quality of life or loss of lives. *This likelihood is determined by the likelihood of potential impacts and the system's adaptive capacity.* The process of adaptation can decrease vulnerability. Given these definitions, the *general objective* of vulnerability assessments is to inform the decision-making of specific stakeholders about options for adapting to the impacts of global change (Schröter et al. 2004). Stakeholders are people and organizations with specific interests in specific parts of the human-environment system. Thus global change vulnerability assessments link directly with the broader aim of sustainability science, where successful research is measured not only by scientific merit but also by the usefulness of the resulting products and recommendations (Kates et al. 2001, Clark and Dickson 2003). Products and recommendations can be considered useful if they help stakeholders improve their decision-making. "Improved decision-making" is such that leads to more sustainable management of the human-environment system. To achieve its general objective, vulnerability assessments should satisfy at least five criteria: It should have a knowledge base from various disciplines and stakeholder participation, be place based (i.e. sub-country level), consider multiple interacting stresses, examine differential adaptive capacity, and be prospective as well as historical (Schröter et al. 2004).

The role of ecological sciences in vulnerability assessment

What does *ecological science* have to offer to vulnerability assessment? Impacts of global changes on ecosystems have already been observed. For example, climate change affects the phenology (e.g. bud break of trees, spring arrival of birds), species ranges and distribution of plants and animals, as well as the composition, dynamics and processes within ecological communities (Walther et al. 2002). Impacts on ecosystems are of direct importance to human society, because ecosystems provide services that sustain and fulfill human life (Daily 1997). Ecosystem services form the vital links within the coupled human-environment system through providing food and timber, clean water, aesthetic value and other necessities. Therefore, in addition to immediate global change effects on humans (e.g. hazards like floods or heat waves), an essential but not sufficient part of our vulnerability is due to impacts on ecosystems and the services they provide. In other words, to know the potential impacts of global change on ecosystem services within a specific region is to understand an essential part of this region's vulnerability. An important contribution of ecological science is therefore to study the current and potential future impacts of global change on ecosystem services. Naturally, the stakeholders relying on these ecosystem services should be involved in the studies in order to agree on useful indicators and to specify appropriate temporal and spatial scales.

A European vulnerability assessment – methodological steps

In the following we will illustrate an example of a European vulnerability assessment based on a consistent set of multiple, spatially explicit global change scenarios, a framework of ecosystem models and a generic indicator of differential adaptive capacity. In this assessment we looked at ecosystems in terms of the services they provide to human sectors, such as carbon storage, food production, biodiversity, scenic beauty, and many more. The ultimate result of the project is spatially explicit maps of vulnerability per ecosystem service for multiple scenarios and time slices within the next century (10' x 10' grid resolution over EU15 plus Norway and Switzerland, baseline 1990, future time slices 2020, 2050, 2080, scenarios based on the Special Report of Emissions Scenarios A1fi, A2, B1, B2).

A consistent set of multiple, spatially explicit global change scenarios

Projection of socio-economic and biophysical variables to the next century cover a range of possible futures, without assigning probabilities or likelihood to any individual scenario. To deal with this unknown uncertainty, we based our global change projections on a range of coarse narratives, the so-called marker scenarios, or IPCC Special Report of Emission Scenarios (SRES) A1f, A2, B1 and B2 (Nakicenovic and Swart 2000). We used four different general circulation models to simulate possible climatic changes resulting from these four emission scenarios. We then developed a set of land use and nitrogen deposition scenarios that are linked to the climate scenarios and the socio-economics derived from the SRES storylines. This resulted in a consistent set of scenarios at high spatial resolution for the main global change drivers in Europe.

A framework of ecosystem models – quantifying potential impacts

We used a set of state-of-the-art ecosystem models to translate the scenarios of global change into potential impacts. In a stakeholder-guided process we selected a range of indicators for ecosystem services that are related to the sectors agriculture, forestry, carbon storage and energy, water, biodiversity and mountain tourism. According to the ecosystem models, the provision of ecosystem services will change with global change during the 21^{st} century. For example, potential impacts on the agricultural sector include carbon losses from soil and changes in crop suitability. In the forestry sector, wood production is likely to increase in most areas, due to growing forests and increasing forested area. However, climatic stress will probably lead to regional problems such as increased fire risk in the Mediterranean and shifts in tree species distribution. The full range of environmental impact scenarios from our pan-European assessment provides spatially explicit projections of ecosystem services over time, while being honest about the attached uncertainties.

A generic indicator of differential adaptive capacity

We used projections of socio-economic variables to develop a spatially explicit and quantitative index of adaptive capacity (macro-scale: province level), based on six determinants: power, flexibility, freedom, motivation, knowledge and urgency. For these determinants we selected indicators such as gross domestic product, female activity rate, age structure, literacy index and urbanisation. Fuzzy inference rules were then applied to aggregate the individual indicator values into one measure of adaptive capacity per spatial unit. The resulting generic index captures one of many dimensions of adaptive capacity.

Integration into vulnerability maps

Empirical and theoretical evidence of how potential impacts and adaptive capacity can be combined into measures of vulnerability is very limited. Therefore, we created a visual combination of these elements without quantifying a specific relationship. The resulting maps illustrate vulnerability in terms of negative potential impacts and limited adaptive capacity. All results are made available to stakeholders in form of a digital atlas (spatially and temporal explicit maps of Europe) of exposures, potential impacts, adaptive capacity and a dimension of vulnerability. With this tool scenarios, time slices and regions can be compared for each ecosystem service indicator. The maps are accompanied by careful documentation of the underlying assumptions and limitations of the approach. In comparison of European regions, the Mediterranean seems most vulnerable within Europe. Multiple potential impacts on multiple sectors were projected. These include water shortages especially in the summer months when demand peaks due to tourism, increased fire risk in the forestry sector, losses in the carbon storage potential, northward shifts in the distribution of tree species like maritime pine and cork oak, and losses of agricultural potential due to drought. These potential impacts combine with low adaptive capacity (based on a socio-economic regional scale generic index).

Stakeholder dialogue

A dialogue between stakeholders and scientists was initiated at the beginning of the project and has been continued, intensified, and evaluated throughout the project. The general objective of this dialogue was to facilitate a more appropriate assessment of vulnerability, i.e. to produce results that would adequately inform the decision-making of stakeholders. In particular the aims of the stakeholder dialogue were to (1) identify indicators of changes in ecosystem services; (2) settle useful scales and units at which these indicators should be measured or modelled; (3) discuss thresholds for these indicators that represent limits outside which the adaptive capacity of the sectors is exceeded; and (4) present and discuss results as well as the format they are presented in (clarity of maps, graphs, etc). Practical steps in the stakeholder dialogue were the preparation, running, evaluation and reporting of a number of workshops, and the development of an evaluation and dissemination strategy.

In the course of the communication between scientists and stakeholders we have structured the assessment into six sectors: agriculture, forestry, climate protection (carbon storage) and energy, water, biodiversity & nature conservation, and tourism & recreation (especially in mountains). It was recognised that the sectors, as well as the ecosystem services they use, are highly interdependent.

Discussion

Vulnerability is a dynamic outcome of both environmental and social processes occurring at multiple scales (O'Brien et al. 2004). When the maps of vulnerability produced with our approach depict problematic regions, further attention should be directed to these regions to analyse their vulnerability in the context of nested scales and on higher and lower resolution than the 10'x10' latitude longitude grid. Our vulnerability maps show vulnerable areas per sector and ecosystem service, and per future time slice. Currently no model of the human-environment system exists that reflects all interactions between ecosystem services and sectors for a range of nested scales. Our vulnerability maps are therefore not maps of total European vulnerability, but of essential aspects constituting the overall vulnerability. These maps can be used to anticipate vulnerability of different sectors based on specific ecosystem services, as a basis for discussion of interactions between these sectors and ecosystem services. For example, as stakeholders from the climate protection sector have pointed out, planting forests to store carbon has implications for the aesthetic value of a landscape, and therefore for the tourism sector, as well as for the runoff in a particular region, and therefore for the water sector. In our vulnerability-mapping tool all ecosystem services are presented in a common dimension which facilitates the examination of such interactions.

In this vulnerability assessment, the supply of ecosystem services is used as a measure of human well-being under the influence of global change stressors, similar to the approach suggested by Luers et al. (2003). Perceived well-being, as well as anticipated vulnerability is always based on a value judgement. Stakeholders from different sectors may base their value judgement on different assumptions – in other words, some aspects of vulnerability are individual. In our stakeholder dialogue, it became apparent that many stakeholders are rather interested in potential impacts than in generic vulnerability maps. Stakeholders used their individual values to judge the severity of a potential impact. Furthermore, stakeholders often wished to account for their own individual adaptive capacity when interpreting potential impacts. The generic adaptive capacity index we developed may have informed them of the socio-economic context in which they might operate in the future. However, their anticipated future ability to adapt to change was a matter of personal perception. In a flood-prone area in Germany it has recently been shown that "perceived adaptive capacity" is a major determinant of whether people will take adaptation measures or not (Grothmann and Reusswig 2004). It seems that more place based studies could better take account of the individual nature of vulnerability.

Conclusion

The digital atlas of impact and vulnerability maps of Europe adds to the basis for discussion between stakeholders and policy makers, thereby facilitating sustainable management of Europe's natural resources under global change. However, not least from repeated interactions with stakeholders we conclude that aggregated measures of vulnerability are of limited value. In our integrated assessment they came to serve as a way to alert us to regions or sectors that were then analysed further by consulting the underlying data. We conclude that often information on potential impacts will be sufficient to stakeholders who will then explore their vulnerability themselves, using knowledge about their own adaptive capacity and their individual values.

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