Forest and natural ecosystem managers in the landscape – multiscale modelling, challenges and opportunities

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Abstract: Forest and natural ecosystem management operations are generally planned and implemented on individual land management units, at the community or ecosystem scale: field, plot, woodlot... But the effects of such operations on neighbouring units are often poorly taken into account. In addition, under changing environmental, regulatory, and economic conditions, it is increasingly important to address sustainable management at larger scales. Managers increasingly require advanced decision support tools (DSS = Decision Support Systems), such as expert and knowledge based systems, multi-criteria techniques as well as communication and visualization tools. Many models address environmental and ecological processes at the field, forest stand or agricultural activity scale, but they rarely capture interactions between farming, sylvicultural or ecological engineering practices and potential impacts on the landscape. In this presentation we shall outline some of the challenges modellers are facing in applied ecology, when moving upwards from plant to community and landscape. Several examples will be taken from recent and on-going integrated projects, focusing on decision support systems, aiming at improving connections between scientists and management practitioners for developing and implementing techniques in ecological engineering and ecosystem management.

Keywords: Applied Ecology; Forest; Ecosystem Management; Ecological Engineering; Sustainable Management; Multiscale; Multi-Criteria; Visualization

Introduction – the Global Change context

In the 21st century even more than previously, managers and decision-makers are increasingly facing new challenges, in relation to natural and/or anthropogenic changes. Climate change is one important element which profoundly modifies the way forest or natural ecosystem planning must be envisaged. Whatever the future political decisions, climate models clearly show that an increase in temperature and in CO_2 concentration is bound to occur, and an increase in number and extent of extreme climatic events is to be expected (IPCC, 2007), with consequences on natural dynamics: forest growth is impacted, but also future geographical distribution of species (MEA, 2005a). In addition, important changes in land-use are impacting large forest areas. Such changes can be somewhat predictable, thanks to various "LUCC" models (Land Use & Land Cover Change, Verburg *et al*., 2004), but in many cases they are very difficult to predict, mainly due to socio-political uncertainty (Butkiewicz and Yanikkaya, 2005). For example, the Millenium Ecosystem Assessment (MEA, 2005b) developed four global scenarios to explore plausible futures for ecosystems and human well-being. They explored two global development paths, one in which the world becomes increasingly globalized and the other in which it becomes increasingly regionalized, as well as two different approaches to ecosystem management, one in which actions are reactive and most problems are addressed only after they become obvious and the other in which ecosystem management is proactive and policies deliberately seek to maintain ecosystem services for the long term. These result in very different trends, predicting degradation of many ecosystem services, or improvement of some services, according to the scenarios – at present, approximately 60% of the ecosystem services examined during the Millennium Ecosystem Assessment are being degraded or used unsustainably.

In this changing and uncertain environment, including regulatory and economic conditions, forest and natural ecosystem managers increasingly require advanced decision support tools (DSS = Decision Support Systems), such as expert and knowledge based systems, multi-criteria techniques as well as communication and visualization tools.

1. Forest and Natural Ecosystem Management

1.1. Multiple objectives

In the past, forest management focused on timber production. In the early days of forest science[1] such management was based on the observation of natural forests, and human interventions sought to benefit from natural processes and influence them in order to obtain specific products (fuelwood, timber for construction of houses and ships, for sustaining mining galleries…). In the 20th century more intensive sylviculture was applied, including change of species ("plantation sylviculture"), large scale mechanization, the use of chemical or natural fertilizers, pesticides … (Savill *et al*., 1997). With increasing attention being given to environmental issues, forest management has recently evolved towards a reduction of differences between natural and managed ecosystems and landscapes, to ensure long-term maintenance of ecosystem functions and thereby retain the social and economic benefits they provide to society (von Gadow *et al.,* 2000).

New terms describing this evolution have appeared, such as "close to nature" forest management, "forest ecosystem management", "integrated resource management", "forest-zoning management", "natural disturbance model management", or "forest landscape management" (Baskent *et al.,* 2002). The main message underlying these modern concepts is the fact that it is no longer possible to manage a forest or natural ecosystem with one

[1] Late 18th - early 19th century: Evelyn in the UK, Cotta and Hartig in Germany, Lorentz and Parade in France

single objective, but that it is necessary to address multiple objectives, including timber or fiber production, but also a great number of other services. “Ecosystem services” are the benefits people obtain from ecosystems (MEA, 2005b). These include *provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling.

Some ecosystem services have a high economic importance, particularly provisioning services (food, timber, fiber, NTFPs), whereas many others are not traded in markets. Forests are increasingly considered as an important issue for carbon mitigation, including sequestration in the forest, storage in forest products, and substitution of fossil fuels or energy-demanding manufactured products. Another important role of forests and natural systems concerns disturbance: management operations (“ecological engineering”) are often devoted to reducing disturbance, such as erosion, landslides… Biodiversity has become an increasing concern worldwide, particularly since the Rio “Earth Summit” in 1992 and the signature of the Convention on Biological Diversity, up to the proclamation by the UN of year 2010 as “International Year of Biodiversity”. Forest and natural ecosystem management addresses biodiversity and its various components: genes, species, ecosystems. Many important issues must be considered in this respect, such as pollination, seed dispersal (including GMO dispersal), invasive and/or alien species… Even though the relative economic importance of agriculture and forestry is declining in industrial countries, enjoyment and recreational options are growing. Socio-cultural values of forest and natural areas are important worldwide. Although few ecosystem services are directly marketable, there is a trend towards a greater use of economic instruments and market-based approaches in the management of ecosystem services (MEA, 2005b).

In addition to managing natural systems with a view of producing ecosystem services, such as carbon mitigation, or reduction and restoration of disturbances, managers must also adapt their actions to future changes. Anticipating climate change, changes in global policy and land-use, or disturbance due to extreme events is an important challenge. For example, with an increase in temperature many plant and animal species are susceptible of migrating towards higher latitudes and altitudes (Root *et al.*, 2003) and forest managers should favour species or genotypes sufficiently plastic or adapted to warmer environments. They must also be prepared to face new pest and disease outbreaks, such as has been observed in France for the expansion of the pine processionary moth towards the North (Robinet *et al.*, 2007). Although it is considered hazardous to attribute specific climatic events directly to global change, such as the storm Lothar which swept through Western Europe in December 1999 causing the highest damage ever reported in Europe, extreme climatic events are expected to become more frequent (the storm Xynthia is hitting the Western coasts of Europe while these lines are being written in February 2010). Preventive measures against storm damages require for example the conversion of non-site adapted and unstable forest stands in order to strengthen their storm resistance (Requardt *et al.*, 2007), or increasing stand diversity at the landscape scale to increase global forest resilience. Such undertakings are of long term nature and will show no immediate reduction of damages caused by storms, or other disasters.

1.2. Scale and organization level

In addition to addressing multiple objectives, forest and natural ecosystem managers increasingly need to address more global organization levels. Many operations must be performed at the level of the organism, such as a plant (tree): foresters practice selective logging or pruning, and farmers precision agriculture. Traditionally, basic silvicultural operations are practiced at the level of a forest parcel, which together with the agricultural field are most often the basic management units for most operations. Although often overlooked, borders are important for many ecosystem services: field or forest stand borders, and particularly hedgerows, ditches and embankments. Global forest management generally takes place at the "forest estate" level, and farmers consider the entire farm scale for their decisions. But recent trends lead forest managers to base their decisions on larger organization levels, moving upwards from parcel and forest estate to landscape (Nabuurs *et al*., 1998; Bell and Apostol, 2008). Regional and national policy-makers and forest industry managers generally consider regional or national scales.

There is often a high spatio-temporal dependency between management operations. For example, forest logging (in particular clear-cutting) can have an important impact on erosion, including landslides, which can occur almost immediately but also after some delay, and in the near vicinity but also at some distance from the logging site. Management oriented towards landslide prevention reduces the risk of catastrophe of susceptible areas lower down the slope. Management of mangroves is important to protect neighbouring rural and urbanized areas from floods coming from the sea. The management of a forest or natural area for wildfire prevention has direct effects on the fire risk of neighbouring areas, and mismanagement (letting timber build up in a forest) can seriously increase the fire risk even in remote places. The spatio-temporal pattern of plantations is important for protection and prevention: fire and erosion risk can be reduced if forests are managed with more diversity, which can include diversity in sizes (young and older trees in irregular stands or in a mosaic of even-aged stands) or in species composition (mixed stands or mosaics of pure stands of different species). Management in one area can have important impacts on biodiversity at large distances, by favouring continuity or increasing fragmentation between habitats or by creating or destroying corridors, such as "green-blue veins". This is important for fauna and flora, as well as for seed and pollen dispersal. Dispersal of GMOs is in particular an important issue at the landscape scale.

2. Forest and Natural Ecosystem Modelling

Among the four scenarios exploring plausible futures for ecosystems developed by the Millenium Ecosystem Assessment (MEA, 2005b), two concern approaches to ecosystem management in which actions are reactive and most problems are addressed only after they become obvious. These result in a high degradation of ecosystem services. The two scenarios in which ecosystem management is proactive and policies deliberately seek to maintain services for the long term result in a higher number of improved ecosystem services. The use of advanced decision support tools (DSS = Decision Support Systems), most generally based on various types of modelling tools, can be of great interest for forest and natural ecosystem managers to become more proactive instead of simply reactive.

2.1. Models

Models have long been used by forest managers, from yield tables through modern spatially explicit individual tree-based models and/or functional-structural models (Pretzsch, 2009; Sievänen *et al*., 2000), up to forest resource models for regional and/or industry planning (Nabuurs *et al.,* 1998). In the past, models focused on timber production and economic return, but multiple criteria increasingly affect management decisions, and models have been developed to account for a number of additional objectives (Diaz-Balteiro and Romero, 2008). With progress in computer capacity and in mathematical developments, as well as in theoretical ecology and modelling, forest modellers turn towards the concept of "complexity" (Kuuluvainen, 2009). With increasing interest in landscape ecology, landscape models are also being developed (Turner and Gardner, 1991; Kurz *et al*., 2000; Mladenoff, 2004; Gaucherel *at al*., 2006; Scheller and Mladenoff, 2007; Gaucherel and Houet, 2009) and Seppelt *et al.* (2009) pointed out many challenging issues on simulating complex environmental systems.

Whatever the objective of their modelling work (basic scientific knowledge improvement and organization, or practice-oriented scenario building), modellers face the same issues as managers: to address multiple objectives, at multiple scales. Some examples of models applied to forest management at different scales are shown in Fig. 1.

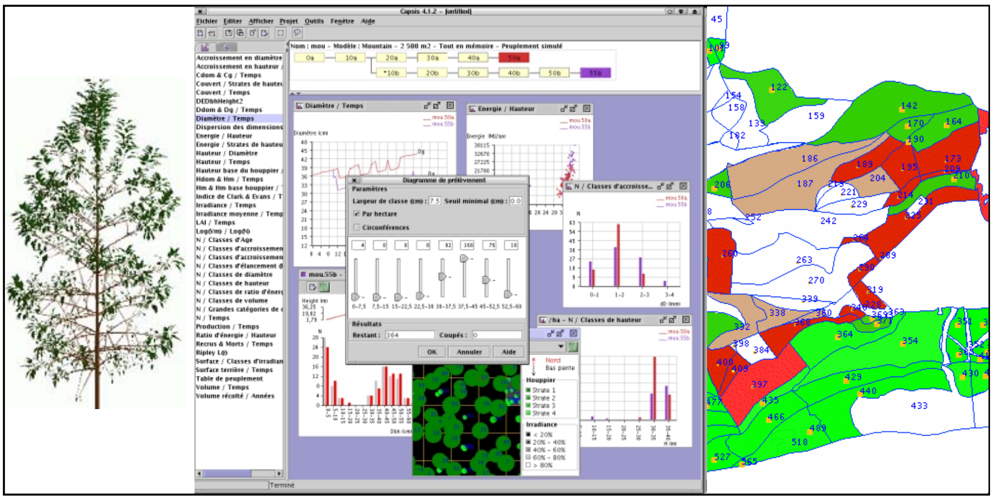

Figure 1. Illustration of models at different scalse: individual tree architectural model (left, Barczi et al.*, 2008), uneven-aged stand dynamics model based on the Capsis modelling platform (center, Courbaud* et al.*, 2003, de Coligny, 2007), multiple species heterogeneous forest landscape model (right, Dreyfus, 2008)*

The outputs of such models are most often mainly related to timber production, but in some cases also include other ecosystem services, such as biological diversity or susceptibility to windfall or to wildfire. At the landscape scale, managers can also address landscape aesthetics, and models can help visualize the result of scenarios, to serve as negotiation tools with various local or regional stakeholders (Fig. 2, Griffon *et al*., 2010).

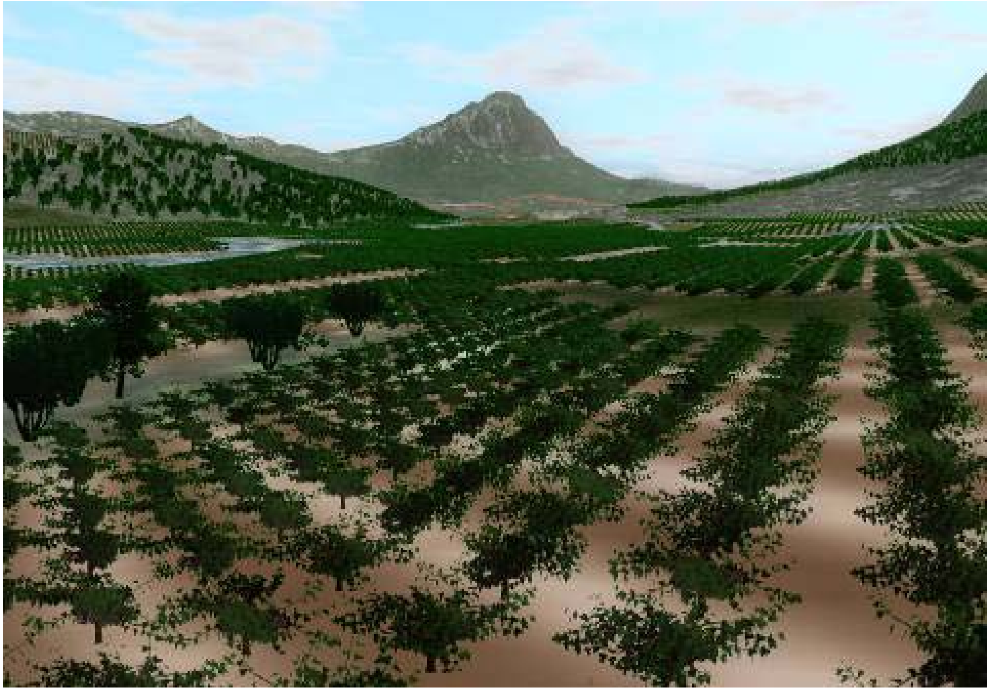

Figure 2. Visualization of a Mediterranean landscape as can be expected according to one of four land-use change scenarios, with the Pic St Loup mountain in the background (Griffon et al., 2010).

2.2. Modelling issues

Despite the large number of very efficient forest and landscape dynamics models available, a number of issues remain to be addressed.

- There is established but incomplete evidence that changes being made in ecosystems are increasing the likelihood of nonlinear changes in ecosystems –including accelerating, abrupt, and potentially irreversible changes–, with important consequences for human well-being. Threshold effects –abrupt or nonlinear changes or regime shifts in a system in response to a gradual or linear change in single or multiple drivers– have been commonly encountered and are often associated with changes in biodiversity (MEA, 2005b).
- As mentioned beforehand, there is often a high spatio-temporal dependency between ecosystems, and in particular management operations. The concepts of landscape ecology increasingly address these interactions, but this remains an important issue for modelling.
- Models representing either the biophysical components or socio-economic aspects of landscapes are becoming numerous. Models coupling biophysical and socio-economic issues are starting to be developed, very often with the use of Agent Based Models (Matthews, 2006; Janssen and Ostrom, 2006, Mayer and Sarjoughian, 2007).

However, though there are many examples of models for policy decisions, modelling policy decisions remains a difficult task (Vanclay *et al.*, 2003).

- The issue of complexity in environmental systems is an important issue, and ecosystems are increasingly taken in consideration as “complex systems” (Seppelt *et al.*, 2009; Gaucherel, 2009). The “complex systems” approach and theory may –at least partly– help to solve the problem of nonlinearity (see for example the complex systems society http://cssociety.org/).
- Addressing increasingly larger organization levels poses the question of data acquisition and of data quality. Regional, state-wide, and world-wide databases are being developed, but the data are not always freely available, even though they are often collected by public organizations or publicly funded. In addition, these data are generally collected with the aim of building indicators for policy use. Models often require different, and/or additional data for calibration and parameterization. For confidentiality reasons, data are often aggregated and the initial raw data are not available. Sharing high quality data between modellers, and between modellers and policy-makers, has become a particular challenge.
- Modellers often develop models with the aim of improving scientific knowledge –both in the areas of mathematics or statistics, and in ecology. Some of these models can be applied to policy-making, but it is also of great interest to develop models specifically designed for practical use. For use by managers or policy-makers, it is generally necessary to build user-friendly frameworks around decision-support systems, such as the Capsis environment (Fig. 1) or the Seamless framework (Fig. 3, van Ittersum *et al.*, 2008).

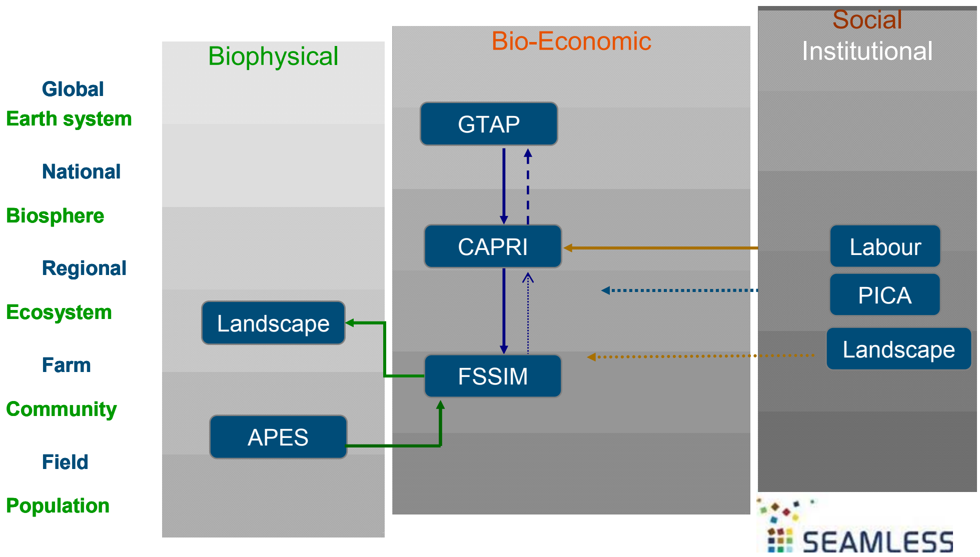

Figure 3. The Seamless multi-objective multi-scale modelling framework: System for Environmental and Agricultural Modelling: Linking European Science and Society (van Ittersum et al.*, 2008).*

3. Management and Modelling challenges

3.1. Multiple objectives and multiple scales

Agricultural and forest management, and ecological engineering –and related models– most often address 1 or 2 objectives, rarely a few more, and rarely the interactions between these objectives. Among many, we can cite: timber; non-timber forest products; biomass; carbon (balance – adaptation – mitigation - sequestration); nutrients & sustainability; disturbance (fire, storms, drought - extreme climatic events); ecological engineering (soil, wind erosion); conservation, habitat; wildlife (conservation - hunting); biodiversity (plants, invertebrates, birds, mammals); invasive and/or alien species; recreation… Managers –and models– generally address the considered objectives at the most appropriate organization level(s) : for example timber production is considered at the parcel and forest estate, as well as regional scale; fire prevention is considered at the patch and border level as well as landscape; recreation at the landscape scale. However, models rarely account for spatial dependency, that is, they generally simulate the processes and the fate of each pixel as if it was independent of all other pixels. Figure 4 shows an example of objectives considered according to the most appropriate scale (thin arrows). However, although there is a trend for forest management to address multiple objectives, neither forest management nor models address the entire spectrum from plant to region for a large number of objectives to be considered (wide arrows).

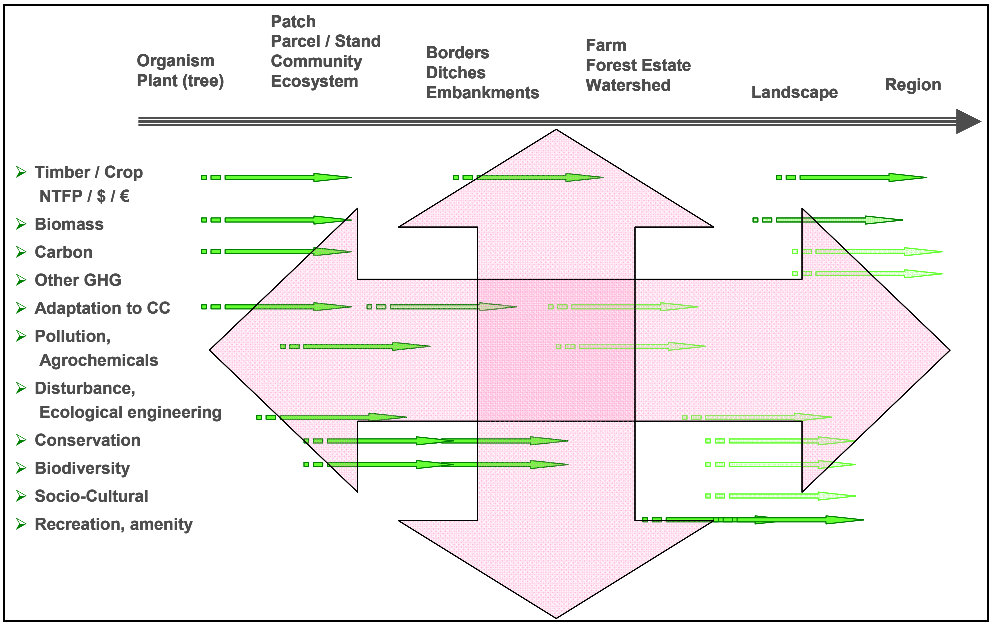

Figure 4. Examples of sustainable development objectives applied at different scales.

One example of multi-objective multi-scale modelling framework for decision support and policy-making is the framework developed by the Seamless project (Fig. 3, van Ittersum *et al*., 2008 ; http://www.seamlessassociation.org/).

3.2. DSS and scenario building – optimization

Forest and natural ecosystem management must no longer be restricted to the forest, but it must nowadays encompass the entire spectrum of land-use, including agriculture as well as urban planning. Not only must one engage in *multiple-objective multi-scale* modelling, but also in *multiple actor* modelling, the actors including forest managers, farmers, as well as local governments and regional or national policy-makers.

Among additional challenges for forest managers, one is to decide on the *Criteria & Indicators* to consider. Indicators are generally built to address a question at a specific organization level, but extending them for more global policy-making is often problematic: for example nitrate leaching can be estimated at a field and up to a watershed scale, but regional policy-makers lack good indicators.

Decisions are often based on *economic criteria*, however though it may be relatively easy to build economic indicators for *provisioning services* (food, water, timber, fiber, non-timber forest products), developing market-based approaches in the management of the other types of ecosystem services (*regulating services*, *cultural services*, *supporting services*) is an issue of particular interest: there is a trend towards a greater use of economic instruments for valuing ecosystem services (Costanza *et al*., 1997; WSTB, 2004; DEFRA, 2007). However, one should question the universal domination of trade and market, and instead of giving “a value to everything” (Pimm, 1997), should one not place ethics before trade and market, following Tilman (2000): “*Ethics should, among other things, apportion costs and benefits between individuals and society as a whole, and between current generations and all future generations. A sustainable world will require an ethic that is ultimately as incorporated into culture and as long lasting as a constitutional bill of rights or as religious commandments.*” The balance between sheep farming, which can be addressed with economic instruments, and the conservation of wildlife –including wolves which have expanded into the French Alps in recent years, or bears which have been re-introduced in the Pyrenees– is more an ethical issue than an economic one.

Optimization is another challenge: multiple criteria decision making for forest sustainability, and particularly in connection with group decision-making, remains quite an open research area (Diaz-Balteiro and Romero, 2008), as well as seeking methods for optimizing forest management (Le Moguédec and Loisel, 2010). How can one optimize a landscape, what is meant by an optimal landscape (Gaucherel, 2009)? How should policy-makers organize a landscape in order to produce the required ecosystem services?

Policy-makers and land managers often refer to *scenarios* for planning different management options and analysing their impact on the long term. Decision Support Systems are useful tools for scenario building. Most often, the scenarios tested with such tools and models remain within a range of “probable” scenarios (such as for example the four Millenium Ecosystem Assessment scenarios). However, it could be of interest to test extreme scenarios, which appear unrealistic today, but could in future become possible. For example, in a recent past a global temperature increase of 5°C was deemed unrealistic, whereas now such an increase is within the range of IPCC projections for 2100. Extreme climatic events are improbable, but the droughts experienced in Australia since the beginning of the 21st century were the worst ever recorded, as were the windstorms Lothar and Martin in Western Europe (26 and 27 December 1999). Considering the global impact of meat consumption on greenhouse gases, an example of extreme scenarios could be to test a decrease of 50%, 80% or 100% of World meat consumption. In present conditions, Nitrogen produced by human input is expected to double by 2050, another extreme scenario could be to test a drastic reduction of nitrogen fertilizer in agricultural activities.

Conclusion

In the past 20 years, and even more so since the beginning of the 21st century, a large number of models destined to forest and natural ecosystem management have been developed, with multicriteria or multiscale approaches (Verburg *et al*., 2008). With improvements in computer capacity, mathematical developments on the issue of complexity, multicriteria optimisation and multiscale modelling methods, there is now a great opportunity for developing robust decision support systems for long- and short-term planning.

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