COST Action *E25*

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European Network for long-term Forest Ecosystem and Landscape Research

Scientific Issues Related to Sustainable Forest Management in an Ecosystem and Landscape Perspective

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Working Group 1: Scope of the action and guidelines for national inventories of research sites

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ABSTRACT

The newly established "*European Network for long-term Forest Ecosystem and Landscape Research*" (ENFORS) – COST Action *E25*, needed to specify its remit in association with its member countries. The established working group did this by giving a comprehensive overview of the scientific issues related to sustainable forest management from an ecosystem and landscape point of view. It started by describing the management questions at stake, followed by an introduction of the associated scientific questions in general, and finally pointed out a few strategic scientific issues.

Sustainable forest management is not new to European forestry, however it is an evolving concept, the conditions for which have recently been subjected to important environmental (*e.g.* global change) and socio-economic (*e.g.* increased number of stakeholders, interactions between land uses) changes. The related management questions arise in a triangular network. The apexes of the triangle are: (a) the *management objectives* (*e.g.* production, soil protection, biodiversity and water conservation, prevention of natural hazards, mitigation of climate change, social welfare, economic development); (b) *the pressures on the forests* (*e.g.* management practices, air pollution, pests, diseases, browsing, climate change, ownership, depopulation, fires, trends in wood markets, public perception, cross-sectional policies); (c) *the means of control* (*e.g.* tree species, stand structure, spatial patterns, rotation, thinning cycles, vegetation control, liming, fertilisation). The resulting management questions demand for *knowledge needed*, in particular in relation to the new spatial and temporal scales (*i.e.* going from the stand scale to that of forests, landscapes and the biosphere with their associated temporal scales) introduced by the changed situation for sustainable forest management.

Four *main fields of interests* describing the scientific questions in general and that are of a more applied nature arise from the management questions at stake. In terms of (1) *multi-functionality of forests*, the ecological knowledge needs to be improved to meet the demanding social expectation for each forest function, an understanding of the interactions between them is necessary, and redefinition of the conditions of sustainability of particular forest ecosystems is a concern. The (2) *long-term trends in the environment* mainly concern the effects of climate change on forest ecosystems, forest ecosystems as places for actively maintaining, preserving and managing the global carbon storage, and the environmental consequences of atmospheric deposition. The questions related to long-term effects of historic land use, landscape structure and its links to the way ecosystems function, and the conversion of one land-use form to another, make up the scientific questions of (3) *land use and the role of forests in the landscape*. The questions of (4) *stochastic disturbances* are mainly related to biodiversity and risk management.

The relevance of four *priority research areas* is identified from the general scientific questions. Strategic issues for significantly improving the scientific knowledge of (1) *biogeochemical cycling* are long-term aspects of nutrient and carbon cycling, carbon-nitrogen interactions, and landscape aspects related to water quality and quantity. A better understanding of the functional role of (2) *biodiversity*, and the processes of maintenance and development of biodiversity is needed. Closely related to biogeochemical cycling and biodiversity are the strategic issues of (3) *landscape and ecosystem dynamics* that are stability, resistance and resilience, patterns and interactions between ecosystems, and the creation of a hierarchical spatio-temporal framework. Finally, the understanding of human behaviour and economic systems is necessary when considering dynamics at the landscape level. Conflict management, perception and representation, and valuation are the key components of (4) *socio-economics*, where social and natural sciences can co-operate particularly at the scale of landscape management.

INTRODUCTION

AIMS AND OUTLINE OF THE DOCUMENT

The objective of this paper is to specify the scope of the "European Network for long-term Forest Ecosystem and Landscape Research" (ENFORS) – COST Action *E25*. Although the general aims have already been presented in the "Technical Annex of the Memorandum of Understanding" it was considered necessary to create a more detailed framework, in association with the member countries. This framework will be used to direct national inventories of existing field research facilities, and it will also function as a common guideline for the future development of the Action.

The expected outcome of ENFORS is a contribution to the sustainable management of forests in Europe. Many of the problems associated with sustainable forest management (SFM) relate to questions and understanding at the ecosystem and landscape levels, as well as requiring long-term series of data. This is well documented in the special issue of Forest Ecology and Management "Pathways to the Wise Management of Forests in Europe", which concluded with a proposal for developing an "Ecosystem and landscape forestry" (Andersson *et al.* 2000b). This is the reason for the present COST Action *E25* to foster the establishment of a network of research sites dedicated to long-term studies of the ecosystem and landscape.

Therefore the document aims to give a comprehensive overview of the scientific issues related to SFM from an ecosystem and landscape point of view. It starts with a description of the management questions at stake, then it introduces the associated scientific questions in general, and finally it points out a few strategic scientific issues.

THE EUROPEAN PERSPECTIVE AND BACKGROUND

The European continent contains a range of forest biomes, from boreal to temperate and Mediterranean forests. It has a long history of human influence, with good historical records of environmental changes as well as of human impacts.

In Southern Europe, we find the *evergreen Mediterranean forests* that have adapted to mild winters and summer drought with subsequent fires. The regional biodiversity is one of the highest in the world with a high degree of endemic plant and animal species (Blondel and Aronson 1999). Historically, the Mediterranean zone hosted refuge areas for temperate forests during the last glacial maximum (Huntley 1993). Today, these refuge areas are places with the highest genetic diversity for some of the typical temperate tree species (*e.g. Abies alba*: Konnert and Bergmann 1995 and *Fagus sylvatica*: Comps *et al.* 1991, Leonardi and Menozzi 1995). The Mediterranean is also a European region with a high human pressure and with the longest history of human influence. Mediterranean forests have always been a rich environmental resource for human populations and non-timber benefits have traditionally been of great importance (*e.g.* resins, cork, dyes, nuts, fruits, mushrooms, and grazing areas). Human impact has led to vast deforestation as well as to huge natural afforestation depending on the period in history and the location. Consequently, conservation of biodiversity, afforestation, fire control, and soil preservation are among today's major concerns (Scarascia-Mugnozza *et al.* 2000).

The *temperate deciduous forests* in central Europe have adapted to wet summers and cold winters with water unavailable for short periods. The temperate forests in Europe, dominated by deciduous broad-leaved trees, are relatively tree species poor in comparison to the other temperate forests of the world. This is due to historic environmental changes caused by recurrent glacial periods combined with orography (Huntley 1993), but also to the forest management of the last 200 years. Together with human management, storm and small-scale windthrows are the major disturbance factors in these ecosystems. Major human impact on temperate forests began during the Iron Age, when mankind passed from the hunting and gathering life style to that mainly depending on agriculture. Since then, the human impact has varied with the population density fluctuations in the forest area, with deforestation periods followed by periods of afforestation, as well as the multiple-use of the forest: wood for construction and source for energy, forests as pastures, litter raking, *etc*. Today, the concerns about the temperate forests are related to the changing socio-economic conditions (wood-market, ownership trends or changes, demand for public participation, *etc*.) and environment (windthrow, air pollution, climate change, *etc*.). Finally, the excess of conifer-dominated monocultures is a specific problem in European temperate forests which is under revision and which calls for particular methods of ecosystem rehabilitation.

The *boreal forests* of Europe are a part of the circumpolar belt commonly referred to as the taiga. The boreal forest is generally species poor and it is dominated by coniferous evergreen tree species, which have adapted to extremely cold winters and to a short growing season. The broad-leaved tree species are mainly limited to the early successional stages that follow after disturbances such as fire, windthrow and snow break. The boreal forest has a relatively short history of human influence. Although the early hunter and gathering societies influenced the boreal forests (*e.g.* fuel-wood and fire), the human impact began to be significant at the time of the population increase and introduction of agriculture during the Iron Age (Berglund 1969). The impact and the use of forests were in the beginning in the form of grazing/browsing by livestock, clearing of agricultural land, fuel-wood, potash, and tar (Berglund 1969). Fire has always been the major natural disturbance in boreal forests and it is the factor under which these forests have evolved (Zackrisson 1977). However, the natural fire regimes have always been influenced by man to a varying degree, developing from the use of fire and no mechanisms to control it, to today's practice of preventing large-scale fires. Today, the boreal forests are mainly used for timber production, through even-aged and monocultural forest stands. Large areas of wetlands have been drained for forestry and agricultural purposes. There is a general concern for the biodiversity of the boreal forests and their wetlands due to the historical use of these ecosystems. Due to the expected large climate changes in northern Europe the consequent effects on the boreal forests are a major concern (Kellomäki 2000).

The *alpine and mountain forest ecosystems* are found all over Europe, with varying light regimes depending on latitude. Their environment is characterised by climatic gradients (*e.g.* temperature, precipitation, wind, and insolation) causing altitudinal zonation of vegetation types within short distances. The winter is cold and the growing season short, which together with other environmental factors (*e.g.* browsing by livestock and wild game) give rise to long regeneration periods. Human impact on mountain forests varies among European regions, and generally reflects the historical development of the local human activities. However, mountain forests have traditionally been used for multiple purposes and non-timber benefits (livestock production, natural hazard – avalanches and landslides – prevention, hunting, and berries) to a higher degree than lowland forests. Air pollution and its consequences have been and still are major concerns for these forest ecosystems. Today, these forest landscapes are characterised by abandonment of agricultural land and depopulation, sometimes with important natural re-vegetation processes. Furthermore, the increasing demand for recreation has added to the expected benefits from mountain forests, and sometimes becomes the main priority and economical value.

Hence, Europe is a diverse region with many unique forest ecosystems, which calls for management options and practices adapted to local and regional conditions. However, it is not within the scope of this paper to go into detail about specific scientific issues associated with each type of European forest ecosystems, but rather to focus on broader issues that are common to most, if not to all, forest ecosystems of Europe. Those issues, however, may refer to different aspects, depending on the region. The abandonment of agricultural land and climate change are two such examples of issues common to all European regions, but which have different consequences depending on geographical region. For example, the abandonment of agricultural land leads to afforestation in northern and central Europe and in mountainous regions, while it may lead to desertification resulting in soil erosion in the southern region of Europe where drought, intense grazing/browsing and fire are present (Margaris *et al.* 1996, Piussi and Farrell 2000).

MANAGEMENT QUESTIONS

The management-related questions are numerous, but they are not always related to scientific issues. They contemplate various levels of: (i) spatial scales (from local to global, for example from the contribution of forests to the nutrient budget of a plantation to the carbon budget of the planet); (ii) temporal scales (from a single event to long term trends, for example from the impact of logging on biodiversity to the consequences of accelerating tree growth); (iii) socio-economic scale of interest (from a specific policy to general issues, from a local situation to the region). Our aim, in the present document, is to break down the management questions in a way that could be useful for elaborating research priorities and bridging the gap between future scientific priorities and the real world of management.

The development of the SFM master plan is one of the major reasons for the broadening and the increase of management questions. These generally combine the expected benefits from the forests, the concerns for their future and the management required to achieve this. In other words, a synthesis can be made, in terms of the knowledge needed to implement the innovative forest management approach that should be formulated according to those questions.

SUSTAINABLE FOREST MANAGEMENT (SFM)

SFM is the global background of the management questions that will be developed below. Even if the topic could be considered as relatively new and its definition not completely stabilised yet, we should recognise that the concept of SFM is not new to foresters. Ecologically, SFM can be defined as "the maintenance of a balanced nutrition of the plant cover, maintenance of the soil capacity for future production, maintenance of the hydrological stability of catchments, or the maintenance of other society-centred values and amenities" (Farrell *et al*. 2000). However, we should admit that this is not enough because we should also consider its socio-economic dimensions and acknowledge that the political dimension is one of the main driving forces in the evolution of this concept. Therefore, we will not elaborate from the official definition[1] and guidelines about SFM given at the second Ministerial Conference on the Protection of Forests in Europe (Helsinki 1993), nor using the criteria and indicators developed at the third Ministerial Conference on the Protection of Forests in Europe (Lisbon 1998; Liason Unit Vienna 2000). Instead we prefer to use them as a baseline, and look at new aspects and approaches that are derived from them.

SFM is as stated not new; it has always been claimed as the general objective by foresters in Europe. Currently, sustainability is also demanded by the Society, where it is expressed by

[1] The second Ministerial Conference on the Protection of Forests in Europe concluded that sustainable forest management "means the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems" (Resolution H1, Helsinki 1993).

different groups and at different levels. In the past, SFM was mainly focussed on wood production and sustainable yield. Other functions of the forest were considered, but the general belief was that a balanced wood production would guarantee the other benefits expected from the forest. It is now difficult to use this assertion, because the stakeholders define the other benefits more precisely, also demanding reliable information about the effective impact of forest management. The main consequences of this changed situation are a renewed debate on forest functions and the need for new information and representations, linking multidisciplinary and systematic approaches with new spatial and temporal scales.

An important evolution, to take the European context of land-use and local development strategies into account, is that SFM is more and more associated with agriculture, rural development and land planning policies, giving more emphasis to the socio-economic functions of forests. Land tenure should also be mentioned as a major issue for the SFM of European forests, given the weight of privately owned forests and the diversity of regional situations. The profiles of private owners are very different and include forest industries, farmers, and urban people, whose interests, objectives, and means of action differ a lot. The trend in ownership structure in central and southern Europe is dominated by the fragmentation of properties through inheritance, except in eastern European countries where privatisation of the forest is the main issue affecting the ownership today. To illustrate future questions linked to both aspects of cross-sectional policies and land tenure, we demonstrate that we will need consistency between forest and socio-economic data.

Once SFM is accepted as the way of managing the forest for multiple benefits, there are other questions that are still open. One of them concerns the possible specialisation of forest management units according to the expected functions to be satisfied: should the functions be separated into specialised areas using a zoning process, or should every forest become multi-functional? Probably a mixture of the two approaches will be recommended. Nevertheless, it must be underlined that multi-functionality is the choice generally made for European forests (at least in the Helsinki SFM process and in most national forest policies throughout Europe).

Finally, we should mention the link made between the sustainability issues and concerns about global change, which originated from the contemporary interest that sustainability and global change issues have received at an international level, starting at the Conference in Rio, 1992. The concerns about the possible impacts of global changes on the way forest ecosystems function started as early as the late '60s and '70s, driven by large-scale environmental factors such as trans-boundary air pollution transport observed in northern Europe and the associated worries about soil acidification (Environment '82 committee 1982). Later, during the '80s and '90s, the effects of air pollution, nitrogen deposition, increasing CO_2, drought and storms, and the observation of increasing productivity became environmental issues, all over Europe. It is the acknowledgement of those environmental issues that gave rise to the special consideration of the role that SFM plays in the impact of global change on forests and its mitigation.

In conclusion, SFM demands a holistic approach to the forest, balanced interests for the different functions of the forest, a historical background, knowledge of the socio-economic situation and dynamics, as well as a proper consideration of the changes in the global environment.

Box 1. **Ecosystem management**

"Ecosystem management" is an approach that was developed initially for national forests in the USA, as an answer to increasing public pressure on forest management. The larger community of scientists and managers adopted its principles rapidly. They illustrate quite well the modifications demanded by SFM to forest management.

It aims to be different from other forest management approaches in the scope and depth of analysis done before interventions on the ground. Under ecosystem management, ground interventions continue to involve the same techniques used traditionally in forestry by its many disciplines. However, comprehensive analysis determines what techniques to use, where and when to use them, the suitable mixture of technological tools, and the intensity of applications. Three fundamental questions need to be answered in order to start ecosystem management (see also Fig. 1): a) What do people collectively want from the ecosystem? b) What are the ecological requirements necessary to produce what people want? and c) What are the priorities for the ecosystem goods, services, and states? We must recognise that the changing social and ecological contexts under which forestry operates is demanding the changes that ecosystem management addresses. For this reason we must operate under an adaptive management mode in which we do things, monitor the results, learn lessons from experience, and adapt to the new conditions through planning and reiteration (Table 1). This allows room for innovation.

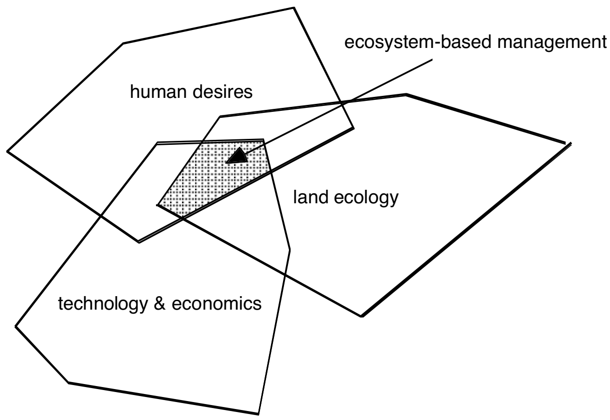

Fig. 1. A framework for an ecosystem-based management. The interaction among human needs, technology and ecology (adopted from Zonneveld 1988).

Table 1. *Principles of managing natural resources for a sustainable development (Schlaepfer 1997)*

Managing natural resources for sustainable management should:	
–	be holistic
–	be ecosystemic
–	be done with a landscape perspective
–	have multiple objectives
–	be based on sound science and good judgement
–	take cognitive, emotional, and moral reactions into account
–	should be based on the precautionary principle

FOREST MANAGEMENT QUESTIONS

Forests are characterised by multi-level management: starting from the people in charge of formulating policies for forests and natural ecosystems, to those in charge of implementing these policies, and then to the land managers and land owners. A triangular framework illustrates the way in which forest management questions may arise, which include all these management levels. The apexes of the triangle are the management objectives, the pressures on the forests, and the means of control (Fig. 2). The generic question can be formulated as follows: "Which management methods could produce the best expected benefits, under the constraints of existing pressures?" If the three terms of the sentence are not expressed, the missing term is generally implicit.

We will explore the three apexes of the triangle, and while doing so we will describe the main questions at stake for managers. The advantage of this presentation is to give some details about the contents of management questions, while maintaining a certain level of generality.

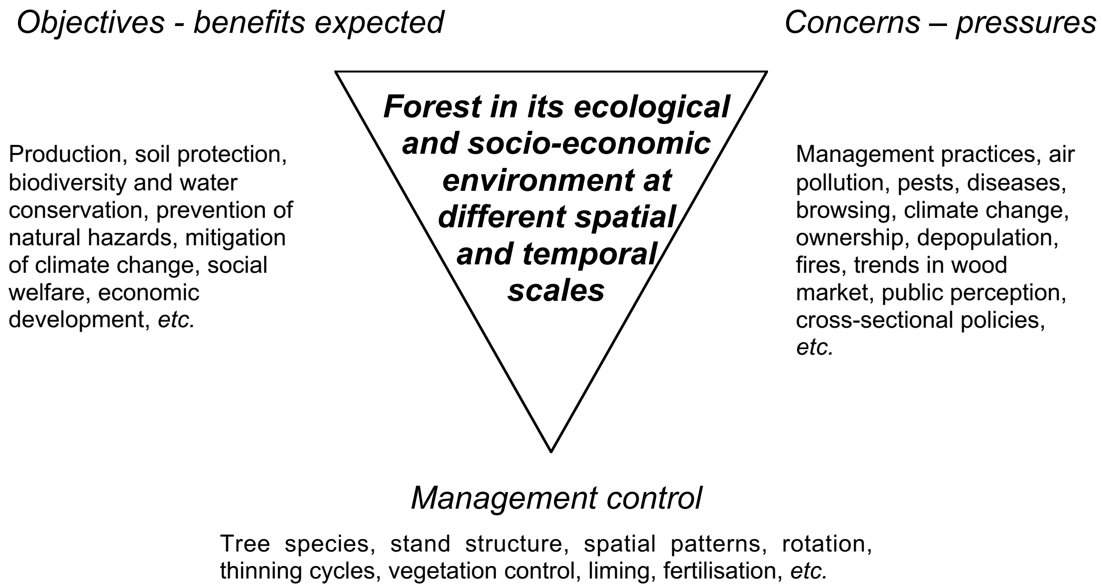

Fig. 2. The triangular network from which management questions arise.

We will use a simple hypothetical case study to further illustrate the process of how management questions arise within the triangular framework described above (see Case Study 1a). This hypothetical case study will appear later in this document, where it will be used to illustrate and clarify the differences between management questions, scientific questions in general, and strategic scientific issues.

Case study 1a. *A simple hypothetical case study as an example of management questions.*

Conditions

Imagine a landscape in which there are only two native tree species. A forest consisting of only the first tree species has gaps in the canopy, permitting access of radiation to the forest floor. This forest has a rich and diverse fauna and flora. The other tree species grows in dense stands and is poorer in fauna and flora species. The forests in this landscape are situated close to a major town and the people use the forest for recreational purposes. A forest company that uses the forest for timber production is also present. The forest company is obliged to manage the forest with regard to sustained biodiversity through regulations in the forest law.

Management questions

Management questions for this hypothetical case study, which are related to sustainable forest management could then be the following:

- Which species or combination of the two species maximises production while still making the forest attractive for recreation?
- Which type of forest landscape is optimal for combining timber production, biodiversity, and recreation?
- Should we aim to have monocultures, mixed stands, or a combination of the two in the landscape?

Objectives-benefits

Referring to SFM, the main benefits expected from the forest are wood and non-wood (cork, mushrooms, berries, *etc*.) production, as well as soil protection, conservation of water and biodiversity, prevention of natural hazards, mitigation of climate change, social welfare and economic development. As already mentioned, with respect to the past, these different objectives are now expressed by a larger number of stakeholders at different levels. The main consequence is that wood production is becoming less important than in the past, although remaining the main source of income. Often, the specific spatial and temporal scales of wood production are no longer the main reference for management, even if it is not yet clear at which scales the other functions could be or should be managed. The fact that most of the other functions consider the forest in its ecological and socio-economic context, as well as the interactions of the forest with its environment, brings new aspects into play. Last but not least, to manage the forest for multi-functionality demands the setting up of a hierarchy among the management priorities with the participation of stakeholders, which means that the relevant information about the way forests function should be adapted to the different categories of stakeholders.

Concerns-pressures

Concerns, or pressures, can be organised into different categories related to the impact of forest management itself, forest health and risks, the impact of climate change, and the socio-economic background. As for the objectives, they may evolve with time. It is important to remember that some concerns come to light as a result of scientific observations and long-term monitoring (*e.g.* climate change and air pollution).

The impact of management practices refers mainly to soil fertility, sensitivity of soils to forest operations, success of natural regeneration and genetic diversity. There are also more specific concerns regarding the protection of certain species and habitats. On the other hand, the impact of former land-use practices and forest management on current forest conditions becomes more and more evident, and is a general aspect that needs to be considered.

Forest health and stability has been at the top of the agenda since the late '60s, because of the reported damage to forests, possibly linked to air pollution. From these, the need for monitoring the way forest ecosystems function was considered a necessity during the '90s. It resulted in the assessment of the large-scale spatial and temporal variations of forest conditions in Europe (ICP-Level I) and the identification of cause and effect relationships at the ecosystem scale by means of intensive monitoring on permanent observation plots (Level II). We must bear in mind that the concerns about the effects of air pollution and other abiotic factors on forest ecosystems should not overshadow the traditional stress factors such as pests, diseases, and browsing. The risks associated with natural hazards (fire, erosion, storm, drought, avalanches, *etc*.) and climate changes are also burning issues for European forests.

The impact of climate change could be seen in several dimensions. One of the most important is related to the adaptation capacity of existing forests to changing climate. This could be analysed in terms of vegetation dynamics and future distribution of species. Furthermore, special attention should be devoted to the possible changes in the occurrence of pests and diseases, and their dynamics. Finally, the generally observed increase of forest productivity in the past decades should be considered in the framework of future balancing of the way ecosystems function and sustainability.

Concerning the socio-economic issues, let us start with the current trends in forest ownership. These trends affect forest management due to the possible changes in the behaviour of forest owners, and in terms of the management possibilities of individuals and the community as a whole. In European countries, two situations are prevalent: (i) the privatisation process of forests in Eastern Europe, and (ii) the excessive fragmentation of private properties in Western Europe. Another important socio-economic factor for many European countries is linked to the depopulation of certain regions with the consequent abandonment of traditional forestry activities, the loss of management expertise and capacity, and the collapse of the infrastructure. Forest fires are also worth mentioning as part of the socio-economic generated pressures on forests. Then comes the purely economic aspect, with the pressures from the wood market (prices and quality demand) as well as the emerging economic value of the other functions provided by the forests. The public perception of the forest and its services are increasingly influencing forest management. Finally, there are several cross-sectional policies that affect the forest such as nature conservation, land planning, water protection and rural development.

Management control

A rapid overview of the variables, over which managers have control, could help in the definition of this aspect of the management questions. At the level of stands and individual forests, the main variables that can be "controlled" by management are: tree species composition, stand structure, spatial patterns within the landscape, rotation periods, thinning cycles, game management, control of invasive vegetation (ultimately with herbicides), liming and fertilisation. Most of them are also relevant at the landscape level, when considering the type of vegetation and land use rather than trees. At higher levels, management become policy and operates through subsidies, regulations, and the organisation of the system in which stakeholders will act and make decisions. Forestry policies are the most obvious example, but all the other policies affecting forest and landscape should also be considered. As for the other aspects (objectives and concerns), as for the management control tools the list is certainly not closed as they are continuously subjected to development.

KNOWLEDGE NEEDED

Historically, foresters have developed certain knowledge of forests focused on the stand level, and related to trees, soils, yield, stand dynamics *etc*. It has been broadened to fauna, flora and habitats, with an increasing concern about biodiversity.

The new situation described above increases the necessity and interest of such knowledge, even if some improvements are needed in substituting the simple observation-derived empiricism with experimental approaches, and taking into account the new concerns linked to global climate change, biodiversity, *etc*. The knowledge that needs to be expanded in particular is that related to the new spatial and temporal scales of interest also taking into consideration the proper representations of a widened public awareness about forest matters. Obviously, knowledge of landscape ecology is necessary to understand the interactions between forests and other land uses, and to set up management options with regard to biodiversity, water or game management, all topics for which the landscape is the key level. Additionally on a global scale it must be remembered that forests (one of the major land covers of the world) play an important role in the biosphere; knowledge about this role must surely be improved. Finally, management decisions are influenced by the way in which knowledge and information are represented and disseminated; having more information and promoting new knowledge also mean work with the users and their concerns.

Box 2. **Ecosystem and Landscape Forestry**

The European Forest Ecosystem Research Network (EFERN), under a concerted action supported by the FAIR programme of the European Commission, provided an analysis of ongoing research about forest ecosystems in Europe from 1996-2000. It set up a database of scientists, research units and projects (see http://ifff.boku.ac.at/efern), and assessed the priorities for future research. Its conclusions are presented in the special issue of the journal Forest Ecology and Management "Pathways to the wise management of forests in Europe" (Führer *et al.* 2000). A major conclusion of EFERN was that the further development and application of SFM would require a change of scale from the basic understanding of the way forest ecosystems function to landscape functioning. This includes both up-scaling of existing results and new approaches at the landscape level. Furthermore, an understanding of the effects of former land use and management on today's ecosystems is required, as well as of the consequences of ongoing changes in the ecosystems caused by the rapid evolution of rural socio-economies and wood markets together with changing climatic and atmospheric environments. To consider the different problems, including the socio-economic aspects in the forest and today's landscape, will require an expansion of concepts from forest stands to landscapes. Forest management is exposed to changes in classical master plans. The concept of "Ecosystem and landscape forestry" summarised in the diagram below provides a framework for such a scale change and it also incorporates the socio-economic aspects at the landscape level (Fig. 3).

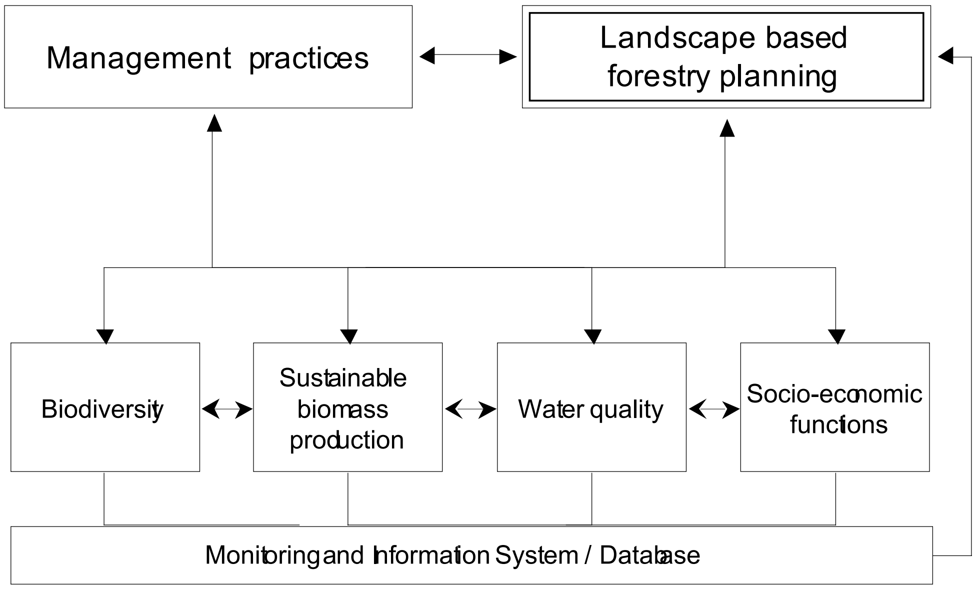

Fig. 3. Major components of ecosystem and landscape forestry aiming at sustainable forest management (Andersson *et al.* 2000b).

More precisely, for ecological questions we need to identify the information which managers need and how it should be presented to them. The ecological knowledge needed for sustainable forest management concerns the ecological processes that are internal to the single forest stands and those concerning the interactions between the forest and other elements of the landscape (ecotones, other land uses, *etc*.). Internal forest processes include the way ecosystems function and internal nutrient, carbon and water cycling, resilience, stability, soil fertility, and forest exploitation. Those processes identified as concerning the interaction between the forest and other elements of the landscape include game behaviour, catchment hydrology and nutrient cycling, vegetation dynamics, and socio-economic pressure. Climate change, increasing CO_2 and land-use patterns affect both the forest and the landscape. Furthermore, a holistic approach to the landscape is needed to have a broader understanding of the way ecosystems function, where the spatial structure of the landscape plays a key role (size, distance, shape of the landscape elements, *etc.*). Therefore, the peculiarity of the landscape-level lies in the correct consideration of its spatial and structural components, and how they affect forest ecosystem functioning and dynamics. The holistic approach also means that landscapes cannot be considered as the addition of single components working in isolation, but as how these components act as an entity. We can now explore which scientific questions are most urgent or most widely applicable with reference to these information needs (cf. Fig. 4).

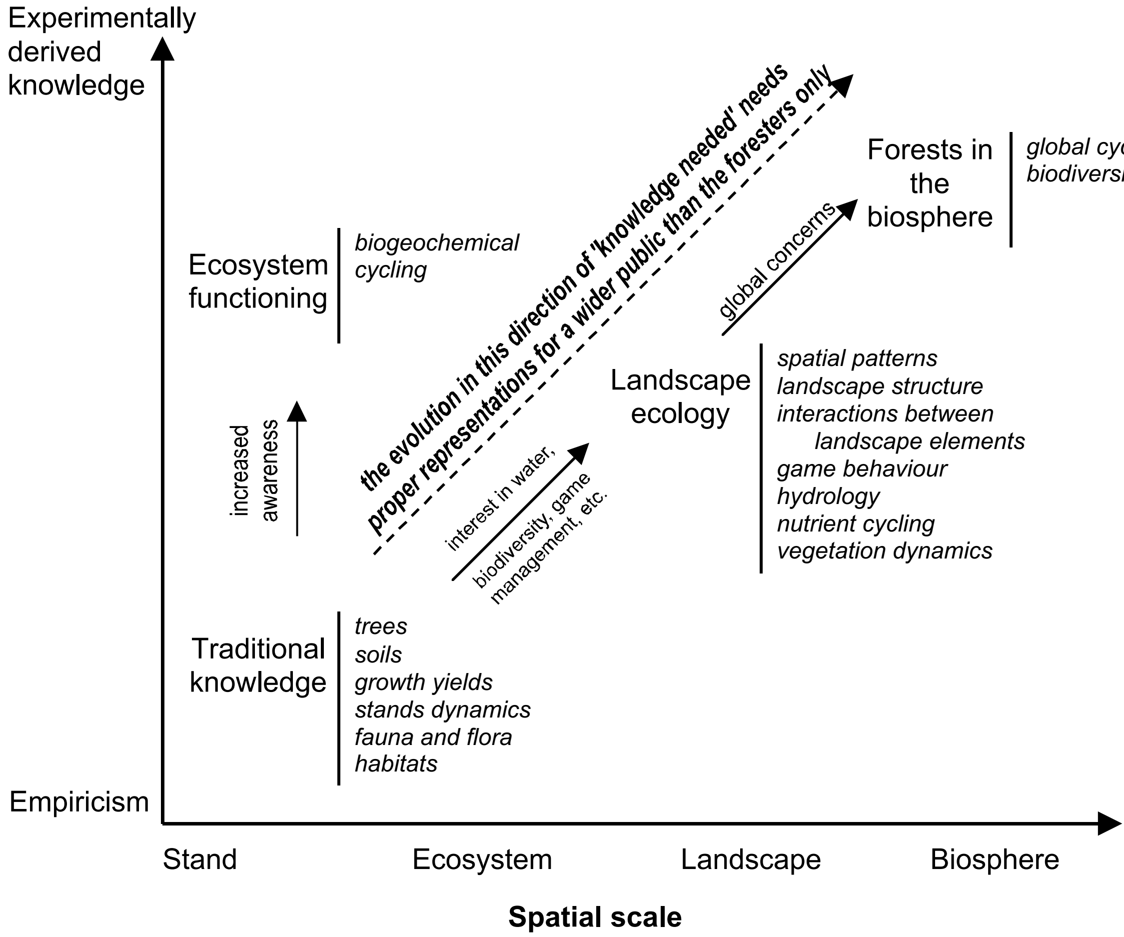

Fig. 4. Evolution of knowledge needed for sustainable forest management.

SCIENTIFIC QUESTIONS IN GENERAL

Scientists from natural or social sciences are those who will probably formulate the scientific questions to be addressed in relation to SFM. Those questions form the basis for the research and the development of new scientific knowledge. Nevertheless, sometimes current ecological theories and available methodologies may limit those questions. Therefore, some of the questions raised from outside the scientific community (*e.g.* from managers or socio-economic groups) could be more difficult because they may challenge existing theories and methodologies. As discussed in the previous sections, forest management questions that arise from the interactions among objectives, concerns and management tools demand knowledge. This knowledge constitutes the bridge between the management questions and the scientific questions/issues, where these two fields interact and where new ideas and concepts can be formulated in terms of SFM (Fig. 5).

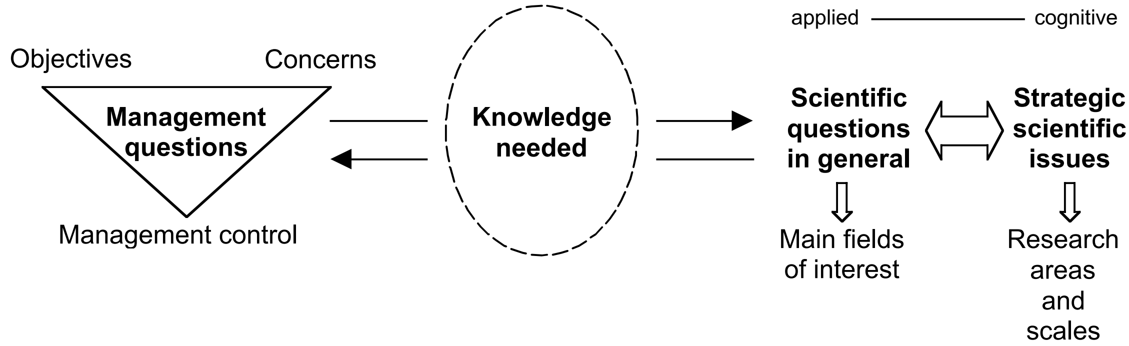

Fig. 5. The relationship between management questions, their demand for knowledge needed, and scientific questions and issues in an ecological context, which illustrate the scientific framework for the "European Network of long-term Forest Ecosystem and Landscape Research" (ENFORS).

Furthermore, we are used to qualifying research that addresses questions that are more directly applicable to management, as applied research. Examples of purely applied research are studies that relate silvicultural practices to the production and the biodiversity of ecosystems, and where these results could be used to formulate recommendations to be applied by the managers. Conversely, research that addresses the understanding of the ecological processes behind growth and patterns of biodiversity is referred to as basic, cognitive or fundamental research. In fact, there is a continuum from the basic to the applied research, but we use this distinction as a practical way of presenting things. In this section, we will concentrate on those scientific questions that are of a more applied nature.

Case study 1b. ... *Continuation of the simple hypothetical case study (see Case study 1a) an example of scientific questions.*

Conditions

In our case study there were conflicting interests between the forest company, the urban people, and the political goals expressed in terms of timber production, recreation, and maintained biodiversity.

Scientific questions

Scientific questions that are generated by the management questions arising from this conflict (see Case study 1a) concern all three aspects within this conflict. Some examples:

- How do the people's perception of and their relationship with nature and forest ecosystems evolve?
- How is the biodiversity affected by the silvicultural methods used for timber production?
- What are the effects of biodiversity on long-term timber production?

As the scientific questions are numerous and address aspects at different ecological and social levels, we have chosen to summarise these questions into a context with some examples, rather than elaborating a complete list of questions. For this, four main fields of interests have been identified in relation to the management questions presented in the previous chapter: multi-functionality of forests, long-term trends in the environment, land use and the role of forests in the landscape, and stochastic disturbances.

Table 2. *Main fields of interests of the scientific questions closely associated with management questions, and a list of the ecological and socio-economic environmental factors associated with them that affect the forest ecosystems*

Multi-functionality of forests	**Long-term trends in the environment**	**Land use and the role of forests in the landscape**	**Stochastic disturbances**
Agroforestry	Increasing CO_2	Abandonment	Avalanches
Biodiversity/nature conservation	Precipitation	Afforestation	Drought
Carbon storage	Temperature	Agriculture	Fires
Game management	Extreme events	Agroforesty	Floods
Non-timber production	Nitrogen deposition	Forestry/Silviculture	Harvest
Recreation	Deposition of pollutants	Fragmentation	Herbivores
Risk management	Trace gases	Livestock and game	Pathogens
Timber production	Species distribution	Planning	Pests
Water management		Set-a-side areas	Storms
		Soil degradation	

MULTI-FUNCTIONALITY OF FORESTS

As mentioned in the previous section, forests have always been used for multiple purposes, but the expectations have recently increased, and have been extended to include most forest types, and have spread from local demand to multi-level services. Though multi-functionality of forests shows regional differences, the functions of the forests that are common to most parts of Europe are timber production, game management, biodiversity and nature conservation, water management, and carbon storage (Appendix 2). The regionally specific functions are: agroforestry that concerns forests mainly in Mediterranean and Eastern countries; non-timber production that is closely connected with local traditions and varies throughout Europe; and risk management that is a priority in mountainous regions. The importance of forests as recreational resources is spreading rapidly in Europe and at the moment concerns two distinct areas: (i) forests close to urban areas, and (ii) relatively remote forests (only within reach of the general public during long weekends and holidays) with high scenic and multi-recreational values.

The scientific questions relate to three categories: (1) the need for more detailed ecological knowledge to meet the demanding social expectations for each forest function, (2) the necessity of understanding the interactions between the different functions and the problems arising when combining them, and (3) concerns about the redefinition of the conditions of sustainability of particular forest ecosystems (*e.g.* old growth, coastal, mountain and urban forests). Some examples of the need for increased ecological knowledge include: biodiversity that is no longer a matter of a list of rare and endangered species, but now concern the environmental requirements of these and other species; water-forest relationships where the old notion that forests are always beneficial to the water quality and quantity is now known to be wrong.

Combining several functions in the forest often reduces the benefits of a single function. For example, biodiversity in forests can be enhanced by longer rotation periods, diversity of silvicultural practices and use of temporary reserves, which may reduce the timber production of the preferred tree species. Another example concerns the interaction between game and forest management, where the damage to forest regeneration not only depends on the population numbers of game, but also depends on the availability of the preferred forage within the habitats. This may be a consequence of the methods used by forest managers for regeneration, the favouritism for certain tree species or due to habitat change caused by other disturbances. Examples of interactions concerning forests and water management concern (i) the role of forest types and different silvicultural practices, and (ii) forests as replacements for other land uses.

Natural forest reserves are few and relatively small in Europe, and they are often isolated islands in the landscape surrounded by intensive land use (European Commission 2000). Therefore, scientific questions concern the maintenance of the natural forest ecosystem dynamics and the consequent effects on forest biodiversity with regard to the fragmented European landscape structure.

LONG-TERM TRENDS IN THE ENVIRONMENT

The scientific questions related to long-term trends in the environment mainly concern the direct and indirect effects of climate change on forest ecosystems (*e.g.* the effects on canopy physiology, species composition, growth rates and carbon allocation, the effects on water use, and the relationship with forest damage), and the environmental consequences of atmospheric deposition.

First, it has to be stressed that a major constraint on the development of climate change research is the availability of ecologically relevant predictions and the identification of threats of climate change for forest ecosystems. Admittedly, quantitative predictions do exist with regard to the future general trends of climatic variables (*e.g.* temperature and rainfall). However, predictions of the frequency of extreme events (*e.g.* storms, extreme rainfall, and severe drought periods) and of climate situations that act as ecological constraints (*e.g.* frost events, critically high temperatures, and changes in the start/end of the growing season), may be even more important for forest ecosystems than the overall trends. From an evolutionary point of view, a better understanding of natural adaptability among species might help to elucidate the importance of climatic variability. Furthermore, the most sensitive ecosystems to climate change may prove to be those ecosystems located in areas where the current growth conditions are at their limits (*e.g.* at the tree line, in mountainous and dry areas), communities that are at the edges of the forests and ecosystem boundaries, and populations that are at the edge of their species distribution range. In this respect, these ecosystems may be critical both from the viewpoint of biodiversity and productivity. Numerous studies do exist, which have looked at the effects of climate change on single species or species assemblies. However, these are mainly concerned with single components of climate and land-use changes (*e.g.* increased carbon dioxide, ultraviolet-B radiation, nitrogen deposition, temperature, or habitat fragmentation). Therefore, the most important contribution within this research area would be considerations about whole ecosystems, the observation of the interactions and the combined effects of multiple components of climate and land-use changes.

The scientific questions about climate change also concern the forest ecosystems as places for actively maintaining, preserving and managing global carbon storage, as the increased CO_2 level in the atmosphere is one of the major driving forces for the observed and expected climate changes. For this, there is a need for quantitative relationships on carbon fluxes, budgets and pools within a wide range of forest ecosystems and their relationships with other ecosystems as well as to the global carbon pools. The qualitative understanding of these quantitative patterns is needed to make predictions and scenario models.

Atmospheric deposition of chemicals such as toxic gases (*e.g.* SO_2, O_3, NO_x, F and H_2O_2), wet and dry deposition (*e.g.* SO_2, NO_x, HCl and NH_3) and heavy metals (*e.g.* Al, Pb, Hg, Cd and Zn) may have detrimental effects (soil acidification, leaching, lowered stress resistance and vitality, loss of productivity *etc.*) on ecosystems, while they may be beneficial (*e.g.* increased productivity) when they are in the form of essential nutrients (*e.g.* NH_4^+, NH_3, NO_3^-, PO_4^{3-} and SO_4^{2-}). Some of the increasing trends of atmospheric pollutants have levelled off or even gone into reverse, such as the SO_2 pollution. The future trends and distribution patterns of other atmospheric chemicals are still uncertain, for example the nitrogen depositions from agriculture and transport. The direct effects of atmospheric chemicals are quite well known, but the long-term indirect effects and feedback mechanisms caused by atmospheric deposition require deeper understanding. We would also like to mention the need for further development of knowledge about interactions between atmospheric pollutants, and other abiotic (*e.g.* drought, water logging and wind) and biotic (*e.g.* fungus, insects and mammalian herbivores) environmental stress factors.

LAND USE AND THE ROLE OF FORESTS IN THE LANDSCAPE

Land use often has dramatic effects on a particular site, but in terms of sustainability it is necessary to have an over-view of the landscape in order to understand the overall effects on the forest ecosystems. A dramatic change at a single location may be insignificant at the landscape scale (*e.g.* the opening of a small gap in a forest stand); conversely an apparently insignificant change at the site level may have major landscape implications in some circumstances (*e.g.* the extinction of a key soil species controlling nitrogen cycling). The scientific questions of land use are generally characterised by three dimensions: (1) the temporal aspects, (2) the spatial context, and (3) the transition phase.

The temporal aspects concern for example the long-term effects of past land use on forest ecosystems (*e.g.* forests on former agricultural land and uniform forest management) and the possible predictions of future behaviour (*e.g.* after abandonment and afforestation). The long-term effects related to forest ecosystems are mainly those affecting biodiversity, productivity, carbon-nitrogen cycles, erosion, soil compaction, and hydrology.

The spatial context of land use deals with the landscape structure and its links to the way ecosystems function. Game, livestock and pest population dynamics are affected by factors at the stand level, but even more important are the factors acting at the landscape level such as the effects of the changes in land-use proportions and their fragmentation. The effects of forest borders on deposition rates and forest resistance to wind, for example, are also important.

The transition phase relates to problems associated with the conversion of one land-use form to another. In Europe, abandonment, afforestation, and traditional activities (*e.g.* small-scale practices and coppice management) are common examples (Hüttl *et al.* 2000, Kräuchi *et al.* 2000, Scarascia-Mugnozza *et al.* 2000) and the scientific questions concern the effects on nutrient cycling, water balance, and biodiversity. Although man is the dominant cause of land-use changes in Europe, there are also naturally occurring land-use changes; particularly those linked to natural re-colonisation and succession processes (*e.g.* land elevation, wetland-forest conversion, and disturbance caused successions).

Box 3. Functional complexity

Ecological complexity represents biological diversity but in a broad sense, including not only species diversity but also diversity of ecosystems and landscapes as well as genetic diversity within species (Sala 1996). Ecological complexity may affect not only average ecosystem functioning but also the system response to extreme conditions. Each level of organisation requires specific management actions. (Odum 1983, Beyers and Odum 1993, Lugo 1995). Defining hierarchies by size criteria presents a problem to ecosystem management because the units of management may not have biotic or ecological meaning. Ideally, the units of ecological classification and management should be similar to the units of biotic organisation. The scientific challenge is the identification and understanding of biological hierarchies beyond the population level and up to the global level. Our understanding of ecosystem processes clearly depends on the availability of monitoring data. Information at temporal and spatial scales is therefore important in the definition of forest ecosystem and landscape management goals. However there is no nature-given scale at which a system is sustainable. Sustainability without a stated scale has no meaning (Allen and Hoekstra 1994). Successful ecosystem management requires understanding of all scales in the hierarchy of biotic function. Better understanding of the hierarchies of time and space contributes to more successful environmental management (Morrison *et al.* 1982, Magnuson 1990, Swanson and Sparks 1990, Beyers and Odum 1993). However, hierarchies of time and space can be different from hierarchies of biotic function.

STOCHASTIC DISTURBANCES

Disturbance factors alter the forest ecosystems at different spatial and temporal scales and therefore can affect either single species or whole communities (Nilsson 1997). Consequently, disturbances have implications on the way ecosystems function and affect forest structure, composition, productivity, biodiversity, water balances, and nutrient cycling (*e.g.* Wardle *et al.* 1997). Some of the disturbances are natural while others are anthropogenic (*e.g.* management). Species within forest ecosystems have generally evolved in response to the natural disturbance regimes and show adaptations to them. Therefore, the natural disturbance regimes need to be quantified and their effects ascertained as they play a key role in the understanding of the forest biodiversity and how silvicultural operations contribute to it (Bengtsson *et al.* 2000).

The effects and consequences of disturbances (natural and anthropogenic) are highly dependent on the spatial scale at which they are studied; as an example, fires can eradicate species at the stand level, but then create a mosaic of habitats at the landscape level creating greater biodiversity. Forests can be used to protect the landscape from natural hazards; examples of this use (risk management) are the prevention of avalanches, flooding, landslides and torrents. The scientific questions concern the influence of forest species composition, structure and landscape pattern on the role of the forest in protecting the territory from these hazards.

PRIORITY STRATEGIC SCIENTIFIC ISSUES

Some of the scientific questions that are of a more applied nature were discussed in the previous section and identified as belonging to four main fields of interest (multi-functionality of forests, long-term trends in the environment, land use and the role of forests in the landscape, and stochastic disturbances). Four relevant priority research areas were derived from them: (1) biogeochemical cycling, (2) biodiversity, (3) landscape and ecosystem dynamics, and (4) socio-economics. So as to focus more on priorities, we will indicate some strategic issues necessary for a significant improvement in scientific knowledge within each of them.

To further illustrate the development of strategic scientific issues that are of a more basic nature we can once again look at the case study (Case study 1c).

Case study 1c. *... Continuation of the simple hypothetical case study (see Case study 1a and 1b) as an example of strategic scientific issues.*

Conditions

The forest in our hypothetical landscape contains two species with their associated fauna and flora. The forest is either made up of a mixture of the two tree species or each species alone. Earlier research has shown that the biodiversity is higher in forests with tree species X only than in forests with tree species Y only, and that a mixture of the two tree species has the highest biodiversity. However, knowledge is lacking at the landscape level on how the biodiversity is maintained in a landscape that has different spatial patterns of successional stages of single- and mixed-species forests, for example, caused by silvicultural methods.

Scientific issue

To be able to understand the effects of forest management on biodiversity at the landscape level, new basic ecological knowledge of how this forest has evolved in conjunction with its natural disturbance regimes is needed. Therefore, the scientific issue concerns:

– the processes of natural disturbance regimes and their effects on biodiversity at the landscape level.

Biogeochemical cycling

Basic studies of the biogeochemical cycle (nutrient, carbon, and water cycles) are essential to understand and predict the way forest ecosystems function and their interactions with neighbouring ecosystems. They need *in situ* observations at different spatial scales, from local to global, to deal with questions concerning – in the order of increasing scale – soil fertility, hydrology of watersheds, and the carbon balance of the atmosphere. The temporal dimension also demands particular approaches and methods to measure the specific trends and variability at each temporal scale. The inter-annual processes in this area are poorly documented and need a special attention. The long-term processes have already been covered by approaches like dendrochronology and stable isotope methods for reconstructing the way forest ecosystems functioned in the past, and chronosequences of forest stands are commonly used to evaluate the balance of nutrients over a rotation. Nevertheless, it is worth mentioning the value of long-term observations, which call for the conservation of old experiments and the setting up of new research sites for the future generations. Finally, modelling is the essential complement to *in situ* observations (see Box 4) and has already been well developed in the area of biogeochemical cycling. Here we point out the following strategic issues:

- ***long-term aspects of nutrient and carbon cycling;***
- ***carbon-nitrogen interactions;***
- ***landscape aspects related to water quality and quantity.***

Long-term aspects of nutrient and carbon cycling

A long-term outlook on nutrient and carbon cycling is implicit in the understanding of sustainable production in ecosystems. Specifically, these long-term aspects concern the feedback mechanisms related to mineralisation of carbon and nutrients in the soil, such as those caused by changes in litter quality and composition (Andersson *et al.* 2000a). More specific to nitrogen are the immobilisation and the subsequent re-mineralisation processes, where atmospheric deposition and fertilisation are examples of environmental factors causing potentially long-term effects on these processes. Other long-term processes lacking scientific knowledge concern weathering of mineral nutrients where the near-root environment and mycorrhiza are still 'black boxes'. This brings us to species interactions that concern the competition between plants and microorganisms, and the long-term turnover of soil micro-fauna caused by environmental change.

Carbon-nitrogen interactions

The most significant lack of knowledge with regard to carbon-nitrogen interactions concerns the understanding of soil processes, remembering that nitrogen is the most frequent limiting nutrient for European forests although other essential nutrients may limit growth under specific conditions. For example, in the case of fresh litter substrates the C/N-ratio influences processes such as decomposition rates and soil organic matter accumulation. This means that nitrogen deposition affects carbon and nitrogen sequestration in soils. These effects may differ among forest types (*e.g.* differences in litter quality, composition of micro-organisms and mycorrhizal communities), where the different species-soil interactions are key components for a deeper understanding at the landscape level considering the distribution of forest types and with regard to local and regional estimations of carbon and nitrogen budgets. The consequences on nitrogen and carbon retention have further effects on the leaching process into neighbouring ecosystems.

Box 4. **Biogeochemical models**

There is a clear need to use models, capable of simulating ecosystem functions, for testing hypotheses of environment-growth relationships at large spatial scales. Models of the biogeochemical cycling (BGC) family are extremely useful tools to analyse, compare and predict the cycling of carbon within terrestrial ecosystems, and to scale its dynamics from stands to landscapes (or continents). Three frequently-used models of the BGC-family are currently available: TEM, CENTURY, and Biome-BGC. The TEM (Terrestrial Ecosystem Model, version 4) model (Raich *et al.* 1991, McGuire *et al.* 1992, Melillo *et al.* 1993) describes carbon and nitrogen dynamics of plants and soils for non-wetland ecosystems of the globe. The CENTURY (version 4) model (Parton *et al.* 1993) simulates C, N, P, and S dynamics of grasslands, forests, and savannas. The model uses monthly temperature and precipitation data as well as atmospheric CO2 and N as inputs to estimate monthly pools and fluxes of carbon and nitrogen in ecosystems. The Biome-BGC model (Thornton 1998) is designed to simulate the dominant processes controlling fluxes and pools of water, carbon and nitrogen in non-agricultural ecosystems. The model requires daily meteorological data, soil and plant/vegetation-specific parameters, and theoretically, it is scalable from individual trees to global applications (at low taxonomic resolution, usually). Of the three models, Biome-BGC is the most up-to-date and best suited for studies of net ecosystem exchange of carbon, including the influences of changing atmospheric chemistry, changing nutrient deposition rates, inter-annual climate variability, and natural and managed disturbances. Its prime advantages are the daily time intervals, and its well-balanced requirements of input parameters (Zimmermann personal communication). The Q-model – an ecosystem model based on carbon and nitrogen – represents another approach in biogeochemical cycling modelling (Ågren and Bosatta 1998; see Ågren 1999 for a review of different model approaches; and Porté and Bartelink 2002 for a review of modelling mixed forest growth).

Landscape aspects related to water quality and quantity

The water cycle involves processes occurring at several spatial scales: *e.g.* the large circulation systems and subsequent redistribution of water operate at the global level, processes related to precipitation and long-distance river systems operate at the regional level, surface runoff and throughflow are at the landscape level, interception, direct throughfall, crown drip, stem flow and evapotranspiration are at the stand level, and internal water transportation is at level of individual trees. At all these levels, water is important as a medium for transport of nutrients and pollutants. The forest as an element in the landscape influences these processes (Brooks *et al.* 1997). The subsequent effects may concern the quality of the water in rivers, lakes and groundwater bodies, and the quantity of water exported to neighbouring ecosystems (*e.g.* rivers and agricultural land) (Roberts 1999). The role of different forest types and geomorphologic conditions are determining factors for the leaching processes in the entire catchment area. This role of forests is determined both by the internal forest structures (*e.g.* species composition, stand structure, age distribution, and timber harvest) and the landscape structures (*e.g.* interactions between forests and other landscape elements, edge effects, and fragmentation). Particularly, the long-term dynamics are largely unknown here.

Biodiversity

Biodiversity concerns biotic variations at all levels, *e.g.* from genes to ecosystems, and from local to global. In relation to our analysis of the scientific questions at stake, we consider the following as strategic issues within biodiversity:

- ***the functional role of biodiversity;***
- ***the processes of maintenance and development of biodiversity.***

Functional role of biodiversity

The effects of biodiversity on forest ecosystems and the way they function (*e.g.* ecosystem stability, resilience, stress resistance, productivity *etc.*) are still unclear (and *vice versa*) although certain relationships have been demonstrated (Bengtsson *et al.* 2000). For instance, biodiversity in terms of functional groups, species, and genetic diversity correlate with ecosystem characteristics and processes such as productivity (Burkhart and Tham 1992), nutrient cycling (Loreau 1995), and pest damage dynamics (Bengtsson *et al.* 1997). However, the quantitative relationships are not always coherent with the predictions of present ecological hypotheses about biodiversity and ecosystem functions and the results from experiments are ambiguous (Bengtsson *et al.* 2000). So far most such studies have been carried out on isolated ecosystems and in particular lake and grassland ecosystems and there is a lack of forest ecosystem studies. At the landscape level, there is also a need for experiments and observational studies across multiple ecosystem types in the future. Other aspects of biodiversity and the way ecosystems function are those relating to the establishment of functional groups and keystone species and the identification of the possible roles of rare species (Bengtsson *et al.* 2000).

Processes of maintenance and development of biodiversity

Maintenance and development of biodiversity need to consider dynamic processes such as succession after perturbations, population fluctuations caused by competition, species adaptation and inter-/intraspecific mechanisms. Rather than focusing on species conservation *per se* it is most often the maintenance of these dynamic processes that is of interest for long-term and sustainable management of biodiversity. However, the maintenance of dynamic processes is limited by spatial and temporal extent. For example, the maintenance of natural fire regimes often requires access to large areas with many different ecosystems, and to include the succession from pioneer to secondary vegetation communities requires longer rotation periods than those commonly used within intensive forest management. Therefore, studies of the interaction between dynamic processes and their spatial and temporal extent are needed. Related issues to those of dynamic processes are the impact of simplification of ecosystems, which may lead to a loss of key functional processes (succession, population fluctuations, intra-/interspecific competition *etc.*).

Landscape and ecosystem dynamics

Ecosystems, and landscapes in particular, are not static but they and their components change in size, shape, spatial arrangement and function. Studying the effects on dynamic systems and evaluating their consequences are highly scale dependent and the conclusions drawn from these studies will depend on the spatial and temporal scale chosen. Therefore, definitions of research objectives and scales are central to research on landscape and ecosystem dynamics. Here we identify some strategic issues related to landscape and ecosystem dynamics, although acknowledging that they are closely related to the other priority research areas such as biogeochemical cycling and biodiversity:

– ***stability, resistance and resilience;***
– ***patterns and interactions between ecosystems;***
– ***hierarchical spatio-temporal frameworks.***

<u>Stability, resistance and resilience</u>

The way ecosystems behave in response to perturbations is one way of describing ecosystem dynamics. Stability, resistance, and resilience are three common ways of describing the type of properties of forests (Führer 2000). Plant-herbivore interactions, soil-plant interactions, and internal population dynamics are processes intrinsic to forests, but they may have effects at higher levels as well. Their importance in relation to landscape dynamics in this field must be further clarified.

<u>Patterns and interactions between ecosystems</u>

Changes in the landscape structure in terms of size, shape and distribution patterns of its components lead to changes in the physical degree of connectedness and isolation among ecosystems and habitats, which in turn have ecological consequences for the organisms by changing the connectivity among the subpopulations in the landscape. These patterns of landscape change from fine to coarse grain, from heterogeneous to homogeneous, and from diverse to monotonous. They affect species differently as species perceive their environment at different spatial and temporal scales. Another aspect of structural landscape changes concerns the nutrient cycling, where for example the relationships between deposition-storage-leaching and input-internal turnover-output of nutrients depend on the distribution patterns of ecosystems in the landscape. Additionally, little is known about the effects of the spatial dynamics of seed dispersal and selective foraging by mammalian herbivores on ecosystem productivity and nutrient cycling (Pastor *et al.* 1999). The challenge lies in developing new methods, tools and theories for handling this complexity. It should be mentioned that the consequences and effects are highly scale dependent and the conclusions may become contradictory when passing from one scale to another.

<u>Hierarchical spatio-temporal frameworks</u>

Ecological processes operate and environmental factors act at different spatial and temporal scales. Some of these operate across several scales while others do so at more specific levels. In terms of sustainability, it is important to study the ecological processes at all spatial and temporal scales in order to understand the effects occurring at the landscape level. That is, to study the processes from those occurring at the very small scale (*e.g.* the near-root environment), to those operating at the landscape level (*e.g.* leaching of nutrients to neighbouring ecosystems), and ultimately to those at the very large scale (*e.g.* long-distance air-borne pollutants). For a comprehensive understanding of the consequences and processes in this hierarchy of scales, the spatial and temporal scales must not be studied independently, but an understanding should be foreseen on how those scales relate and interact with each other. A "hierarchical spatio-temporal framework" for forest ecosystem and landscape processes is needed to integrate the ecological understanding into SFM.

Box 5. Models for studying landscape and ecosystem dynamics

The number of spatially explicit models is increasing fast, mainly because of the evolution of computer power and more sophisticated Geographic Information Systems (GIS). They are too numerous to give a complete overview here, but we will mention a few examples of modelling families dealing with landscape and ecosystem dynamics: models of metapopulation, host-parasitoid and gap dynamics.

The 'classical' metapopulation concept (Levins 1969, 1970) is a system of local populations that are linked by dispersal. The local populations are subject to extinction and the habitat patches are subsequently recolonised, and the balance between these processes is the focal point. Several types of metapopulation models exist (Harrison 1991): the core-satellite (Boorman and Levitt 1973) population models that are closely linked to the island-biogeographic theory (MacArthur and Wilson 1967); the source-sink population models that are considering habitat heterogeneity (Pulliam 1988, Pulliam 1996); the patch population models where the recolonisation occurs more or less instantly after local extinction; and non-equilibrium metapopulation models where the rate of local extinction is symptomatic of a general decline. These models are examples of population dynamics models at the landscape level, and they are valid tools within conservation biology. Although the metapopulation concept is well developed, empirical support for some of the fundamental components of the theory such as dispersal is to a large extent lacking.

Models of prey-predator, host-pathogen, and host-parasitoid systems contribute to the understanding of ecosystem dynamics. The apparent spatial patterning in host-parasitoid systems in combination with the awareness of altered landscapes have caused the evolution of the earliest host-parasitoid model – the Nicholson-Bailey model (Nicholson and Bailey 1935) – to incorporate the spatial dimension. Cellular automata have been common spatial model frameworks for these models (*e.g.* Comins *et al.* 1992), which are also commonly used in other types of models such as those of plant competition (*e.g.* Crawley and May 1987, Silvertown *et al.* 1992).

An important family of models studying forest dynamics are the gap models, which were developed to study forest succession with special emphasis on mixed species stands. The earliest gap models were developed during the '70s (Franc *et al.* 2000) such as the JABOWA (Botkin *et al.* 1972) and the FORET (Shugart and West 1977) models. Gap models are individual-based but distant independent, which means that there is no spatial positioning of individual trees within the cells ("gaps"). The competition among trees due to horizontal components (*e.g.* crown expansion and subsequent light competition) is thus not considered in these models, contrary to distant-dependent models (for a review of models for heterogeneous forests see Franc *et al.* 2000).

Socio-economics

Understanding human behaviour and economic systems is necessary when considering dynamics at the landscape level. However, the interactions between social and natural sciences are few. Being aware of the difficulty, we limit our ambition to the following strategic issues, which should be understood as a way of co-operation between social and natural sciences at the particular scale of landscape management questions:

- ***conflict management;***
- ***perception and representation;***
- ***valuation.***

<u>Conflict management</u>

Conflicts arise from opposing interests among different stakeholders. As mentioned previously, the categories of stakeholders have grown recently and have become more diverse than before. Therefore, new methods are needed in terms of pre-evaluation of potential conflicts, prevention of emerging conflicts, participation of stakeholders and solutions for existing conflicts. This need for new methods should be developed by integrating scientific knowledge from both social and natural sciences. Evaluation of appropriate levels for dealing with different types of conflicts is also an urgent issue, which relates to the combination of the spatial and temporal scales adapted to socio-economic organisations and ecosystems.

Perception and representation

People's perceptions of landscapes (*e.g.* for their scenic values and appropriateness for recreational needs), management policies (*e.g.* the importance of including benefits from non-market valued products), and silvicultural operations (*e.g.* the anticipated effects of clear-cutting on biodiversity) are becoming important components of the processes by which the landscape and its functioning are structured. Evaluation of people's perceptions is therefore a valuable tool in landscape planning, but it is complicated by the perceptions being dynamic. Ways for appropriate evaluation are needed that take these long-term changes into account.

Closely associated, is the question of representation by the stakeholders regarding the problems that are on the agenda. It affects the way they interact, particularly in participating in the processes associated with the definition and implementation of forest policies. The improvement in the dialogue between them goes through a minimum of common representation of the topics debated. One main issue is the kind of information provided, the way it is formulated, and the access to it.

Valuation

Considerations of benefits with non-market values pose problems in decision processes that are built up around products that have economic value, such as the decision chains of European societies. The valuation of landscapes, biodiversity, accessibility of recreational objects *etc.* and their integration into the decision process with products that have a market value needs to be elaborated. For example, how and is it possible to put economic values on the presence of particular species or different landscape types, and can they be incorporated without valuation?

CONCLUSIONS

Although the objective of the paper was to give the scientific focus of the foreseen network of research sites – ENFORS – we have described the questions derived from the evolution of sustainable forest management issues from a more general point of view. As a result, we have given some arguments for the proposed network as an essential part of a European scientific policy to support forest policy makers and managers.

- Knowledge about ***the way ecosystems function*** is essential to answer the demand for a more accurate scientific understanding of the consequences of forest management, the evolution at stake and the possible management decision.
- ***Research sites*** are necessary to provide research programmes with *in situ* observations. They can also contribute to ***interdisciplinary*** enhancement, which is very much in demand due to the nature of the scientific questions identified in this paper. Both the specific forest time intervals and the evolution being studied call for observation on the ***long term***.
- In the current situation, most sites are set up at the forest stand level. Obviously, the ***landscape level*** (and particularly the interaction between the forest and other land uses) appears to be one important scale to reach in the new design of forest research sites.
- Having a ***network of sites*** addresses the need for having a critical mass of data and research to take up the challenge of providing fundamental results and generic models for European forests. For example, the importance of having contrasting situations, as well as a good coverage of European diversity should be stressed.
- Finally, ***generalisation*** of research results as well as ***up-scaling*** from research sites to regional or continental levels should be part of the scientific strategy. Collaboration and synergies between research site activities and ***forest monitoring programmes*** are undoubtedly necessary and rich in potential.

The framework set up in terms of management questions, scientific questions and main scientific issues, will serve as the common reference during the next stages of the COST Action *E25*. It opens the way for an inventory of existing research sites, which contribute or could contribute to it. It also provides the basis from which the following working groups, dedicated to the scientific programme, the instrumentation required and the link with monitoring programmes, will develop the project of a European Network of Forest Research Sites in detail.

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Appendix 2. *Importance of the "Main fields of interest" in Europe at the national and regional level*

The following questionnaire was sent out to the members of ENFORS for mapping the importance of the "Main fields of interest" at the national and regional level. The questionnaire was sent to 24 countries within Europe of which 15 replied.

Questionnaire 'Mapping of national and regional "Main fields of interest"'

Prepared by Dr. Ion Barbu, Romania

Main fields of interest and subjects	***Importance in your country***[a]	***Capacity to react through management and technical measures***[b]	***Gaps in knowledge and management***[c]	***Most urgent act in the scientific field***[d]	***Conclusion***[e]
A. MULTIFUNCTIONALITY					
A1. Agroforestry					
A2. Biodiversity					
A3. Carbon storage					
A4. Game management					
A5. Nature conservation					
A6. Non-timber production					
A7. Recreation					
A8. Timber production					
A9. Water management					
B. LONG-TERM TRENDS					
B1. CO_2					
B2. Deposition of pollutants					
B3. Extreme events					
B4. Precipitation					
B5. Temperature					
B6. Trace gases					
B7. Vegetation types					
C. LAND USE					
C1. Abandonment					
C2. Afforestation					
C3. Agriculture					
C4. Agroforestry					
C5. Planning					
C6. Forestry/Sylviculture					
C7. Livestock					
C8. Set-a-side areas					
C9. Soil degredation					
D. DISTURBANCES					
D1. Avalanches					
D2. Drought					
D3. Fires					
D4. Floods					
D5. Harvest					
D6. Herbivores					
D7. Pathogens					
D8. Storms					
D9. Snow					
	M = Major	I = Integral	E = Equipments		
	r = Reduced	p = Partial	S = Scientist		
	s = Minor	r = Reduced	F = Political/ Financial		

[a]Indicate the importance each subject has in your country.
[b]Indicate whether your country has the capacity or the will to react on the subject through management and technical measures
[c]Indicate where the gaps in knowledge and management occur in your country for each subject.
[d]Within each of the four main fields of interest, indicate which subject that has the highest priority.
[e]Synthesise your answers on 1-4 and indicate the total importance and relevance of each subject for your country.

Completed by:
Name:
Country:
Specialisations:

Importance of the "Main fields of interest" in Europe at the national and regional level.

A. Multi-functionality of forests

		Importance in your country			Capacity to react through management and technical measures		
Factor	Region[a]	Major	Reduced	Minor	Integral	Partial	Reduced
A1. Agroforestry	N-NE	1	1	4	0	5	1
	C	1	1	5	0	3	3
	S	1		1	1	0	1
	Europe	***3***	***2***	***10***	***1***	***8***	***5***
A2. Biodiversity	N-NE	4	2	0	3	3	0
	C	5	2	0	4	3	0
	S	1	1	0	0	2	0
	Europe	***10***	***5***	***0***	***7***	***8***	***0***
A3. Carbon storage	N-NE	3	3	0	1	4	0
	C	6	1	0	2	3	2
	S	1	0	1	0	0	2
	Europe	***10***	***4***	***1***	***3***	***7***	***4***
A4. Game management	N-NE	2	3	1	4	1	1
	C	2	5	0	1	3	1
	S	1	1	0	1	1	0
	Europe	***5***	***9***	***1***	***6***	***5***	***2***
A5. Nature conservation	N-NE	5	1	0	5	1	0
	C	6	1	0	2	5	0
	S	2	0	0	1	1	0
	Europe	***13***	***2***	***0***	***8***	***7***	***0***
A6. Non-timber production	N-NE	1	5	0	4	0	2
	C	1	3	3	1	0	5
	S	1	1	0	1	1	0
	Europe	***3***	***9***	***3***	***6***	***1***	***7***
A7. Recreation	N-NE	4	1	1	3	2	1
	C	2	4	1	2	4	0
	S	1	1	0	1	1	0
	Europe	***7***	***6***	***2***	***6***	***7***	***1***
A8. Timber production	N-NE	5	1	0	4	2	0
	C	5	2	0	6	1	0
	S	1	1	0	1	1	0
	Europe	***11***	***4***	***0***	***11***	***4***	***0***
A9. Water management	N-NE	2	3	1	3	2	0
	C	6	1	0	3	4	0
	S	2	0	0	1	1	0
	Europe	***10***	***4***	***1***	***7***	***7***	***0***

[a]N-NE = Estonia, Finland, Latvia, Lithuania, Iceland, Sweden; C = Austria, Belgium, Czech Republic, Ireland, Netherlands, Romania, United Kingdom; S = Greece and Spain; Europe = N-NE+C+S

Importance of the "Main fields of interest" in Europe at the national and regional level.

A. Multi-functionality of forests

		Gaps in knowledge and management			Most urgent act in the scientific field
Factor	Region[a]	Equipment	Scientist	Political/ Financial	
A1. Agroforestry	N-NE	0	1	4	1
	C	0	2	5	0
	S	0	1	1	0
	Europe	***0***	***5***	***10***	***1***
A2. Biodiversity	N-NE	0	4	3	3
	C	0	6	3	3
	S	1	2	2	2
	Europe	***1***	***12***	***8***	***8***
A3. Carbon storage	N-NE	2	4	3	1
	C	1	4	3	3
	S	1	1	2	1
	Europe	***4***	***9***	***8***	***5***
A4. Game management	N-NE	1	3	4	0
	C	1	1	2	0
	S	0	2	2	1
	Europe	***2***	***6***	***8***	***1***
A5. Nature conservation	N-NE	0	1	5	1
	C	0	5	4	1
	S	0	0	1	1
	Europe	***0***	***6***	***10***	***3***
A6. Non-timber production	N-NE	1	1	4	1
	C	1	1	2	0
	S	0	2	2	1
	Europe	***2***	***4***	***8***	***2***
A7. Recreation	N-NE	0	1	6	0
	C	0	1	4	1
	S	0	0	1	1
	Europe	***0***	***2***	***11***	***2***
A8. Timber production	N-NE	1	2	4	3
	C	0	4	3	1
	S	1	1	2	0
	Europe	***2***	***7***	***9***	***4***
A9. Water management	N-NE	2	1	3	1
	C	1	5	3	4
	S	1	1	2	1
	Europe	***4***	***7***	***8***	***6***

[a]N-NE = Estonia, Finland, Latvia, Lithuania, Iceland, Sweden; C = Austria, Belgium, Czech Republic, Ireland, Netherlands, Romania, United Kingdom; S = Greece and Spain; Europe = N-NE+C+S

Importance of the "Main fields of interest" in Europe at the national and regional level.

B. Long-term trends in the environment

		Importance in your country			Capacity to react through management and technical measures		
Factor	Region[a]	Major	Reduced	Minor	Integral	Partial	Reduced
B1. Carbon dioxide	N-NE	4	2	0	1	5	0
	C	5	1	0	0	2	4
	S	1	1	0	0	1	1
	Europe	***10***	***4***	***0***	***1***	***8***	***5***
B2. Deposition of pollutants	N-NE	0	5	1	0	4	2
	C	5	1	1	0	5	2
	S	0	2	0	0	1	1
	Europe	***5***	***8***	***2***	***0***	***10***	***5***
B3. Extreme events	N-NE	1	4	1	0	4	2
	C	2	1	4	0	3	4
	S	1	1	0	0	1	1
	Europe	***4***	***6***	***5***	***0***	***8***	***7***
B4. Precipitation	N-NE	2	3	1	0	2	4
	C	2	1	4	0	2	5
	S	1	1	0	0	1	1
	Europe	***5***	***5***	***5***	***0***	***5***	***10***
B5. Temperature	N-NE	3	2	1	0	2	4
	C	1	2	4	0	2	5
	S	1	1	0	0	1	1
	Europe	***5***	***5***	***5***	***0***	***5***	***10***
B6. Trace gases	N-NE	1	4	1	1	1	4
	C	1	2	4	0	0	6
	S	0	2	0	0	1	1
	Europe	***2***	***8***	***5***	***1***	***2***	***11***
B7. Vegetation types	N-NE	1	5	0	0	6	0
	C	2	4	0	1	2	3
	S	1	1	0	0	1	1
	Europe	***4***	***10***	***0***	***1***	***9***	***4***

[a]N-NE = Estonia, Finland, Latvia, Lithuania, Iceland, Sweden; C = Austria, Belgium, Czech Republic, Ireland, Netherlands, Romania, United Kingdom; S = Greece and Spain; Europe = N-NE+C+S

Importance of the "Main fields of interest" in Europe at the national and regional level.

B. Long-term trends in the environment

Factor	Region[a]	Gaps in knowledge and management: Equipment	Scientist	Political/ Financial	Most urgent act in the scientific field
B1. Carbon dioxide	N-NE	3	2	3	3
	C	3	5	1	3
	S	2	1	2	1
	Europe	***8***	***8***	***6***	***7***
B2. Deposition of pollutants	N-NE	3	2	3	0
	C	2	5	3	3
	S	2	2	2	0
	Europe	***7***	***9***	***8***	***3***
B3. Extreme events	N-NE	2	2	2	1
	C	1	5	1	1
	S	1	1	2	1
	Europe	***4***	***8***	***5***	***3***
B4. Precipitation	N-NE	3	2	2	2
	C	0	3	0	0
	S	2	1	1	2
	Europe	***5***	***6***	***3***	***4***
B5. Temperature	N-NE	3	3	3	2
	C	1	2	0	0
	S	2	1	1	0
	Europe	***6***	***6***	***4***	***2***
B6. Trace gases	N-NE	4	2	2	0
	C	1	1	1	1
	S	2	1	1	0
	Europe	***7***	***4***	***4***	***1***
B7. Vegetation types	N-NE	1	0	5	2
	C	0	4	2	2
	S	0	2	1	1
	Europe	***1***	***6***	***8***	***5***

[a]N-NE = Estonia, Finland, Latvia, Lithuania, Iceland, Sweden; C = Austria, Belgium, Czech Republic, Ireland, Netherlands, Romania, United Kingdom; S = Greece and Spain; Europe = N-NE+C+S

Importance of the "Main fields of interest" in Europe at the national and regional level.

C. Land use and the role of forests

		Importance in your country			Capacity to react through management and technical measures		
Factor	Region[a]	Major	Reduced	Minor	Integral	Partial	Reduced
C1. Abandonment	N-NE	4	1	1	1	3	2
	C	2	1	4	0	2	4
	S	1	1	0	1	0	1
	Europe	***7***	***3***	***5***	***2***	***5***	***7***
C2. Afforestation	N-NE	3	2	1	3	2	1
	C	3	2	2	4	1	0
	S	1	1	0	1	1	0
	Europe	*7*	***5***	***3***	***8***	***4***	***1***
C3. Agriculture	N-NE	3	3	0	3	3	0
	C	4	2	1	2	2	1
	S	1	1	0	1	1	0
	Europe	***8***	***6***	***1***	***6***	***6***	***1***
C4. Agroforestry	N-NE	1	1	4	1	2	3
	C	1	1	5	0	1	4
	S	1	1	0	1	0	1
	Europe	***3***	***3***	***9***	***2***	***3***	***8***
C5. Planning	N-NE	5	0	0	4	1	0
	C	5	1	1	3	2	0
	S	1	1	0	1	1	0
	Europe	***11***	***2***	***1***	***8***	***4***	***0***
C6. Forestry/ Silviculture	N-NE	5	1	0	5	1	0
	C	6	0	1	5	0	1
	S	1	1	0	1	1	0
	Europe	***12***	***2***	***1***	***11***	***2***	***1***
C7. Livestock	N-NE	1	5	0	2	3	1
	C	3	4	0	2	3	0
	S	1	1	0	1	1	0
	Europe	***5***	***10***	***0***	***5***	*7*	***1***
C8. Set-a-side areas	N-NE	2	1	3	1	2	3
	C	2	5	0	2	3	0
	S	1	1	0	1	1	0
	Europe	***5***	*7*	***3***	***4***	***6***	***3***
C9. Soil degredation	N-NE	1	2	3	1	3	2
	C	3	1	3	1	3	3
	S	2	0	0	0	1	1
	Europe	***6***	***3***	***6***	***2***	*7*	***6***

[a]N-NE = Estonia, Finland, Latvia, Lithuania, Iceland, Sweden; C = Austria, Belgium, Czech Republic, Ireland, Netherlands, Romania, United Kingdom; S = Greece and Spain; Europe = N-NE+C+S

Importance of the "Main fields of interest" in Europe at the national and regional level.

C. Land use and the role of forests

		Gaps in knowledge and management			Most urgent act in the scientific field
Factor	Region[a]	Equipment	Scientist	Political/ Financial	
C1. Abandonment	N-NE	0	1	5	2
	C	0	1	2	1
	S	0	1	1	1
	Europe	***0***	***3***	***8***	***4***
C2. Afforestation	N-NE	0	0	5	2
	C	0	1	3	0
	S	0	1	1	2
	Europe	***0***	***2***	***9***	***4***
C3. Agriculture	N-NE	0	0	6	0
	C	0	1	2	3
	S	0	0	1	1
	Europe	***0***	***1***	***9***	***4***
C4. Agroforestry	N-NE	0	2	4	1
	C	0	0	2	0
	S	0	1	1	0
	Europe	***0***	***3***	***7***	***1***
C5. Planning	N-NE	0	4	4	2
	C	1	3	0	3
	S	0	1	1	2
	Europe	***1***	***8***	***5***	***7***
C6. Forestry/ Silviculture	N-NE	1	2	4	3
	C	0	3	4	2
	S	0	1	1	2
	Europe	***1***	***6***	***9***	***7***
C7. Livestock	N-NE	0	0	5	0
	C	0	3	2	0
	S	1	1	1	1
	Europe	***1***	***4***	***8***	***1***
C8. Set-a-side areas	N-NE	0	2	5	1
	C	0	3	2	0
	S	0	0	1	0
	Europe	***0***	***5***	***8***	***1***
C9. Soil degredation	N-NE	2	2	4	0
	C	0	4	1	1
	S	1	1	2	2
	Europe	***3***	***7***	***7***	***3***

[a]N-NE = Estonia, Finland, Latvia, Lithuania, Iceland, Sweden; C = Austria, Belgium, Czech Republic, Ireland, Netherlands, Romania, United Kingdom; S = Greece and Spain; Europe = N-NE+C+S

Importance of the "Main fields of interest" in Europe at the national and regional level.

D. Stochastic disturbances

		Importance in your country			Capacity to react through management and technical measures		
Factor	Region[a]	Major	Reduced	Minor	Integral	Partial	Reduced
D1. Avalanches	N-NE	0	0	6	1	1	4
	C	1	1	5	1	0	3
	S	0	0	2	0	0	2
	Europe	***1***	***1***	***13***	***2***	***1***	***9***
D2. Drought	N-NE	1	3	2	0	3	3
	C	2	2	3	1	1	4
	S	2	0	0	0	1	1
	Europe	***5***	***5***	***5***	***1***	***5***	***8***
D3. Fires	N-NE	1	1	4	3	1	2
	C	0	2	5	0	3	2
	S	2	0	0	1	1	0
	Europe	***3***	***3***	***9***	***4***	***5***	***4***
D4. Floods	N-NE	1	3	2	1	2	3
	C	3	3	1	1	5	1
	S	1	1	0	0	0	2
	Europe	***5***	***7***	***3***	***2***	***7***	***6***
D5. Harvest	N-NE	5	0	1	6	0	0
	C	2	4	1	1	3	2
	S	1	0	1	0	2	0
	Europe	***8***	***4***	***3***	***7***	***5***	***2***
D6. Herbivores	N-NE	1	5	0	2	3	1
	C	3	2	2	0	4	1
	S	1	0	1	0	2	0
	Europe	***5***	***7***	***3***	***2***	***9***	***2***
D7. Pathogens	N-NE	2	4	0	1	4	1
	C	1	6	0	0	4	2
	S	1	0	1	0	2	0
	Europe	***4***	***10***	***1***	***1***	***10***	***3***
D8. Storms	N-NE	3	3	0	1	3	1
	C	2	4	1	0	2	4
	S	0	1	1	0	0	2
	Europe	***5***	***8***	***2***	***1***	***5***	***7***
D9. Snow	N-NE	0	4	2	0	3	3
	C	3	1	3	0	2	4
	S	0	1	1	0	0	2
	Europe	***3***	***6***	***6***	***0***	***5***	***9***

[a]N-NE = Estonia, Finland, Latvia, Lithuania, Iceland, Sweden; C = Austria, Belgium, Czech Republic, Ireland, Netherlands, Romania, United Kingdom; S = Greece and Spain; Europe = N-NE+C+S

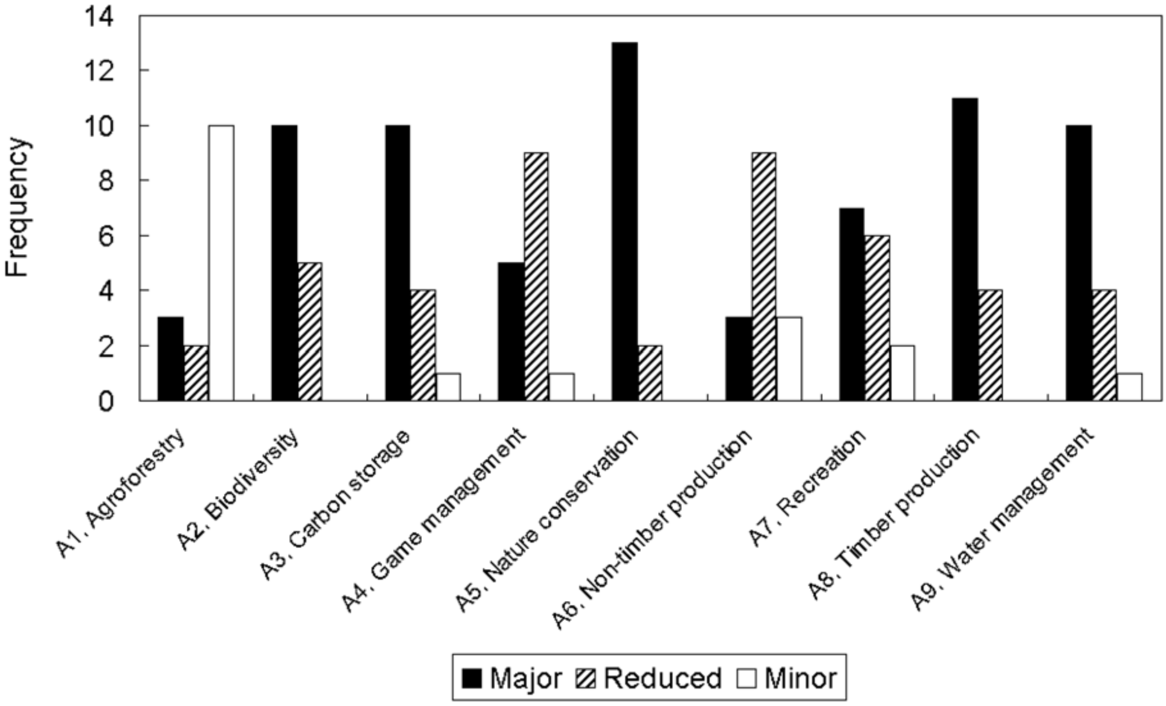
Importance of the "Main fields of interest" in Europe at the national and regional level.

D. Stochastic disturbances

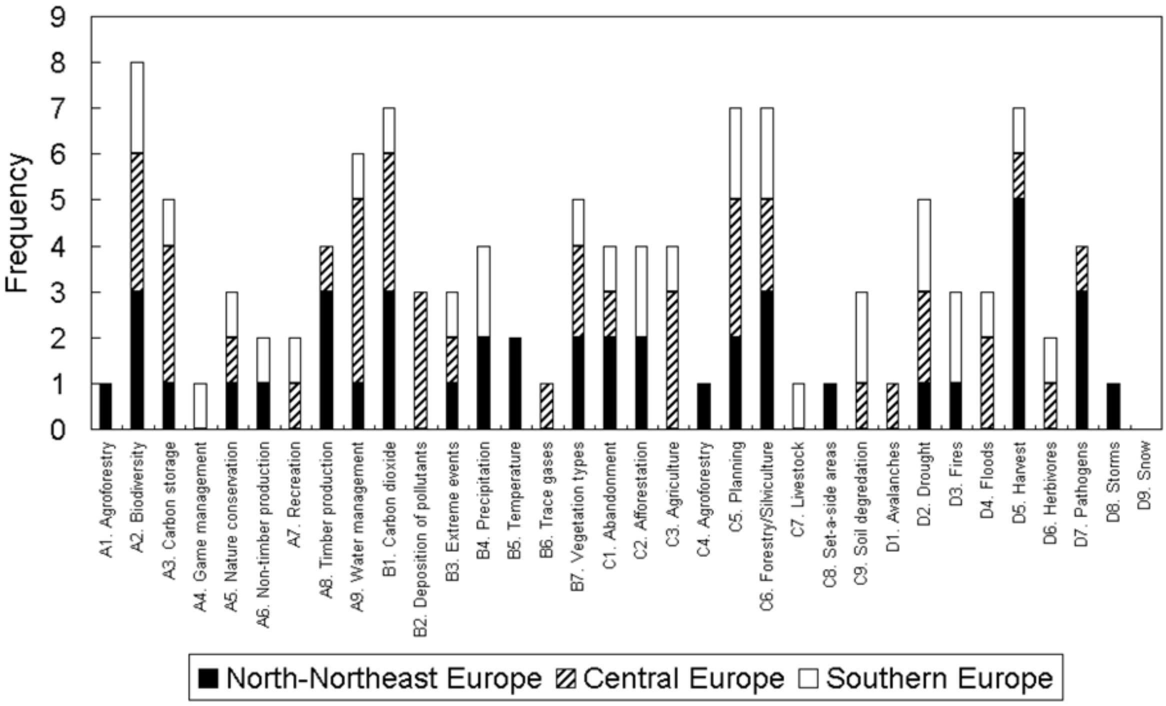
Factor	Region[a]	Gaps in knowledge and management: Equipment	Scientist	Political/ Financial	Most urgent act in the scientific field
D1. Avalanches	N-NE	2	1	2	0
	C	2	2	2	1
	S	2	2	0	0
	Europe	***6***	***5***	***4***	***1***
D2. Drought	N-NE	2	2	2	1
	C	1	3	2	2
	S	1	2	0	2
	Europe	***4***	***7***	***4***	***5***
D3. Fires	N-NE	0	2	3	1
	C	2	1	1	0
	S	0	1	1	2
	Europe	***2***	***4***	***5***	***3***
D4. Floods	N-NE	0	2	3	0
	C	1	4	3	2
	S	0	1	1	1
	Europe	***1***	***7***	***7***	***3***
D5. Harvest	N-NE	0	3	5	5
	C	1	2	1	1
	S	1	1	1	1
	Europe	***2***	***6***	***7***	***7***
D6. Herbivores	N-NE	1	1	4	0
	C	0	1	4	1
	S	0	2	1	1
	Europe	***1***	***4***	***9***	***2***
D7. Pathogens	N-NE	0	2	3	3
	C	4	3	2	1
	S	1	1	1	0
	Europe	***5***	***6***	***6***	***4***
D8. Storms	N-NE	0	2	4	1
	C	2	3	3	0
	S	2	2	0	0
	Europe	***4***	***7***	***7***	***1***
D9. Snow	N-NE	0	3	4	0
	C	2	2	3	0
	S	2	2	0	0
	Europe	***4***	***7***	***7***	***0***

[a]N-NE = Estonia, Finland, Latvia, Lithuania, Iceland, Sweden; C = Austria, Belgium, Czech Republic, Ireland, Netherlands, Romania, United Kingdom; S = Greece and Spain; Europe = N-NE+C+S

Importance of the "Main fields of interest" in Europe at the national and regional level.



Importance of the major functions of European forests as estimated by 15 European countries.



Ranking of the factors within each "Main fields of interest" that has the highest research priority among 15 European countries. N-NE = Estonia, Finland, Latvia, Lithuania, Iceland, Sweden; C = Austria, Belgium, Czech Republic, Ireland, Netherlands, Romania, United Kingdom; S = Greece and Spain