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"MANAGEMENT TOOLS FOR IMPROVING FOREST ECOSYSTEM SERVICES AND PROMOTING SUSTAINABLE FOREST MANAGEMENT AT LOCAL LEVEL"

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List of abbreviations

ACRA	Cooperazione Rurale in Africa e America Latina
ADR	Apical Dominance Ratio
ATO	African Timber Organization
BD	Birds Directive
C&I	Criteria and Indicator
CBD	Convention on Biological Diversity
CE	Commission Errors
CICI	International Conference on Criteria and Indicators
CIRPS	Interuniversity Research Centre on Sustainable Development
CLC	Corine Land Cover
COP	Conference of the Parties
DEM	Digital Elevation Model
EA	Ecosystem Approach
EC	European Commission
ECCI	Expert Consultation on Criteria and Indicators
EEA	European Environment Agency
EU	European Union
FAO	Food and Agriculture Organization
FDU	Forest Destination Unit
FRA	Forest Resources Assessment
GHG	Greenhouse Gas
GIS	Geographic Information System
GPS	Global Position System
HD	Habitats Directive
IAN	Indicators Analytic Network
IFF	Intergovernmental Forum on Forests
Iov	Objectively Verifiable Indicators
IPF	Intergovernmental Panel of Forests
Ir	Regeneration Index
ISTAT	Italian National Institute of Statistics
ITTO	International Tropical Timber Organization
IUCN	International Union for Conservation of Nature
KIA	Kappa Index Agreement
k-NN	k-nearest neighbor
LMOs	Living Modified Organisms
MaB	Man and Biosphere
MCDA	Multi Criteria Decision Analysi
MCML	Multi Criteria Multi Level
MCPFE	Ministerial Conference on the Protection of Forests in Europe
MEA	Millennium Ecosystem Assessment
NFP	National Forest Programme
NGOs	Non-Governmental Organizations
NWFP	Non Wood Forest Product
OA	Overall accuracy
OE	Omission Errors

PA	Producer Accuracy
POPs	Persistent Organic Pollutants
Q	Quartile
QLA	Logical Framework of Action
RFP	Regional Forest Plan
SCI	Site of Community Importance
SD	sustainable development
SFM	sustainable forest management
SICER	*Systeme d'Information, Communication and Evaluation des résultats*
SPA	Special Protected Area
SQL	Structured Query Language
TFP	Territorial Forest Plan
UA	User Accuracy
UFP	Unit Forest Plan
UN	United Nations
UNCED	United Nations Conference on the Environment and Development
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFF	United Nations Forum on Forests
WCED	World Commission on Environment and Development
WHO	World Health Organization
WSSD	World Summit on Sustainable Development

Abstract

After the Brundtland report and the United Nations Conference on Environment and Development (UNCED) in 1992, the concept of sustainable development was adopted in the forest arena, recognizing the importance of forest to the whole world. As a consequence, forest management was changed going from sustainability, in terms of sustainable use of the timber production, to the multifunctional role of forests and up to the definition of the concept of Sustainable Forest Management (SFM).

The acknowledgement of the multifunctional role of forest has led to the increase of the importance of forest resources, and forestry has become a very complex field. The numerous benefits that society receives from forests result in the increased interest of stakeholders, which are often in conflict. The increase of pressure on the demand for multiple uses of forest in the same lands has emphasized the need of new tools for forest management. In response to these issues, many efforts have been made by researchers, although there is still much to do and to learn, because of the current global issues concerning climate change, loss of biodiversity, water scarcity and energy.

SFM plays a crucial role for maintaining healthy, diverse and productive forests ensuring the supply of forest services for human needs. Forest planning represents a very important tool to support SFM, but often the traditional knowledge and management tools are not capable of satisfying all the stakeholders' needs.

The formulation of Forest Management Plans, that are acceptable to all stakeholders, requires the balancing of the different interests and decisions because makers have to meet multiple objectives, or in order to get an acceptable balance if objectives conflict. Hence a large scale management, such as the landscape management is required for a better understanding of the joint production or multiple benefits which forest ecosystems provide to human welfare.

In the latest years, new tools of forest planning have been developed, with particular emphasis at the ecosystem approach and on the importance of the scale management. Territorial Forest Plan (TFP) represents a new and helpful tool of forest planning to support SFM, aiming to the improvement of the ecological connectivity and ensuring the production of forest ecosystem services.

This work stresses the important role of forest planning at territorial level, with particular emphasis on the Natura 2000 site, for allowing the production of ecosystem services such as biodiversity conservation and the water conservation in terms of quality and quantity.

Furthermore, it shows three main tools to support SFM with three different case studies. Firstly it demonstrates the role of Geographic Information System (GIS) technologies in monitoring sustainable management model of forest resources in the Logone Valley between Chad and Cameroon (Africa). The second describes the Multi Criteria Decision Analysis approach for mapping forest area with the same priority forest function. Finally, the participatory approach through the application of Indicators Analytic Networks has been described.

General Introduction

Progress towards Sustainable Forest Management

The relevant role that forests play in modern society is widely recognized and the need for a better management of forest resources is highly required. Forests produce raw material for renewable and environmentally friendly products and play an important role in the global climate and carbon cycle, biological diversity and water balance (FOREST EUROPE et al. 2011). Since the 1990s, sustainable forest management (SFM) has become a highly relevant topic both in forest and environmental policies, due to the fact that forest lands provide a wide range of environmental, economic and social benefits.

The term "Sustainable Forest Management" (SFM) was coined in 1992, deriving from the Forest Principles[1] of the United Nations Conference on the Environment and Development (UNCED). Since then, the concept of SFM is generally defined as a balance between the social, economic and environmental values associated with forest resources, with some considerations of these values for future generations (Gordon M. Hickey 2008). Nevertheless, there are varying definitions of SFM used all around the world. At European level, the concept of SFM has been developed by FOREST EUROPE and contains guidelines and criteria to ensure the optimal balance of forest goods and services. SFM is considered as an efficient tool to help countries and local communities achieve an appropriate equilibrium between the multitudinous needs of society. For this reason, SFM is still an evolving process, and the parameters defining it, change over time because based on the latest scientific knowledge and society's understanding of the concept (Wolfslehner & Seidl 2010).

In response to these issues, new Forest Planning approaches have been required and to date several efforts have been made to implement SFM and to assess the progress towards SFM. Forest Management Planning is the main activity affecting the forest landscape, and it aims to reduce the negative environmental impacts of forest due to human activities (Côté et al. 2010). Furthermore, the modern objectives of forest management planning are to reduce the fragmentation of forest lands, by promoting the ecological connectivity in order to maintain the complexity of landscapes and biodiversity, which allows supplying the ecosystem services more efficiently (Andreella et al. 2010). For these reasons, Forest Planning has to take into account new space-time scales within which human and environmental phenomena occur (C.J. Walters & Holling 1990).

Despite Forest Management Planning is the main tool of SFM, without measurable indicators which allow examining the consequences of the various temporal and spatial scales, it is difficult to assess the planning system toward SFM (R. Tittler et al. 2001).

For this reason and in conformity with the international consensus of forest issues which encourage SFM, seven common thematic elements have been identified and numerous sets of Criteria and indicators (C&I) have been developed in order to assess, monitor and report on forest resource (Wijewardana 2008) and for assessing progress towards SFM (FRA 2010).

This chapter introduces the main steps towards the SFM, starting from the concept of Sustainable Development (SD), then applying the concept of SFM and introducing the C&I implementation. It concludes with the description of a conceptual framework of the thesis, describing its main objectives.

[1] The full title is the Non-legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of All Types of Forests.

The concept of sustainable development

Sustainable Development (SD) has become a widely recognized goal for human society ever since deteriorating environmental conditions in many parts of the world indicate that its sustainability may be at stake (Bossel 1999).
SD is a fundamental and overarching objective at a global level, and it aims to continuously improve the quality of life and wellbeing for present and future generations, by linking economic development, protecting the environment and advocating social human rights.
Sustainable development has been defined in many ways, but the most frequently quoted definition is taken from *Our Common Future*, also known as the Brundtland Report (Brundtland 1987). The World Commission on Environment and Development (WCED) defined Sustainable Development as:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

It contains within it, two key concepts:

1. *the concept of* ***needs****, in particular the essential needs of the world's poor, to which overriding priority should be given;*
2. *the idea of* ***limitations*** *imposed by the state of technology and social organization on the environment's ability to meet present and future needs.*

The report, *Our Common Future*, published by WCED, is taken as a starting point for most discussions on the concept of sustainable development, even if, there had been some significant conceptual precursors that led to the WCED's definition of sustainable development, which in turn was followed by other conceptualization efforts (Mebratu 1998). Before the WCED 1987, already in the 1972, the United Nations Conference on Human Environment in Stockholm, recognized the "*importance of environmental management and the use of environmental assessment as a management tool*", and represents a major step towards the development of the concept of sustainable development.

After WCED 1987, SD has increasingly become the core element of environmental issues, leading to a very broad acceptance of its meaning with very diverse interpretations. After that, thousands of initiatives have been taken at local, national, and global levels in an attempt to address different aspects of the environmental challenges. The other milestone concerning SD, after WCED, was the United Nations Conference on Environment and Development (UNCED), which is also known as the "Rio Conference," or the "Earth Summit" held in Rio de Janeiro in June 1992. UNCED led to the production of major international documents such as the Rio Declaration, Agenda 21, Forest Principles and conventions on desertification, biodiversity, and climate change. UNCED recognized the integral and interdependent nature of the Earth, our home, and proclaimed 27 principles intended to guide the future sustainable development around the world.

Other relevant initiatives towards the sustainable development are represented by:

- ✓ The Kyoto protocol, initially adopted in 1997 and entirely adopted in 2005. It is a protocol on climate change and focuses on the reduction of greenhouse gas (GHG) emissions.
- ✓ The United Nations Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-Making, and Access to Justice in Environmental Matters. It was adopted on 25 June 1998 in the Danish city of Aarhus at the Fourth Ministerial

Conference as part of the "Environment for Europe" process. The Aarhus Convention establishes a number of public rights for individuals and their associations in regards to the environment.

- ✓ The *Millennium Declaration* adopted in 2000 by the United Nations which consists of eight chapters and key objectives, adopted by 189 world leaders, during the Millennium summit.
- ✓ The *Cartagena Protocol on Biosafety to the Convention on Biological Diversity* which is an international agreement and aims to ensure the safe handling, transport and use of Living Modified Organisms (LMOs) resulting from modern biotechnology that may have adverse effects on biological diversity, taking also into account risks on human health. It was completed and adopted in Montreal on 29 January 2000 at an extraordinary meeting of the Conference of the Parties.
- ✓ The Stockholm Convention on Persistent Organic Pollutants which is an international environmental treaty, signed in 2001 and aims to eliminate or restrict the production and the use of persistent organic pollutants (POPs).
- ✓ The International Conference on Financing for Development held in Monterey, Mexico in 2002.
- ✓ The World Summit on Sustainable Development, Johannesburg Summit 2002, which brought together tens of thousands of participants, including heads of State and Government, national delegates and leaders from non-governmental organizations (NGOs), businesses and other major groups in order to focus the world attention and to direct action on meeting difficult challenges, including improving people's lives and conserving natural resources in a world that is growing in population, with an ever-increasing demand for food, water, shelter, sanitation, energy, health services and economic security.

Although the general definition of sustainability touches upon nearly all areas of economic, ecological and social development, three main management rules of resource use have derived from it (Daly 1990):

1. *Harvest rates of renewable resources should not exceed regeneration rates;*
2. *Waste emissions should not exceed the relevant assimilative capacities of ecosystems;*
3. *Non-renewable resources should be exploited in a quasi-sustainable manner by limiting their rate of depletion to the rate of creation of renewable substitutes.*

Sustainability is a dynamic concept, because societies and their environments change, technologies and cultures change, values and aspirations change. For these reasons, a sustainable society must allow and sustain such changes (Bossel 1999).

Sustainable Forest Management

Forests are generally managed to fulfill several functions simultaneously according to the principles of sustainability. However, it is difficult to explicitly define what sustainable forest management is (Adamowicz & P. J. Burton 2003) and there are many SFM definitions in the whole world. The concepts underlying the post-Brundtland which drive towards SFM have been relatively well defined since 1995, even if, the origin of “Sustainability” was first mentioned in a Saxonian forest law in the 17th century and later described by H.C. von Carlowitz 1713 in (Requardt 2007; Kloepffer 2008).

Since UNCED 1992, following the adoption of the *Forest Principles*, developments in Forest management have focused on progress towards Sustainable Forest Management (SFM), as an approach that balances environmental, socio-cultural and economic objectives of management in line with the *Forest Principles.*

Forest Principles and Chapter 11 of Agenda 21, which were the prominent results from UNCED traced the term of the SFM. In particular, the guiding objective of *Forest Principles* is to contribute to the management, to the conservation and to the sustainable development of all type of forests and to provide for their multiple and complementary functions and uses. Principle 2b specifically states that:

"Forest resource and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations."

The concept of SFM has continued to evolve since 1992 through the international forest policy dialogue within Intergovernmental Panel of Forests (IPF), Intergovernmental Forum on Forests (IFF) and United Nations Forum on Forests (UNFF) and through a large number of country-led and eco-regional initiatives aiming at translating the concept into practice, including the development of Criteria and Indicators (C&I) for SFM supported by international organizations such as the Food and Agriculture Organization of the United Nations (FAO), the International Tropical Timber Organization (ITTO), the FOREST EUROPE and other members of the Collaborative Partnership on Forests.

The definition of SFM which has been commonly accepted in Europe was gained by FOREST EUROPE in 1993, during the second Ministerial Conference on the Protection of Forest in Europe, held in Helsinki, Finland. The discussions resulted in Resolutions H1[2] and H2[3] which set out general guidelines for the sustainable management of forests in Europe and the protection of their biodiversity.

In particular Resolution H1 defines for the first time SFM as:

"The stewardship and use of forest lands in a way, and 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."

The concept of SFM has influenced many initiatives, leading to the revision of forest policies and practices, and has been mainstreamed by local, national and international forestry organizations. Furthermore, the relationship between forests and other ecosystems has been increased over the years recognizing the SFM as a tool for application of ecosystem approach (EA). The EA is closely related to systemic silviculture (Corona 2010; Marchetti 2011), as a strategy to promote the sustainable use of environmental resources, such as forests.

However, modern expectations of society have shifted the objective of SFM towards the conservation and the socio-cultural objectives such as biodiversity, carbon storage, climate change and recreational activity. These issues have also been recognized in the EU Forest Action Plan, within which the Commission and the Member States have developed a common vision of forestry and the contribution which forests and forestry make to modern society:

Forests for society: long-term multifunctional forestry fulfilling present and future societal needs and supporting forest-related livelihoods.

Forests make a positive contribution to the quality of life, because they provide a pleasant living environment, and offer opportunities for recreation and preventive healthcare, while maintaining and enhancing environmental amenities and ecological values. It is also important for forests to maintain the spiritual and cultural heritage they contain. This can be achieved through the application of the appropriate

[2] H1: General Guidelines for the Sustainable Management of Forests in Europe.
[3] H2: General Guidelines for the Conservation of Biodiversity of European Forests.

tool of monitoring of SFM such as C&I and the Forest Management Planning with the appropriate scale such as the landscape level (C.J. Walters & Holling 1990; R. Tittler et al. 2001).

The implementation of the Criteria and Indicators (C&I) for SFM

In the past 20 years, as a result of several initiatives about sustainable development, numerous criteria and indicator sets for sustainable management have been proposed, as highlighted in the Agenda 21:

> *"…indicators of sustainable development need to be developed to provide solid bases for decision-making at all levels and to contribute to a self-regulating sustainability of integrated environment and development systems."*

Subsequently many studies have been dedicated to the implementation of the C&I sets and afterwards to their selection and assessment (Pokorny & Adams 2003).
In forestry, criteria and indicators are commonly recognized by the Intergovernmental Panel on Forests (1995-1997) and its successor Intergovernmental Forum on Forests (1997-2000), the United Nations Forum on Forests (UNFF), and the Food and Agriculture Organization of the United Nations (FAO), as appropriate tools for defining, assessing and monitoring progress towards SFM, and for supporting the decision making processes (MCPFE 2007).

Criteria and indicators (C&I) are a powerful tool in implementing SFM (Wijewardana 2008; Wolfslehner & Vacik 2011). C&I characterize the essential components of SFM, and provide information for the formulation of sound policies. Furthermore, they recognize forests as ecosystems that provide a wide, complex and dynamic array of environmental and socio-economic benefits and services. C&I can be used to monitor and assess national trends in forest conditions and forest management at a range of scales (Wijewardana 2008).

The common definition of C&I is:

a) ***criterion*** *is a category of conditions or processes by which sustainable forest management may be assessed. It is characterized by a set of related indicators that can be monitored periodically to assess change.*
b) ***indicator*** *is a measure of an aspect of the criterion. It can be a quantitative or qualitative variable that can be measured or described, and when observed periodically, can demonstrate a trend.*

International initiatives

Since the UNCED 1992, a number of international initiatives has promoted monitoring and information reporting for sustainable forest management (G. M Hickey et al. 2005). The importance placed on the development and the implementation of C&I for SFM by countries has resulted during the past several years in the development of nine separate but conceptually linked initiatives (Requardt 2007).
Already in March 1992, the International Tropical Timber Organization (ITTO) has published the first set of C&I as Criteria for the measurement of sustainable tropical forest management. This set of C&I has been revised in 2005 (ITTO, 2005);
In 1993 the African Timber Organization (ATO) identified five principles, 28 criteria and 60 indicators for sustainable forest management, to be applied at regional, national and forest management unit levels (Castañeda 2000).
Afterwards the development of "Criteria and Indicators" process, termed the Canadian Process and published in March 1995, is considered to be an important step in meeting Canada's domestic commitments on sustainable forest management. They serve as a framework for describing and measuring

the state of Canadian forests, for implementing adaptive forest management, and assessing progress toward sustainability (Hall 2001). Since the Canadian Process, the six criteria and the 83 indicators that have been identified emphasize the multifunctional role of forests taking in consideration also the Aboriginal values.

At same time at the Montreal Process, in 1995, the was the establishment of seven non-legally binding national level criteria and 67 indicators applicable to temperate and boreal forests to be used by policy-makers at national level. Although the criteria strongly resemble the goals, concepts and conditions in the Canadian Process, the seventh criterion in the Montreal Process reports on the infrastructure and institutions that want to implement and monitor sustainable forest management (Hall 2001). In Buenos Aires, 2007 the Working Group approved a revised set of indicators for Criteria 1-6[4].

In 1995, both *Dry – Zone Africa Process* (Nairobi, Kenya) and *Tarapoto Proposal for Criteria and Indicators for Sustainability of the Amazon Forest* (Tarapoto, Peru) have been identified seven national level criteria and 47 indicators (Castañeda 2000) (UNEP/FAO 1996).

Other major international processes on C&I are *Near East Process* (Cairo, Egypt, 1996) in which seven national level criteria and 65 indicators were identified, and *Leparterique Process of Central America* in 1997 in which eight national level criteria and 53 indicators were identified (Raison et al. 2001). In 1999 the Dry Zone Asia Initiative process identified eight national level criteria and 49 indicators for the sustainable management of dry forests in the region (Castañeda 2000).

International efforts to promote C&I have recently (2006) culminated in two high level expert meetings: the International Conference on Criteria and Indicators (CICI) in Guatemala in 2003 (CICI 2003); and the Expert Consultation on Criteria and Indicators for Sustainable Forest Management (ECCI) in the Philippines in 2004 (ECCI 2004). Participants identified seven thematic elements of SFM common to all nine regional and international C&I processes:

1) *Extent of forest resources;*
2) *Biological diversity;*
3) *Forest health and vitality;*
4) *Productive functions of forest resources;*
5) *Protective functions of forest resources;*
6) *Socio-economic functions;*
7) *Legal, policy and institutional framework.*

These seven thematic elements, were acknowledged by UNFF, CICI and FAO in 2003, while in 2004, ECCI recognized that these elements were important for facilitating international communication on forest-related issues. The thematic elements are also used in the FAO-led global Forest Resources Assessment (FRA) as a reporting framework.

Following is a brief explanation for each thematic element:

1) Extent of forest resources

The theme expresses an overall desire to have significant forest cover and stocking, including trees outside forests, to support the social, economic and environmental dimensions of forestry. For example, the existence and extent of specific forest types are important as a basis for conservation efforts. The theme encompasses ambitions to reduce deforestation and to restore and rehabilitate degraded forest

[4] Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests

landscapes. This theme also includes the important function of forests and trees outside forests to store carbon and thereby contribute to moderating the global climate.

2) Biological diversity

The theme concerns the conservation and management of biological diversity at the ecosystem (landscape), species and genetic levels. Such conservation, included to protect areas with fragile ecosystems, ensures that diversity of life is maintained, and provides opportunities to develop new products, for example medicines, in the future. Genetic improvement is also a means to improve forest productivity, for example to ensure high wood production in intensively managed forests.

3) Forest health and vitality

Forests need to be managed so that risks and impacts of unwanted disturbances are minimized, including wildfires, airborne pollution, storm felling, invasive species, pests, diseases and insects. Such disturbances may have an impact on social, economic as well as environmental dimensions of forestry.

4) Productive functions of forest resources

Forests and trees outside forests provide a wide range of wood and non-wood forest products (NWFP). The theme expresses the ambition to maintain a high and valuable supply of primary forest products, while at the same time it ensures that production and harvesting are sustainable and do not compromise management options of future generations.

5) Protective functions of forest resources

The theme addresses the role of forests and trees outside forests to help moderate soil, hydrological and aquatic systems. This includes maintaining clean water including e.g. healthy fish populations, as well as reducing risks or impacts of floods, avalanches, erosion and droughts. Protective functions of forest resources also contribute to ecosystem conservation efforts. Protective functions of forest resources have strong cross-sectorial aspects, as the benefits to agriculture and rural livelihoods are high.

6) Socio-economic functions

The theme addresses the contributions of forest resources to the overall economy, for example through employment, values generated through processing and marketing of forest products and energy, trade, and investments in the forest sector. The theme also addresses the important functions of forest to host and protect sites and landscapes that have high cultural, spiritual or recreational values, and thus includes aspects of land tenure, indigenous and community management systems, and traditional knowledge.

7) Legal, policy and institutional framework

The theme includes the legal, policy and institutional arrangements necessaries to support the above six themes, including participatory decision making, governance and law enforcement, and monitoring and assessment of progress. The theme also addresses broader societal aspects, including fair and equitable use of forest resources, science research and education, infrastructure arrangements to support the forest sector, transfer of technology and capacity building, and public information and communication.

European initiatives

In Europe the main driving force involved in the implementation of C&I set for SFM is FOREST EUROPE[5]. It is the highest forest policy process, addressing all dimensions of SFM. Since the '90s six FOREST EUROPE have taken place (1990 in Strasbourg, 1993 in Helsinki, 1998 in Lisbon, 2003 in Vienna, 2007 in Warsaw and 2011 in Oslo).

The Second FOREST EUROPE, held in Helsinki in 1993, confirmed the commitment of the European forest ministers to cooperate in promoting the protection of forests in Europe. In the follow up process of the

[5] FOREST EUROPE: Former MCPFE (Ministerial Conference on the Protection of Forests in Europe).

Helsinki Conference, the pan-European criteria and indicators were developed to promote and assess progress towards SFM in Europe.

The first effort in order to identify these criteria and indicators was made in the informal technical follow-up meeting held in Brussels in March 1994. Based on the proposals and on the discussions of different countries, the meeting agreed on a draft set of 14 criteria grouped into four categories. The concepts of criterion and indicator were not very clear in the early stages of the work, so the draft set was further developed by the General Coordinating Committee of the follow-up process with the assistance of a Scientific Advisory Group. This draft was then distributed for comments to the signatories of Resolutions H1 and H2 and to the observer states and organizations. Based on the comments which were received, a third draft was prepared for the first expert level follow-up meeting. In June 1994 the core set of 6 criteria and 27 quantitative indicators for sustainable forest management in Europe was adopted in the first expert level follow-up meeting in Geneva.

The first effort to test the suitability of the adopted Pan-European criteria and quantitative indicators and to gather information was carried out in 1994 – 1995 through a questionnaire in which the 27 quantitative indicators were further specified into 44 questions. This questionnaire was sent out to 38 European countries in September 1994. Preliminary results from the questionnaire enquiry were presented in the Interim Report of the Follow-up of the Second Ministerial Conference in March 1995 (Helsinki 1995).

The experiences carried out with the questionnaire showed that the results from different countries were not easily comparable. There is a strong need to broaden the data collection in order to monitor the whole forest ecosystem and to integrate environmental aspects and socio-economic data into forest statistics. Further development is required in the definition of terms and in the harmonization of classifications if data from different countries are to be comparable and the research needs are greatest for measuring and monitoring biological diversity and socioeconomic aspects of forestry.

The Third Ministerial Conference on the Protection of Forests in Europe was held in Lisbon, Portugal on 2-3 June 1998. The Conference evaluated the progress in the implementation of the Helsinki Resolutions and in order to complement Resolutions H1 and H2, the ministers adopted Resolution L1 "People, Forests and Forestry - Enhancement of Socio-Economic Aspects of Sustainable Forest Management". The ministers also gave a high political status on the pan-European criteria, indicators and operational level guidelines by adopting Resolution L2 "Pan-European Criteria, Indicators and Operational Level Guidelines for Sustainable Forest Management".

The ministers adopted the pan-European criteria for SFM and endorsed the related indicators as a basis for international reporting and for the development of national indicators. The ministers also decided to develop a work programme for the implementation of the decisions of the Lisbon Conference and for the improvement of the pan-European indicators.

In the follow up of the Third Ministerial Conference the issue of improving the pan-European criteria and indicators for SFM received a high priority in the overall work.

A questionnaire on the ”Improvement of Pan-European Indicators for Sustainable Forest Management, Data Collection and Reporting” was elaborated by the Liaison Unit and sent to the signatories and observers of the MCPFE in July 1999.

The questionnaire showed that the Criteria 4 (”Biological Diversity”), 5 (”Protective Functions”) and 6 (”Other Socio-Economic Functions and Conditions”) were not covered in a satisfactory way by existing indicators.

Furthermore, what was stated was the need for further clarification and improvement of terms and definitions and the usefulness of exploring possibilities of further aggregation of data, notably for better

communication to decision makers and the public, as well as of enhancing comparability and compatibility of the pan-European C&I with existing sets of C&I for SFM of other international and regional initiatives.
After Lisbon 1998 the represented countries committed themselves to "*proceed to implement, continuously review and further improve the associated indicators*" (Requardt 2007).
Then, an MCPFE Advisory Group was formed to assist the MCPFE during the improvement process. After four Advisory Group Meetings, Triesenberg Liechtenstein, March 2001; Copenhagen Denmark, September 2001; Budapest Hungary, January 2002; Camigliatello Silano Italy, May 2002, and one Expert Level Meeting in Vienna 2002 the work resulted in an **Improved C&I catalogue – containing 6 criteria and 35 associated quantitative indicators as well as additional qualitative indicators** (MCPFE 2002)**.** At the fourth MCPFE held in Vienna in 2003 a revised set of 35 indicators was officially adopted (MCPFE 2003). The list of the current set of Pan European C&I is showed in the figure 1.

The criteria describe the different elements and goals of sustainable forest management:

1) *Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles;*
2) *Maintenance of forest ecosystems' health and vitality;*
3) *Maintenance and encouragement of productive functions of forests (wood and non-wood);*
4) *Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems;*
5) *Maintenance, conservation and appropriate enhancement of protective functions in forest management (notably soil and water); and*
6) *Maintenance of other socio-economic functions and conditions.*

C1-Forest Resources & Carbon	1.1	Forest area
	1.2	Growing stock
	1.3	Age structure and/ or diameter distribution
	1.4	Carbon stock
C2-Health & Vitality	2.1	Deposition of air pollutants
	2.2	Soil condition
	2.3	Defoliation
	2.4	Forest damage
C3-Productive Functions	3.1	Increment and fellings
	3.2	Roundwood
	3.3	Non-wood goods
	3.4	Services
	3.5	Forests under management plans
C4-Biodiversity	4.1	Tree species composition
	4.2	Regeneration
	4.3	Naturalness
	4.4	Introduced tree species
	4.5	Deadwood
	4.6	Genetic resources
	4.7	Landscape pattern
	4.8	Threatened forest species
	4.9	Protected forests
C5-Protective Functions	5.1	Protective forests – soil, water and other ecosystem functions
	5.2	Protective forests – infrastructure and managed natural resources
C6-Socio-Economic Functions	6.1	Forest holdings
	6.2	Contribution of forest sector to GDP
	6.3	Net revenue
	6.4	Expenditures for services
	6.5	Forest sector workforce
	6.6	Occupational safety and health
	6.7	Wood consumption
	6.8	Trade in wood
	6.9	Energy from wood resources
	6.10	Accessibility for recreation
	6.11	Cultural and spiritual values

Figure 1: Set of Criteria and Indicators (C&I) for SFM adopted in the fourth MCPFE and current used at Pan European level.

Since the first set of Pan-European Indicators for SFM has been developed in the early '90s, it was immediately acknowledged as a very important tool for European forest policy (Castañeda 2000; MCPFE 2002; Requardt 2007) and for supporting forest decision makers.

Forest management planning

In line with international efforts to encourage SFM and with the increasing pressure on the forest resource, due to the demand for a multiple use of forest management, Forest Management Planning has become a very important tool of SFM. Not only has the attention on the environmental issues, such as climate change, carbon sequestration and biodiversity increased in the last decades, but also, the socio-cultural

aspects have gained more importance in the forest arena, and many questions and concerns regarding the Forest Management Planning framework have been made. Although the classic hierarchical framework of Forest Planning, within which the main aim is to stress the SFM at all levels, the need for new approaches of forest planning has been increasing in the last decades, as many authors have pointed out (R. Tittler et al. 2001; Chan et al. 2006; Wolfslehner & Seidl 2010).
The current issues of forest management focus on the landscape level processes and interactions, and consequently the importance of scale has risen. Moreover natural regeneration, mortality and disturbance processes have been included in the Forest planning aims and recently the holistic approach has become the new view of modern Forest Management concepts, acknowledging forests as a complex system. Therefore, land use specialization might be required allowing an efficient multiple use of forest (Vincent & Binkley 1993; Zhang 2005).
For this reason, new spatial scales of planning, the active participation of stakeholders in decision making and new methodologies have been used for a better allocation of specific land to alternatives of forest functions (T. Pukkala 2002; Hobbs 2003; Wolfslehner & Seidl 2010).

Starting from these issues, the main topic of the thesis is to identify new management tools for improving forest ecosystem services and promoting SFM at local level.

Outline of the thesis

Since 1992, following the United Nation's Conference on the Environment and Development (UNCED), the multifunctional role that forest resources play on a global scale, in the mitigation of the effects of climate change, in the conservation of biodiversity, in the relationship with water quality and quantity and in the correct function of the biogeochemical cycles has been reinforced (Marchetti 2011). In the same way at local scale the role that forests play in the local economies, in the safeguard of socio economic aspects, in the historical, cultural, educational and tourism value have gained more attention by both owners and decision-makers.

Since the forest ecosystems provide a lot of benefits to society, due to the numerous goods and services that forests supply, the forest ecosystems can be recognized as of vital importance for human wellbeing (Daily 1997). Since different stakeholders perceive different benefits from the same ecosystem processes, they can at the same time be conflicting (Hein et al. 2006), and the ecosystems, such as the forests, are continuously undergoing strong pressure. For this reason, sometimes the traditional knowledge and management tools are not capable of satisfying all the stakeholders' needs (Reynolds 2007; Chan et al. 2006). Therefore, forest management must be continuously developed and adapted to new issues and changes in line with the numerous stakeholders' expectations and the new social and environmental expectations, such as biodiversity and climate change. In response to these issues, several efforts have been made to reconsider the forest management in relation to society change which acknowledges forests as a complex multifunctional system (Wolfslehner & Seidl 2010).

Forestry issues strongly depend on the type of society and of the development model within which they are located (Mermet & Farcy 2011). Forest Management Planning represents the centre of negotiating potential conflicts among individual objectives, land users, land users forms and other stakeholders. For these reasons, Forest Management Planning plays a particular relevant role in contemporary management concepts (Carl J. Walters & Holling 1990; K. V. Gadow et al. 2001), where the planning objectives could be expressed in terms of production of goods and services such as Timber, Fuelwood, Non-Wood Forest Product (NWFP), Water quality and quantity, Climate regulation, Carbon storage, Pollination, Amenity values, Cultural values, etc., which are the so called ecosystem services.

Over the years, the ecosystem services have gained more attention in the research field and subsequently the need of a clear definition, classification and valuation of them has rapidly increased (Fisher et al. 2009; Wallace 2007; De Groot et al. 2002). According to the Millennium Ecosystem Assessment (MEA) 2005 (FAO 2006; Patterson & Coelho 2009) ecosystem services are described by using four broad categories: provisioning, cultural, regulating and supporting services and forests are among the most important providers of them. Some authors have stated that the ecosystem services are classified by taking into account the benefits which people may perceive such as direct or indirect (Patterson & Coelho 2009) rather than the ecosystem process and services themselves (Wallace 2007). However the ecosystem services are heterogeneous in space and time and for this reason an analyzing scale is important in order to reveal the interests of different stakeholders in ecosystem management (Hein et al. 2006; Sheppard & Meitner 2005). There is a need not only to examine the various scales at which ecosystem services are generated and used, but also to understand how the supply of ecosystem services affects the interests of stakeholders at different scales.

The need of methodological responses to these challenges has been stressed in many international and national forest policy dialogues, such us the United Nations Forum on Forests (UNFF), National Forest Programme (NFP) and FOREST EUROPE, with particular emphasis on the Sustainable Forest Management

(SFM) and Ecosystem Approach[6] (EA), highlighting the importance of the link between forest and other biome and the essential role of Criteria and Indicators (C&I) for SFM. Over the years, not only the link between SFM and EA has been strengthened, but furthermore, SFM can be considered as a means of applying the EA to forests (FAO 2003).

The concept of ecosystem services offers an important opportunity to develop a framework to underpin the wise use of natural resources with particular attention on the biodiversity (Chan et al. 2006), that appears therefore as a pre-requisite for the conservation of the complete array of forest ecosystem functions (Nasi & Facility 2002). In response to habitat loss and fragmentation, which are the major threats to biodiversity, the European Union (EU) initiated an above-national approach by launching the Birds Directive (BD issued in 1979, CD 79/409/EEC) and Habitats Directive (HD issued in 1992, CD 92/43/EEC). These form the legal cornerstones of the Natura 2000 network, through the identification of the Special Protected Areas (SPAs for the BD) and Site of Community Importance (SCI for HD).

Despite the fact that Natura 2000 sites and formal protected areas play a vital role in conservation of remnants of natural habitats, the need of conservation issues beyond the boundaries of these areas is strongly required (Polasky et al. 2005). For these reasons, land use and land management decisions in the land outside protected areas are vitally important. Hence a large scale management, such as the landscape management (Schlaepfer et al. 2000), is required for a better understanding of the joint production or multiple benefits which forest ecosystems provide to human welfare.

The formulation of Forest Management Plans, that are acceptable to all stakeholders, requires the balancing of the different interests and decisions because makers have to meet multiple objectives, or in order to get an acceptable balance if objectives conflict.

In response to these matters, in the last decades, new methodologies and new tools of SFM have been developed. In particular, the Multi Criteria Decision Analysis (MCDA) that offers a suitable planning and decision-making framework for natural resources management (G. Mendoza & Martins 2006), and the participatory approach, which provides a better knowledge of social framework conditions and trends on local markets. Many efforts have to date been made into improving the involvement of people’s value in the forest planning process, due to this, there is an increasing demand for active public participation in forestry decision making (S. R. Sheppard 2005; G. A. Mendoza & Prabhu 2005). Furthermore, many applications of C&I for SFM have been defined for measuring the sustainability and a new level of Forest Plan such as Territorial Forest Plan (TFP) has been developed (Cullotta & Maetzke 2009a).

[6] The concept of EA was introduced for the first time in the 5th Conference of Parties (COP 5) of the Convention on Biological Diversity (CBD) in 2000 and during the 7th COP of CBD the Decision VII/11 was adopted.

Conceptual framework

The first chapter outlines the elements to draw the Conceptual Framework (Figure 2). Ecosystem services are considered the main topic for decision makers in the environmental field as well as in forestry. For this reason, forests occupy an important place, due to the multifunctional role that they play in the ecological, economic and social aspects. Thus it is crucial that SFM take into account the different expectations of society, considering both environmental and societal changes. Forest planning plays an important role for implementing SFM at all levels, in particular the TFP, which allows a better understanding of social needs in specific contexts such as a Site of Community Importance, represents a new strategic tool of SFM implementation, thanks to the wide size of the scale. Furthermore, it can be considered as a vector of consensus and participation between the different stakeholders of the forestry field. The main elements that characterize the TFP are the participatory approach, MCDA and GIS. Moreover, the thesis focuses on the TFP implementation where the participatory approach is improved with the application of the C&I for SFM.

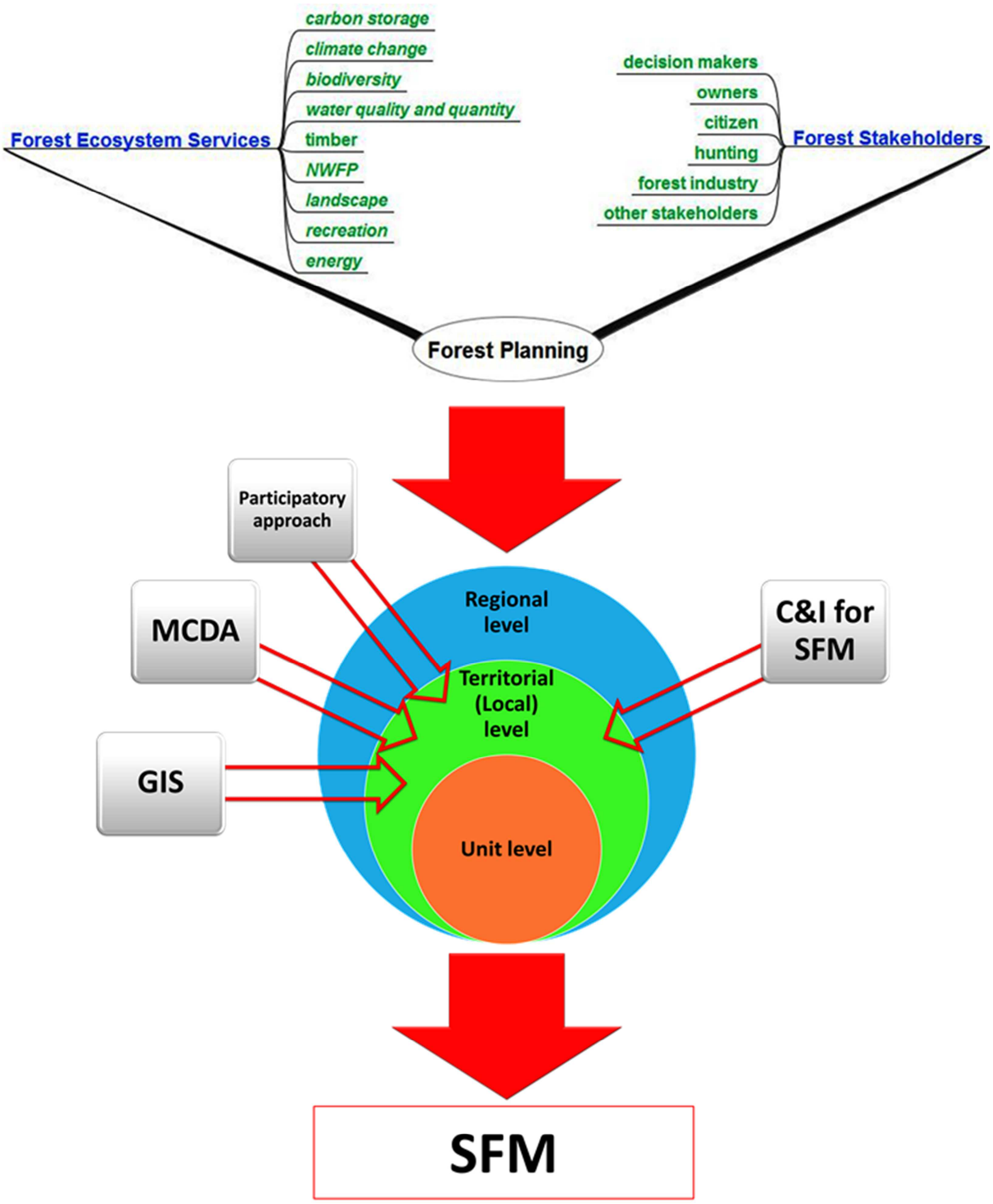

Figure 2: Conceptual Framework of the thesis.

Objectives

This study highlights the important role of Forest Planning in developing a more comprehensive, engaging, open and accountable process to support informed and socially acceptable decision making for SFM.
The aim of this work is to stress the importance of the territorial approach into developing a Forest Plan. With the MCDA and the involvement of the main stakeholders in the implementation of forest plan, TFP can be considered the strategic tool of Forest Management which allows considering the multiple role of forests. Moreover, we argue that the coupled use of C&I for SFM, through Indicators Analytic Network (IAN), and TFP allows to identify silviculture guidelines for managing the forest resources in a more holistic way.

The main objectives of this study were thus:

- ✓ To investigate the dynamics in the development of new tools to support forest management at local level;
- ✓ To test the opportunity to apply the participatory approach in the forest planning implementation;
- ✓ To use indicator analytic networks to understand the knowledge about SFM between the main stakeholders in the specific context;
- ✓ To test the opportunity to use a Territorial Forest Plan and indicator networks together.

To achieve these objectives, what has been hypothesized is that:

- ✓ TFP allows to consider the forest resources in a holistic way by considering the multifunctional role of forest thanks to the wide scale size;
- ✓ The purpose of TFP is to find the optimal allocation of functions considering the forest type and the participatory approach;
- ✓ The integrated use of TFP and C&I can be helpful in implementing forest management through a participatory approach.

Methodological approach

The methodological approach of this thesis has been carried out through different steps as follows:

- ✓ Highlighting the importance of scale in the forest planning concerned with the interaction between forest and water resource;
- ✓ Monitoring of the potential biodiversity conservation *in situ* by the natural regeneration of silver fir within the Site of Community Importance;
- ✓ The role of GIS technology and participatory approach in the collecting and monitoring the rural area activities in the Developing Country (Logone Valley, Africa);
- ✓ A GIS-based approach to map forest functions in a Territorial Forest Plan within Natura2000 site;
- ✓ Indicators Network Analysis to support forest planning decision makers;

It is important to note that this manuscript is based on personal experience carried out in different parts of the world: Chad, Cameroon, France and Italy with particular attention on the Natura 2000 sites. Despite this, the results show that these approaches can also be used in the rural area, outside protected areas.

However from one chapter to another, this study is carried out in various frameworks and different aspects have been considered. In fact the chapters differ on their nature state of the art: published or submitted papers or simply the present version of some research works is still in progress (figure 3).

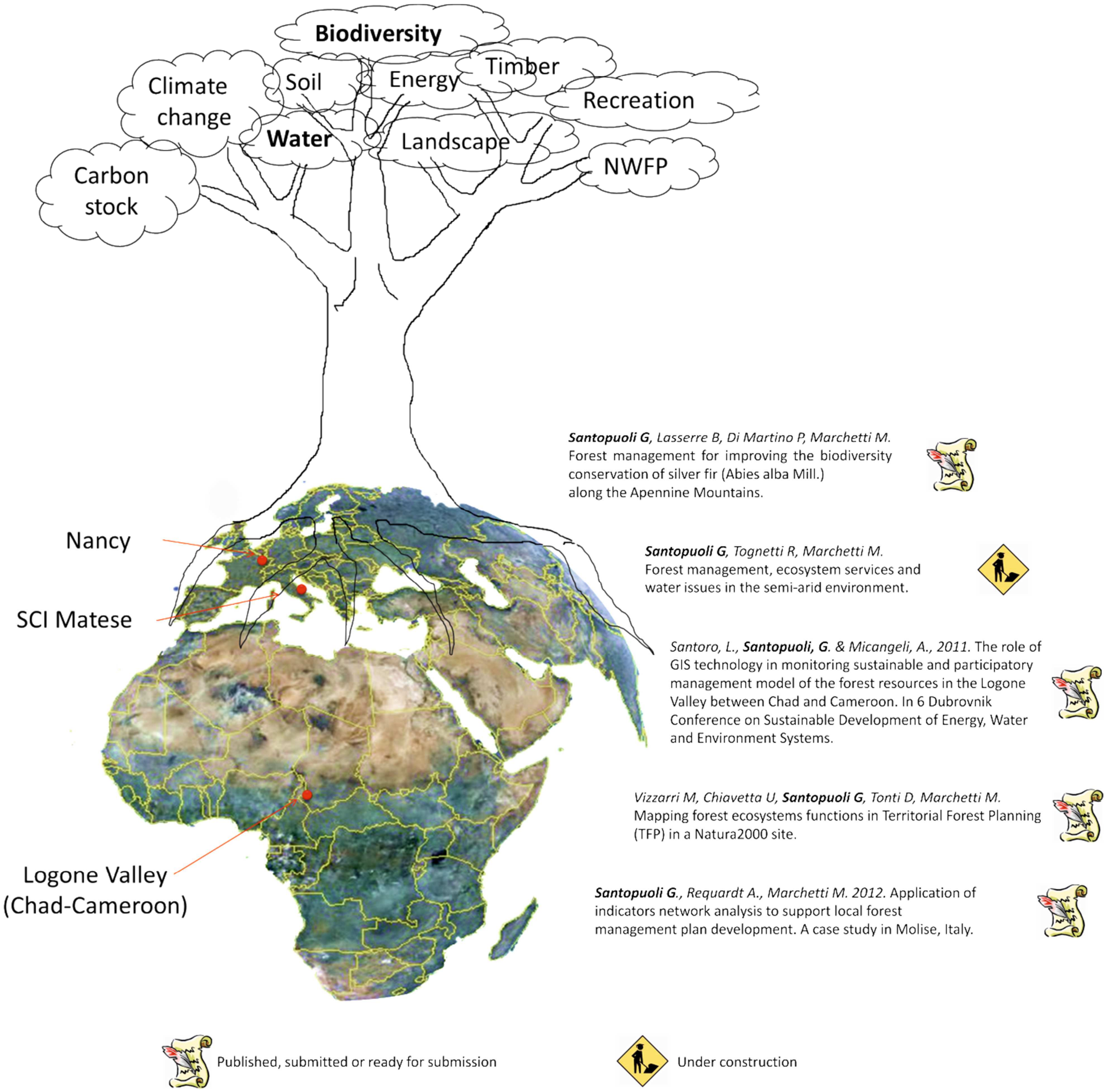

Figure 3: State of progress.

The framework of the thesis is subdivided into two main parts as follow explained. The first part is a general introduction that allowed to draw the conceptual framework. It describes the progress toward the SFM, highlighting the milestone of sustainable development (SD), of the SFM and the implementation of C&I for SFM (Chapter 1). The second part contains two chapters. Chapter 2 emphasizes the forest ecosystem services and the EA application to the forest sector and two working papers about the ecosystem services have been included. The first concerns forest and water interactions at the Mediterranean scale and the second regards the biodiversity conservation of silver fir (*Abies alba Mill*.) along the Apennine Mountains. The third chapter explains the role of the Geographic Information System and the participatory approach into forest plan implementation, which is based on three working papers. The first highlights the potential of GIS in the monitoring of the main activities concerned with the rural area in Logone Valley (Africa). The second is about the Multi Criteria Decision Analysis (MCDA) used to support the forest management plan at local scale in the Site of Community Importance (SCI) in Molise Region. Finally the last is a working paper concerned with the participatory approach through the indicators network in the SCI. The final chapter outlines in the discussions and the conclusions of the thesis.

Case studies

Forest Ecosystem Services and Ecosystem Approach

Paper published, submitted or still in progress

Santopuoli G, Tognetti R, Marchetti M. Forest management, ecosystem services and water issues in the semi-arid environment. In progress.

Santopuoli G, Lasserre B, Di Martino P, Marchetti M. Forest management for improving the biodiversity conservation of silver fir *(Abies alba Mill.)* along the Apennine Mountains. Submitted.

In recent years, the increased concerns about the maintenance of biodiversity and other ecosystem services in the face of global changes have led to a replacement of the focus from timber production to an emphasis on a wide range of economic, social and ecological objectives. According to the International Union for Conservation of Nature (IUCN), the delivery of ecosystem services depends in many cases on the maintenance of biodiversity. For this reason, conservation of forest biodiversity appears therefore as a prerequisite for the conservation of a complete array of forest ecosystem functions (Loreau et al. 2001) due to biodiversity and provides a vast array of forest products, a storehouse for genetic resources, an insurance against extreme events, tourism and recreation values.

Ecosystem services are the benefits humankind derives from the workings of the natural world (MEA 2005). The Millennium Ecosystem Assessment distinguishes four categories of ecosystem services: supporting, regulating, provisioning and cultural (Figure 4).

- ✓ Supporting services which provide the basic infrastructure for life on Earth, including the formation of soils, the cycling of water and of basic nutrients, and the primary production of materials for all other services.
- ✓ Regulating services which maintain the environment in a fit condition for human habitation, most notably maintaining a healthy climate and mitigating the effects of pollution.
- ✓ Provisioning services which provide food, water, energy, materials for building and clothing, and plants for medicines.
- ✓ Cultural services which recognize that people, communities and societies place value (including economic value) on nature and the environment for their own sake or simply find pleasure in them.

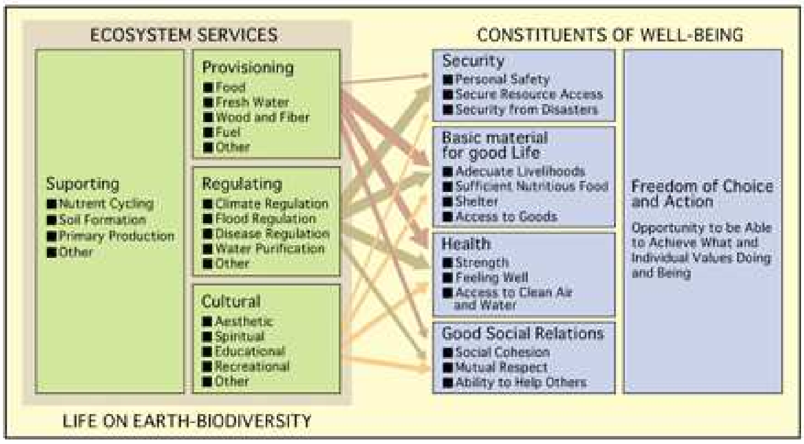

Figure 4: Ecosystem services (MEA 2005).

The concept of ecosystem services has become an important model for linking the functioning of ecosystems and human welfare, affecting the wide range of the decision making context (Fisher et al. 2009).

Since the ecosystem services are defined as the benefits for human, it is important to consider that different stakeholders perceive differently the benefits from the same ecosystem process and often they can be conflicting (Hein et al. 2006). This is particularly evident in the forest arena, where a lot of stakeholders are involved. Forests are part of our cultural and historical heritage and serving society with a multitude of goods and services (MEA 2005). Forest goods include wood such as harvested timber, deadwood, bark, cork, but also Non-Wood Forest Products (NWFP) comprising berries, mushrooms and truffle. The main forest services are the protection of soils from erosion, the regulation of the watersheds and local hydrological systems by reducing variations in water flows, as well as the contribution to the climate regulation, carbon storage and purification of air and freshwater. Furthermore forests are important biodiversity repositories with the greatest assemblage of species found in any terrestrial ecosystem. Forest ecosystems also supply numerous social and cultural services and represent a privileged place for outdoor recreation and leisure.

Since human wellbeing is strongly affected by Ecosystem Services and whereas forests (natural and human made or modified) are among the most important providers of goods and services for the whole world (FRA 2010; Patterson & Coelho 2009), forest management is a crucial tool used to maintain healthy, diverse and productive forests ensuring the supply of services for human needs. For this reason, factors such as forest ownership structure and the importance of national environmental and social conditions influence forest ecosystem management targets, thereby affecting biodiversity. The main efforts for the conservation of biodiversity have been made through the protected areas and the Natura2000 network. However, in the last decades the conservation of biodiversity has become one of the main topics of forest management in all the forestland and not only in the protected areas (Polasky et al. 2005). For this reason, since UNCED 1992, and particularly within the CBD, the concept of the Ecosystem Approach was introduced (COP 7 Decision VII/11) and which integrates conservation measures (e.g., protected areas) and sustainable use of biological diversity.

"The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in equitable way."

The ecosystem approach provides an integrating framework for implementation of the objectives of the CBD and incorporates three important considerations:

a) *Management of living components is considered alongside with economic and social considerations at the ecosystem level of organization and not simply a focus on managing species and habitats;*
b) *If management of land, water, and living resources in equitable ways is to be sustainable, it must be integrated and work within the natural limits and utilize the natural functioning of ecosystems;*
c) *Ecosystem management is a social process; there are many interested communities, which must be involved through the development of efficient and effective structures and processes for decision-making and management.*

Furthermore, it recognizes that humans, with their cultural diversity, are an integral component of many ecosystems, as highlighted also in the Man and the Biosphere (MaB) Programme. Launched in the early 1970s, it aims globally to set a scientific basis for the improvement of the relationships between people and their environment. It also proposes an interdisciplinary research agenda and capacity building that target the ecological, social and economic dimensions of biodiversity loss and the reduction of this loss.

The concept of ecosystem approach and subsequently the concept of systemic silviculture (Corona 2010) offer an important input in the development of new tools and strategies for improving the multifunctional forest management.

Despite the fact that forests supply numerous services to nature and humankind, our attention has focussed on the importance of forest management in the conservation of the quality and quantity of water resource and the important role of forest management in to conservation *in situ* of biodiversity. For this reason, in the following paragraphs these two forest ecosystem services are considered.

Forest and water interactions

Forests have a close relationship with our water resource and Sustainable Forest Management is of vital importance for the supply of good-quality fresh water, protection from natural hazards like floods or soil erosion, and for combating desertification. One fifth of European forests and other wooded land are designated primarily for the protection of water supplies, the prevention of soil erosion and the provision of other important ecosystem services (FOREST EUROPE et al. 2011) .

The relationship between forests and water is a critical issue that must be accorded with high priority by forest decision makers. Humans and other living things depend on water for life and health. Nevertheless, the World Health Organization reports that about 80 percent of the world's people live in places where the only available water is unsafe (MEA 2005). Water related problems such as overuse, scarcity, pollution, floods and drought are an increasingly important challenge to sustainable development. While forested catchments supply a large proportion of all water used for domestic, agricultural and industrial needs, the availability and especially the quality of water are strongly influenced by forests and thus depend on proper forest management. Forest watershed capture and store water, contributing to the quantity of water available and to the seasonal flow of water (Krieger 2001).

Often, the common understanding is that more forests mean more water but it is not true, because an increasing forest cover may have undesirable consequences for water yield. This raises important querries about current afforestation strategies: combating desertification and site location may justify future afforestation.

The amount of water used by forests is also an issue of concern, particularly as the world increasingly looks to planted forests for carbon fixation, energy and wood supply and landscape rehabilitation. Tree canopies reduce groundwater and stream flow, through interception of precipitation and evaporation and transpiration from the foliage. As both natural and human-established forests use more water than most replaced land cover (including agriculture and forage), there is no question that forest removal (even partial) increases downstream water yields. This is particularly evident in the Mediterranean region which is faced with water scarcity due to limited and irregular rainfall patterns and increasing water demand as a result of population growth and the expansion of irrigated areas (Birot et al. 2011).

Furthermore, the integration of water with other ecosystem services should be based on a better understanding of how ecosystem services interact with one another (Muys & Mavsar 2011). This is why forest planning, at landscape scale, can be helpful to understand the relation between forest ecosystem services including the water resources.

Forest management, water and arid environment

Water is a unique natural resource, renewable but at the same time limited. The availability and quality of water in many regions of the world are more and more threatened by overuse, misuse and pollution (I. Calder et al. 2008). Furthermore, the distribution of water is unbalanced among the world. It has been highlighted by World Health Organization (WHO) that about 80 percent of the world's people live in places where the only available water is unsafe (F. Castañeda et al. 2007). In particular the planetary water supply is dominated by the oceans, approximately 97 percent of all the water on the Earth, while the other 3 percent is held as freshwater in glaciers and icecaps, groundwater, lakes, soil, the atmosphere and within life. In addition, water moves from one reservoir to another through processes like evaporation, condensation, precipitation, deposition, runoff, infiltration, sublimation, transpiration, melting, and groundwater flow.

Recent studies on water resources agree that water-related problems such as overuse, scarcity, pollution, floods and drought are an increasingly important challenge to sustainable development (F. Castañeda et al. 2007). Many causes like the climate change during the last decades, the increase of human population, the change in the alimentary habitude and the continuous requirement of the non-seasonal agricultural products have affected these problems. Experts predict that the amount of water needed by humans could exceed the amount available by as much as 40 percent by 2030, making water management a priority in the sustainability agenda. For these reasons the demand of water has increased, for both domestic and agricultural uses and the water resource are under increasing strong pressure.

Forest catchments are recognized as the most important source for supplying a large portion of water for domestic, agricultural, industrial and ecological needs. Forests provide numerous benefits in the conservation of quality and quantity of water, by intercepting precipitation, evaporating moisture from vegetative surfaces, transpiring soil moisture, capturing fog water and maintaining soil infiltration.

Water professionals' concern is that the greater variability in the amount and seasonality of rainfall and stream flows, as well as the increasing frequency and intensity of extreme hydrological events will increase with a warming world, and place ever increasing challenges on conventional water practices and policies (G. J. J. Bergkamp et al. 2003). Water is only one of a number of vital natural resources and it is imperative that water issues are not considered in isolation (UN-WATER 2008). Governments and other stakeholders should develop policies and implement programmes that promote holistic, multidisciplinary and multistakeholder approaches that link forests, water, watersheds, the environment and people as outlined in the fifth MCPFE (Varsawa, Poland) 2007.

The aim of this work is to stress the important role of forests and forest management in maintaining forests in a good state of conservation in order to preserve water quality and quantity as well as a forest ecosystem service.

Forest management and water

Forest catchments are recognized as the most important source supplying a large portion of water for domestic, agricultural, industrial and ecological needs in both upstream and downstream areas. The interactions between forests and water and the benefits of forests for water supply are multiple. Forests provide numerous benefits in the conservation of quality and quantity of water, by intercepting precipitation, evaporating moisture from vegetative surfaces, transpiring soil moisture, capturing fog water and maintaining soil infiltration. The relationship between forests and water is a critical issue that must be accorded high priority in both policy and researcher fields. Several initiatives concerning the water resource have taken place. An important milestone at a global level was the «International Expert Meeting on Forests and Water» held in 2002 in Shiga, Japan, in the context of the 3rd World Water Forum. The adoption of the MCPFE Warsaw Resolution 2 in November 2007 was a further milestone and triggered a series of important events in 2008 such as the Third International Conference on Forests and Water (Mragowo, Poland), the plenary session on forests and water during the European Forest Week (Rome, Italy) and the conference on «Water and Forests: a Convenient Truth?» (Barcelona, Spain). Recently the UN-Water International Conference "Water in the Green Economy in Practice: Towards Rio 2012" (Zaragoza, Spain) highlighted that water is a key driver of economic and social development and it also has a basic function in maintaining the integrity of the natural environment. In the same event water was recognized as closely linked to the green economy because it is interwoven with sustainable development issues such as health, food security, energy and poverty. In addition, after the "Water for life International Decade 2005-2015" the United Nations General Assembly is expected to adopt a resolution declaring 2012 as the International Year of Water.

The multifunctional role of forests is widely recognized in the forest science. Forests provide numerous good and services, not only timber but they are also helpful in alleviating poverty, the provision of safe drinking water, food security, conservation and sustainable use of biodiversity, and providing other cultural and socio-economic benefits (FRA 2010).

Vegetation factors, in particular forests such as species, density, basal area and silvicultural system (Baskent & Keleş 2009) have a great influence on spatial variation in soil water dynamics because of heterogeneity in rainfall redistribution and evapotranspiration processes (Breshears et al. 1997; I. R. Calder 2002). Furthermore about one fifth of Europe's forests are reported to fulfill protective functions for water supplies, the prevention of soil erosion and the provision of other important ecosystem services (FOREST EUROPE et al. 2011). The importance of protective forests is clearly recognized, especially in mountainous areas which represents the main source of water supply (Liniger & Weingartner 1998). For this reason experts recognized the need to take actions at all levels with regard to Sustainable Forest Management (SFM), as outlined in paragraph 42 of the World Summit on Sustainable Development (WSSD) Plan of Implementation, which emphasized the multiple benefits of both natural and planted forests and trees (Strachan 2005).

SFM can be considered as the key factor in water resources management in general and upland resources development in particular. Both intact natural forests and well-managed forests generally produce high quality water, thus SFM should be incorporated within the development and implementation of national/regional and local strategies, plans and programmes with regard to integrated river basin, watershed and groundwater management.

Rainfall reaches the ground in a non uniform pattern due to the different types of land cover. In particular not all of the precipitation that falls on a forest reaches the forest floor. Precipitation can be partitioned into one fraction that is intercepted by the canopy and which is subsequently evaporated (Interception). Intercepted precipitation may be stored on leaves, branches or stems or may evaporate back into the atmosphere. The interception varies greatly among species and its water storage capacity, forest density and structure, and climate condition such as humidity of the air (Shuguang 1997) and also by the energy available to evaporate water. It can be as high as 50 percent of rainfall in some areas (I. R. Calder 1990), with closed forest canopy conditions.

Another fraction that comes into contact with the canopy coalesces and reaches the ground by flowing down the plant structure (Stemflow). Stemflow strongly depends on canopy morphology referred to the shape of tree and in particular to bark roughness. For instance, upturned branches serve to funnel water towards the stem. A further fraction may or may not have contact with the canopy and falls to the ground between the various components of the vegetation (Throughfall) (Aboal et al. 1999; Levia et al. 2011). Throughfall depends on the silviculture system, the species composition, as well as on the forest canopy. Basically Stemflow tends to deposit water deeper into the soil than throughfall does (Liang & Ken'ichirou Kosugi 2011).

Water may also enter an ecosystem as ground water that flows laterally from adjacent ecosystems, otherwise surface runoff and flood events may also increase the loss of water in the ground. In undisturbed forests, there is generally a low surface runoff, due to high infiltration rates (Hümann et al. 2011).

In certain circumstances, forests can also contribute to reducing storm flow peaks for a given input of precipitation. Forests also play an important role in reducing soil erosion and subsequent downstream sedimentation. By maintaining or improving soil infiltration and soil water-storage capacity, they influence the timing of water delivery.

Although forests influence the amount of water available and quality, the climate change influences the role of forests, not only in the contribution of the water control through the increase of evapotranspiration, but also in the development of new forest adaptation strategies. Changes to the climate are already leading to more unstable and shifting water regimes around the world (G. J. J. Bergkamp et al. 2003). The changes in climate that have been anticipated in the coming decades will have diverse effects on moisture availability, ranging from alterations in timing and volume of stream flow to the lowering of water levels in many wetlands, the expansion of thermokarst lakes in the Arctic and a decline in mist water availability in tropical mountain forests (Bates et al. 2008). With the existing climate change scenario, almost half the world's population will be living in areas of high water stress by 2030, including between 75 million and 250 million people in Africa. In addition, water scarcity in some arid and semiarid places will displace between 24 million and 700 million people (http://www.un.org/waterforlifedecade/scarcity.shtml).

Climate change and water affect the biodiversity and the ecosystem services increasing risk for human safety in landscapes through extreme weather events. In fact observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems (Bates et al. 2008). Furthermore, not only climate change affect the loss of water by increasing the evapotranspiration, but also it affects the role of forests especially in the Mediterranean area where climate is uncertain and energy crises loom raises many questions on the availability and renewal of water resources, the fertility of soil, the survival of forests, natural balances and land development(Birot et al. 2011). There are many consequences also in the soil structure and chemical property allowing the soil degradation (Corona 2005). In addition, overgrazing and forest fire increase soil degradation and subsequently loss of biodiversity.

For this reason it is helpful to develop new tools of forest planning that take into account not only the forest resource, but all the rural landscape, considering the multitude of forest good and services. This is why, the importance of land management at the local scale, such as watershed level, plays a crucial role in to implementing the EA.

The integrated management of natural resource, considering forest, land use, soil and water resource coupled with the mitigation of cataclysmic events and the fight against desertification can represent the key towards sustainable development. Although it is clearly recognized that forest management can be helpful to preserve water quality and quantity, there is a need to improve the understanding about the relationship between soil, forest and water (I. R. Calder 2002). It is necessary to recognize that water can be considered as a forest ecosystem service and to assess the value of it (Gatto et al. 2009).

Forests can be considered helpful to contribute into mitigating the effects of floods and droughts, allowing to achieve the aims of the EU Water Framework Directive 2000/60 EC. In particular they can be helpful in the provision of the sufficient supply of good quality of water, a significant reduction in pollution of groundwater, the protection of territorial waters and finally they can improve the surface water and groundwater as needed for sustainable, balanced and equitable water use. Although forests are helpful to preserve water resources, the directive framework of water did not highlight the important role of forests.

Subsequently this role was stressed during the fifth MCPFE in Warsaw (Poland) 2007, where one resolution adopted was Forest and Water. Further SFM was recognized to be of vital importance for the supply of good-quality fresh water, protection from natural hazards like floods or soil erosion, and for combating desertification.

In particular SFM in relation to water maintains and enhances the protective functions of forests for water and soil, as well as for mitigating local water-related natural disasters including public and private partnerships. Furthermore, SFM assesses afforestation and reforestation programmes in terms of their effects on quality and quantity of water resources, flood alleviation and soil. Finally SFM promotes the restoration of degraded forests, particularly in floodplains and upper watershed areas for the benefit of the water environment, flood reduction, conservation of biodiversity and soil protection (Birot et al. 2011).

Conclusions

Water is the most vital element of all natural resources and essential to life. However, availability and quality of fresh water in many regions of the world are increasingly endangered by overuse, misuse and pollution. Due to the growing imbalance between water supply and demand in the world, there is an increasing need to ensure adequate water quality and quantity. Through the Warsaw Resolution on Forests and Water, adopted at the fifth Ministerial Conference, the responsible ministers emphasized the vital role of SFM in protecting water quality and promoting overall watershed management. They stressed the importance of developing, improving and coordinating policies for forest and water resource management.

Woodlands protect water bodies and watercourses by trapping sediments and pollutants from other up-slope land use and activities. In Europe, 96.3 million hectares of forests are designated for the protection of soil and water. This corresponds to 10 percent of the total forest area.

Forests also play a significant role in water availability. They influence the amount of available water by intercepting precipitation, evaporating moisture from vegetative surfaces, transpiring soil moisture, capturing fog water and maintaining soil infiltration. At the same time, forests may influence the timing of water delivery by maintaining and improving soil infiltration and the soil's water-storage capacity.

Since SFM is considered as a means to apply the EA, forest management planning is a very prestigious discipline and it plays a strategic role in implementing SFM principles. Furthermore, the territorial scale, such as landscape or watershed or also protected area, allow a better consideration concerned with the protective forest function and the water supply, more than the unit level or regional level (Kaimowitz 2004).

Protected areas, in particular Wetlands, provide fundamental ecological services and are regulators of water regimes and sources of biodiversity at all levels such as species, genetic and ecosystem. According to a research study of the World Bank, out of 105 cities, 33 use fresh water from water basins located inside protected areas in which forest type soils are prevalent (N. Dudley & Stolton 2003).

A better integration of forest management and water policy plans and measures could be vital in achieving good water status and sustainable management of water resources.

Fostering biodiversity conservation

According to the CBD, forest biological diversity is a broad term that refers to all life forms found within forested areas and the ecological roles they perform. As such, forest biological diversity encompasses not just trees but the multitude of plants, animals and micro-organisms that inhabit forest areas and their associated genetic diversity. Forest biological diversity can be considered at different levels, including the ecosystem, landscapes, species, populations and genetics. Complex interactions can occur within and amongst these levels. In biologically diverse forests, this complexity allows organisms to adapt to continually changing environmental conditions and to maintain ecosystem functions.

In the annex to decision II/9, the Conference of the Parties recognized that:

"Forest biological diversity results from evolutionary processes over thousands and even millions of years which, in themselves, are driven by ecological forces such as climate, fire, competition and disturbance. Furthermore, the diversity of forest ecosystems (in both physical and biological features) results in high levels of adaptation, a feature of forest ecosystems which is an integral component of their biological diversity. Within specific forest ecosystems, the maintenance of ecological processes is dependent upon the maintenance of their biological diversity."

Deforestation, fragmentation and degradation are the main threats to the loss of forest biodiversity. Furthermore, the conversion of land use, overgrazing, unsustainable forest management, the introduction of invasive alien plant and animal species, infrastructure development (e.g. road building, hydro-electrical development, urban sprawl), anthropogenic forest fires, pollution, and climate change are all having negative impacts on forest biological diversity.

Since UNCED 1992, forest biological diversity has increasingly been recognized as an integral component of sustainable forest management and subsequently several international meetings have been held and numerous processes have been created. For example, forest biodiversity conservation was one of the main issues addressed at the Ministerial Conference in Helsinki in 1993, as a response to the objectives and measures set out in the CBD. Helsinki Resolution 2 provides General Guidelines for Conservation of the Biodiversity of European Forests. In 2003, the forest ministers adopted Vienna Resolution 4, Conserving and Enhancing Forest Biological Diversity in Europe, as well as the FOREST EUROPE: Assessment Guidelines for Protected and Protective Forest and Other Wooded Land in Europe. Several of the FOREST EUROPE criteria and indicators for sustainable forest management are relevant to forest biodiversity. Criterion 4, with nine associated indicators, is directed exclusively towards biodiversity in forests.

Over the years, sustainable forest management practices have been implemented to promote the conservation and enhancement of biological diversity. These forest practices have led to increased natural regeneration and more mixed species stands. This is particularly evident along the Apennine Mountains where the natural presence of Silver fir (*Abies alba Mill.*) is unusual. Despite this, it is possible to have the diffusion of the conifer through the conservation *in situ* of the natural regeneration.

Forest management for improving the biodiversity conservation of silver fir *(Abies alba Mill.)* along the Apennine Mountains.

Introduction

Since forests supply numerous goods and services to society, the conservation of biodiversity is one of the most important ecosystem services that forests provide (Daily 1997; FAO 2006). Biodiversity loss can affect ecosystem functions and services, due to the fact that a large pool of species is required to sustain the assembly and functioning of the ecosystem in landscapes subject (Hector e Bagchi 2007; Loreau et al. 2001). Maintaining healthy biodiversity can play a significant role in climate change mitigation and the world's protected areas - national parks, marine reserves, wilderness areas and so on - are essential for safeguarding this role. Habitat loss and fragmentation represent the major threats to biodiversity (EEA 2006), and for this reason numerous formal protected areas have been established. Despite this, the conservation of biodiversity is crucial also in the areas outside the formal protected areas (Ellis & L. Porter-Bolland 2008; Polasky et al. 2005).

Silver fir (*Abies alba Mill.)* is considered a rare species along the Apennine mountains. The silver fir is distributed predominantly in European mountain forests. It preferentially occurs under cold climatic conditions, with low temperature amplitudes and a relatively high annual precipitation (Gellini & Grossoni 1997). It sometimes forms monospecific stands but it often occurs with Norway spruce (Picea abies Karst.), common beech (*Fagus sylvatica L*.), sycamore maple (Acer pseudoplatanus L.) and other trees forming the rich stands of mixed mountain forests. Apart from its ecological importance (including a general easiness for natural regeneration) it is considered as a high technological quality wood used for furniture, construction timber and pulp. In the history of forest vegetation in Italy and particularly in the Apennine mountains, silver fir has had particular importance. In fact, its natural presence is unusual along the Apennines and it is almost unique in this latitude. In the Molise Region it was commonly found in the past, but currently it is limited and localized in few areas. Nowadays the only pure silver fir forests are identified in the areas of *Pescopennataro*, *Pietrabbondante* and *Sant'Angelo del Pesco* with an area of few hundred hectares (Capretta 1991). The current regression of silver fir in a few small areas depends on many causes: human impact, climate change after the last glaciation, species competitions especially with beech (Capretta 1991). According to Di Matteo (2001) silver fir which is present in Molise has a particular ecological meaning because it is in a peculiar position between the beech forest and the turkey oak forest (*Quercus cerris L.)*, establishing a mixed forest community.
The study area examined in this work is located in the village of Pietrabbondante, in the Monteluponi forest, edging with the Collemeluccio Man and Biosphere (MaB) reserve. The aim of this work was to assess the possibility that silver fir can develop inside the oak forests of the Apennines, through natural regeneration. Many authors both at national and international level, have studied the natural regeneration of silver fir in the past, under many aspects such as light radiation (I. Mercurio & R. Mercurio 2008), or also forest gaps (Magini 1967; L. Bianchi & Paci 2008; L. Bianchi, Paci, et al. 2006; Dobrowolska 1998; Dobrowolska & Veblen 2008).

Twenty-one field observations (see Figure 5) within the forest were carried out to classify the forest type, the forest structure, the species composition and the growing stock. Furthermore, field observations were performed inside 21 transects to investigate the natural regeneration of silver fir. The main focus was to calculate the regeneration index (*Ir*) of silver fir and to perform a comparison between the lengths of leader shoot and twigs forming the upper whorl (formed in the current season), as an indicator of health and vitality of each single plant.

The final aim was to consider the opportunity to include the forest in the current MaB reserve. Results show that the Monteluponi forest is a high-quality site to promote the conservation and the natural diffusion of silver fir, contributing to the challenge of biodiversity conservation highly recognized at global level.

Material and method

The study area is a forest called Bosco Monteluponi, located in the Molise Region, in the southern part of the village of Pietrabbondante, at an altitude between 850 and 980 m above sea level. It is very close to the Collemeluccio MaB reserve (see Figure 5).

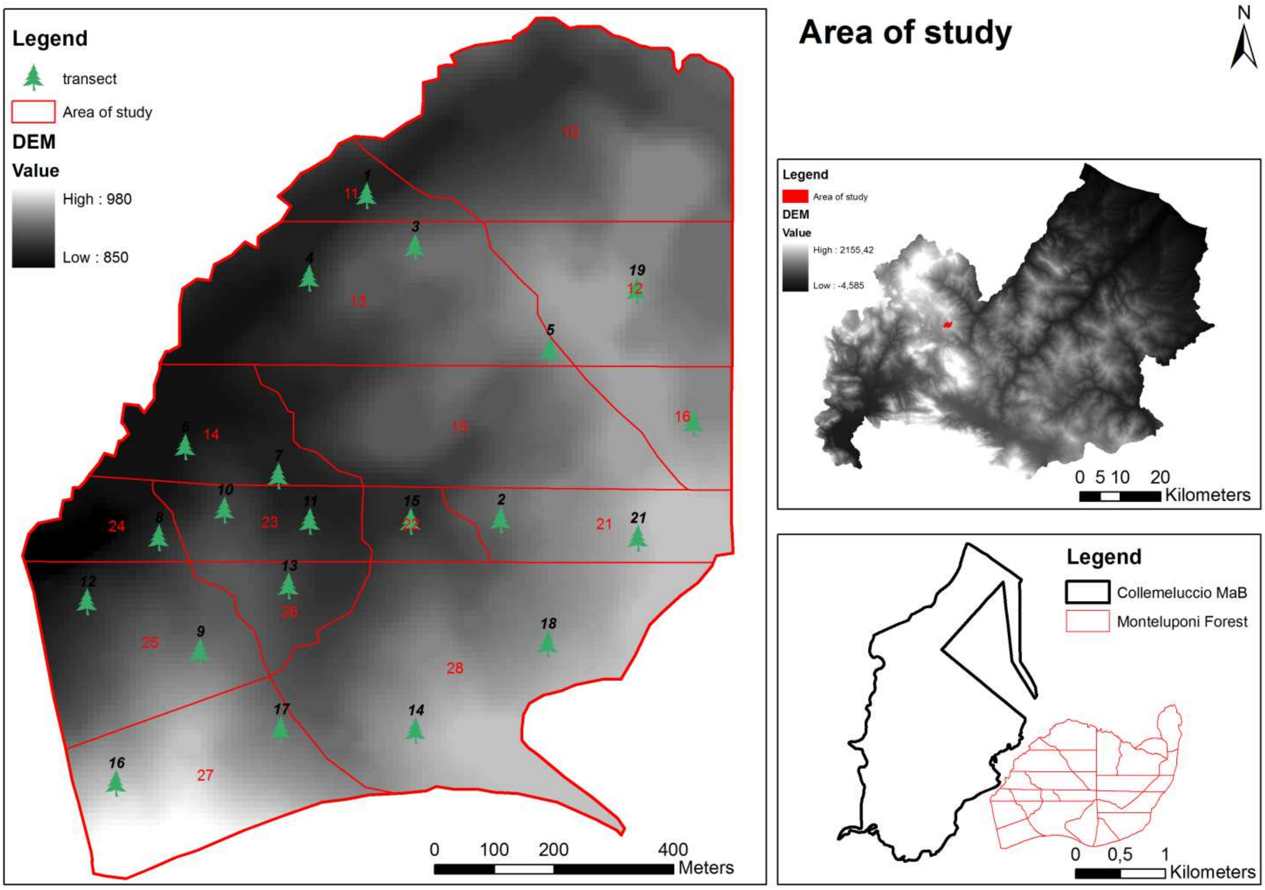

Figure 5: study Area. The image on the left shows the geographic location of the test areas. The images on the right show the geographic position of study area in Molise Region (top) and the proximity with the Collemeluccio MaB reserve (bottom).

According to the analysis of the data from the local weather station located in the site called "Giardino" at 934 m above sea level, the mean temperature is 8.5 °C and the precipitation amount is 934 mm annually. According to the Pavari classification the areas located at an altitude higher than 900 m above sea level are classified in "Fagetum" while the areas located at an altitude lower than 900 m above sea level are classified as "Castanetum". The forest is 196.67 hectares large and according the Forest Type Map (Garfì e Marchetti 2011), all the forest is classified as a Turkey oak, with a high forest sylviculture treatment. Despite this, in terms of volume and density, the main species which are present in the forest are turkey oak and beech, but since the last forest plan (1969-78) the presence of silver fir seems to have increased, improving the ecological value of all the forest, even if the important ecological value of the forest was already recognized. In fact the forest is part of the Site of Community Importance (SCI) called *"Bosco di Collemeluccio, Selvapiana, Castiglione, La Cocozza".* Furthermore, due to its position, edging the Collemeluccio MaB reserve, its value in contributing to biodiversity conservation has gained more attention over the years. After several field observations aiming at verifying the presence of silver fir in the forest, 21 test areas were identified for data collection through field observations. This is the reason why only the western part was involved in test areas and not the whole forest. Although the choice of the location of areas was subjective, the selection depended on the forest structure and was representative of forest stands. The shape of each area was circular with a 15 m radius. The centre of the area was georeferenced and subsequently a transect with the same centre of the circular area was built for each area. The shape of the transect was rectangular, North-South oriented, with the longer edge 10m long and a 20m^2 surface. The position of the study area and the distribution of the test areas are shown in Figure 5.

Tree parameters measured in the circular areas were the diameter and height of each plant with a diameter higher than 3 cm. While the main parameters observed in the transects concerning the silver fir natural regeneration were the diameter and height of each plant with a height smaller than 3 m (Magini 1967). Furthermore, for each silver fir plant, the crown radius and the crown ratio, the number of twigs, the length (mm) of both the leader shoot and the twigs of the last season were observed.

These data were utilized to calculate the regeneration index:

$$Ir = N * \frac{Hm}{S}$$

Where:

Ir= regeneration index (1/m);

N= number of plants;

Hm= mean of the heights (centimeter);

S= surface of the transect (square meter).

Apical Dominance Ratio (ADR) was calculated for each plant dividing the length of leader shoot by the mean length of upper whorl twigs (Robakowski et al. 2004; Parent & C. Messier 1995)

Results

In total 12 species were identified in the forest, more than 2500 plants were measured, in both circular areas and transects, at different altitudes, slopes and aspects. 88% of the measured trees have a diameter higher than 3 cm, within the circular areas, while 12% have a diameter smaller than 3 cm, within the transects (mainly fir regeneration). In Figure 6, the diameter distribution for each species is presented; 6 species are not included for the very low number of measured plants. It can be observed that the majority of plants present small diameters. Basically the vertical structure of the forest is constituted by turkey oak, beech and silver fir at the top and many other species below, as hornbeam (*Carpinus betulus),* maples (*Acer campestre and Acer obtusatum*), European ash (*Fraxinus excelsior, L*), and Chequer (*Sorbus torminalis*). The box plot in figure 6 helps to understand the structure of the forest observing the distribution of the diameter for each species. In the box plot, the lower limit of the box corresponds to the value of the 1st quartile (Q1) of the distribution and the upper limit to the 3rd quartile (Q3); the horizontal black lines inside the box represents the median value. The vertical lines connect two extreme values, obtained as a linear combination of the Q1 and Q3 values. Extreme cases with values more than 3 box lengths from the upper or lower edge of the box are reported by outlined stars while outliers with values between 1.5 and 3 box lengths from the upper or lower edge of the box are reported by outlined circles.

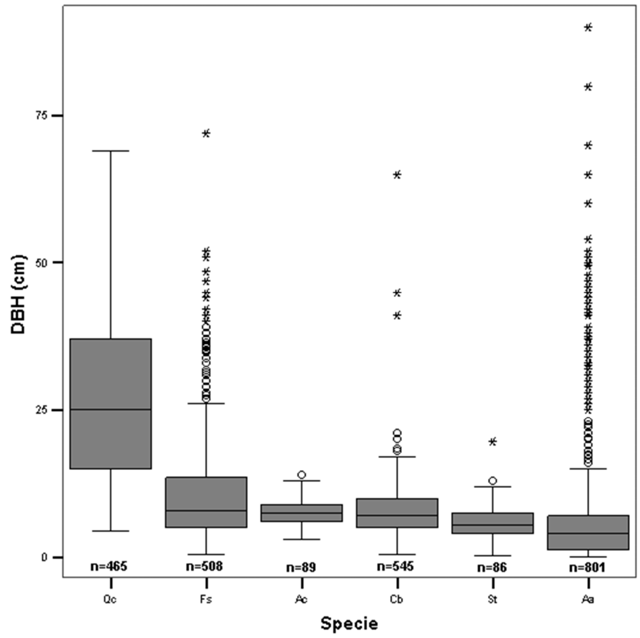

Figure 6: Diameter distribution for each species. The numbers under the boxes indicate the number of trees measured for the main species.(Qc: Quercus cerris, Fs: Fagus sylvatica, Ac: Acer campestre, Cb: Carpinus betulus, St: Sorbus torminalis, Aa: Abies alba).

Two important aspects can be underlined from Figure 6. The turkey oak is the species that presents, in average, the biggest trees, in fact 75% of the trees are bigger than the other 2/3 of all the other species. On the other hand, the silver fir is the species which has absolutely the biggest tree with a diameter that reaches 90 cm, even if the diameters of the majority of trees are smaller than 15 cm.

It can be observed that turkey oak is the specie that presents the most homogeneous diameter distribution with a high variability, between 4.50 cm and 69 cm.

Similarly, maples and chequer are species with an homogeneous diameter distribution but with a much lower number of measured trees than turkey oak. The other species, beech, silver fir and hornbeam show a more heterogeneous distribution of the diameter with high variability, as highlighted by the presence of many outliers and extremes. In particular beech and silver fir, present a lot of trees with diameter values out of the box. This tends to indicate that most plants of beech and fir are grouped characterized by small diameters, lower than 15 cm surely correlated to the large presence of regeneration trees. For this reason the few high dimension trees present in the forest result out of the box range and are visualized as outliers and extremes in the box plot.

The box plot confirms that turkey oak is the main specie in terms of basal area, but on the other hand the presence of natural regeneration is lower than the other species. It can be explained by the fact that turkey oak is a shade intolerant specie, thus there is a high competition with beech and silver fir regeneration. Furthermore, over the years the silvicultural practices has promoted the conservation of silver fir as highlighted by the forest management plan, due to the ecological importance of its presence along the Apennine. For this reason, and considering that silver fir is a shade-tolerant species, it presents a high level of regeneration. Heterogeneity of silver fir diameter distribution can be explained by the combination of both these considerations that allowed the growth of the mature trees as undisturbed and allowed a spread presence of fir regenerations. Moreover, beech is also a shade tolerant species and a high level of natural regeneration was registered as well. The heterogeneity of beech is lower than silver fir, due to the fact that beech is managed to supply timber as turkey oak. Finally hornbeam and chequer, although important for biodiversity, are considered as understorey plants and as a consequence are harvested without specific management.

The total basal area calculated is 57.63 m^2. It corresponds to 38.84 m^2/ha. Overall the turkey oak is the species with the highest basal area value, 58% of the total. Successively beech represents 18% and silver fir 15% of the total basal area. Hornbeam, maple and chequer represent 8.5% all together and, finally, *Acer obtusatum*, European ash, hazel (*Corillus avellana*), European cornel (Cornus mas), hawthorn (*Crategus monogyna*) and *Pyrus piraster*, are species characterized by a very low basal area.
Overall the species composition of the forest consists in 3 dominant species and 9 species as understorey. Regarding these latter, the number of measured trees for 6 of them is fewer than 10 and as a consequence are not included in the following graphs. Figure 7, represents the hypsometric relationship also known as height/diameter curve, for the main species. The form of the curve may indicate a forest stand's development and growth stage.

The correlation between height and diameter for each species is high as shown in the chart below. It can be observed that the silver fir is the species with the highest value of RSquare 0.87. This chart supports the previous considerations that turkey oak is the emergent species due to higher trees, with few small trees while most of the trees of all the other species present small diameters and small heights. However, the hypsometric relationships show that there is not particular competition between the species.

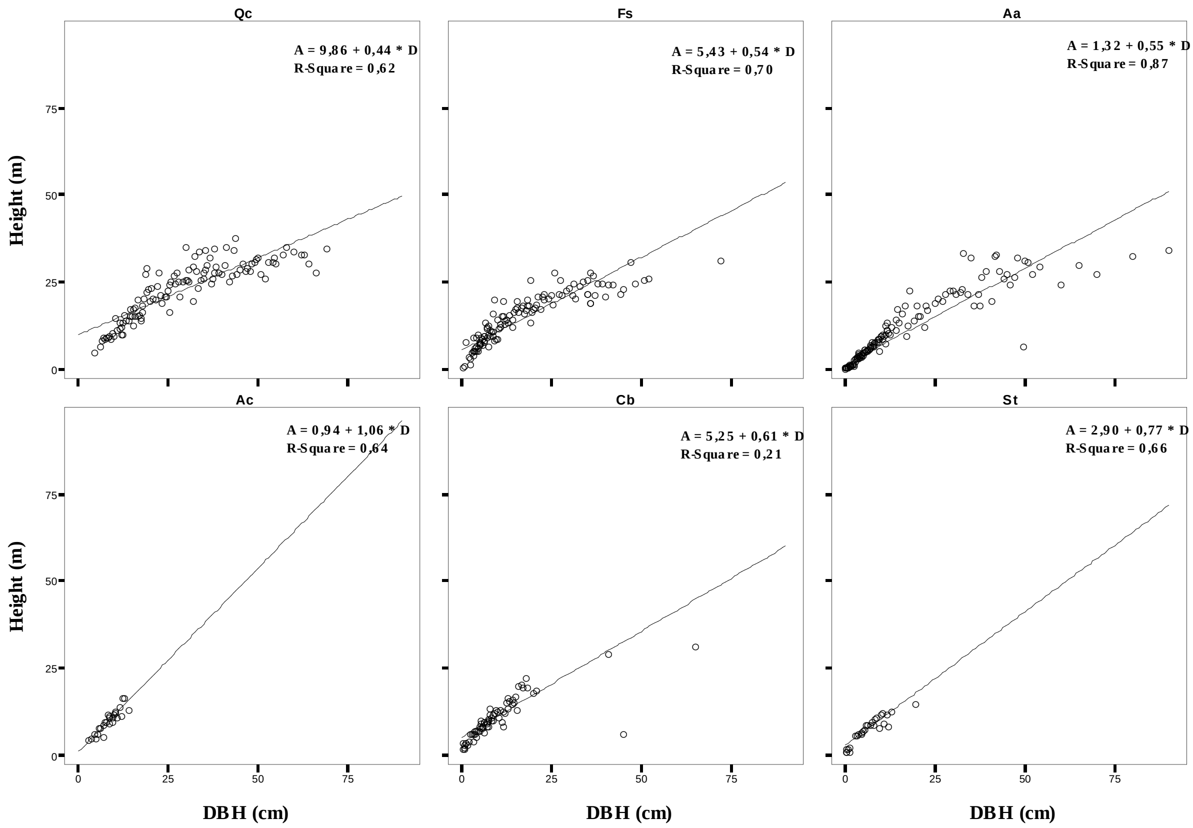

Figure 7: Height/diameter curves, calculated for the main species within the Monteluponi forest.

Considering the species composition, based on the number of trees and the basal area, Figure 8 shows the distribution of these variables among the forest. Basically the image consists in the overlay of the Digital

Elevation Model (DEM) and the results of field observations. The parameters taken into consideration are referred only to the species that are mainly present: turkey oak, beech and silver fir which represent the canopy layer. In this way it is possible to observe if the different aspect, altitude or slope affect the current presence and distribution of the species, with particular emphasis on the silver fir.

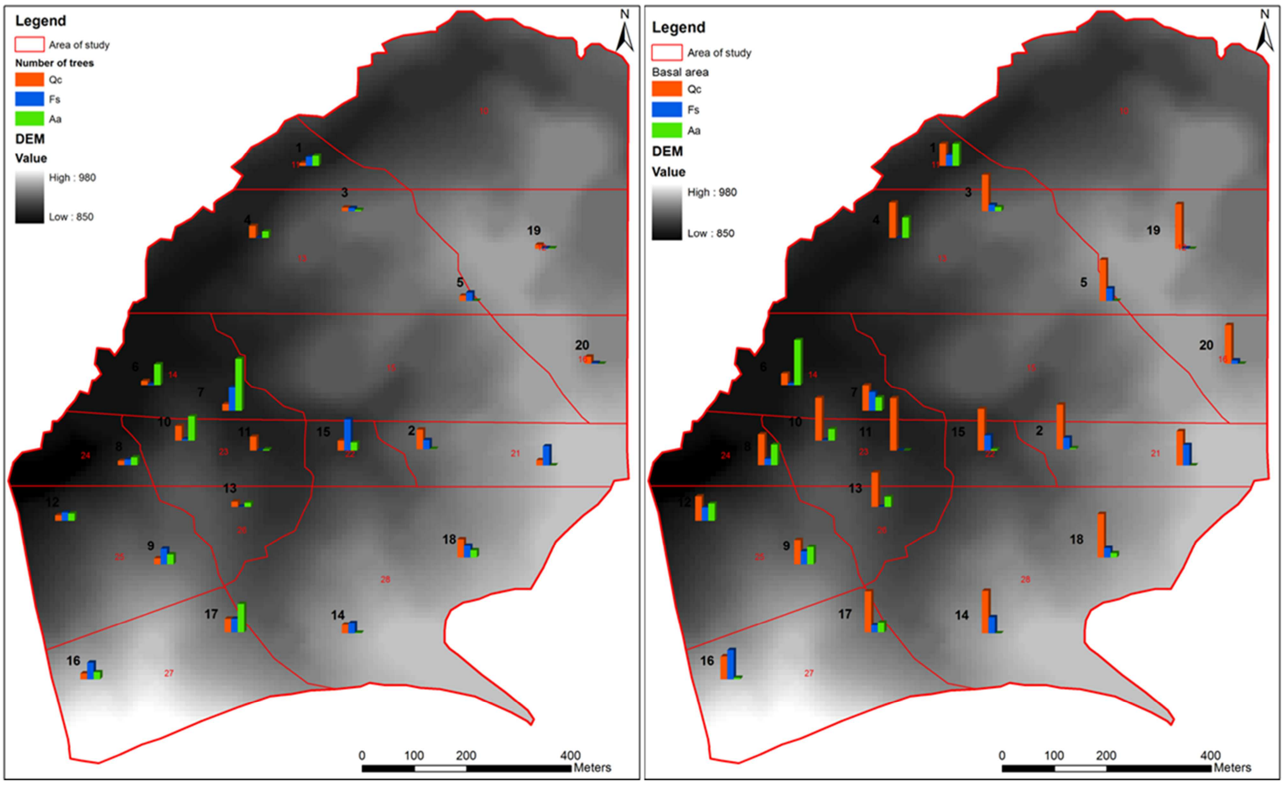

Figure 8: The image on the left shows the comparison between the main tree species in terms of the number of trees. The image on the right shows the comparison of the species composition in terms of basal area.

The image on the left shows the distribution of species based on the number of trees for each of them. While the image on the right shows the distribution of species according to the basal area. It is clear that even if turkey oak is present with a smaller number of trees, it is the species with the highest value of basal area almost in all the test areas. Furthermore, the distribution of the species is homogenous among the area while the distributions of beech and silver fir are more heterogeneous.

Although the number of trees is often bigger for beech than for turkey oak, the value of basal area is lower in almost all the field observations. Two main observations emerge from the figure. Firstly, beech is the main species present at highest altitude in north facing aspect, while in the area in East facing aspect beech disappears. Regarding silver fir, most plants are in the western part of the study area, closer to Collemeluccio MaB reserve, but its presence is noted also in the South, South–East part of the area, far away from Collemeluccio with a lower value of basal area. Beech and silver fir seem to be in competition; their presence is alternating, with silver fir closer to the Collemeluccio MaB and beech far away from MaB.

This confirms that, in this context, the aspect, slope and altitude do not affect the diffusion of silver fir, but the distance from Collemeluccio is the main justification of the silver fir distribution.

From Figure 9 the trend of the presence of silver fir among the study area can be observed through the comparison of data from two different dates: 1969 and 2007. The 1969 data are taken from the forest plan while the 2007 data are the results of field observations.

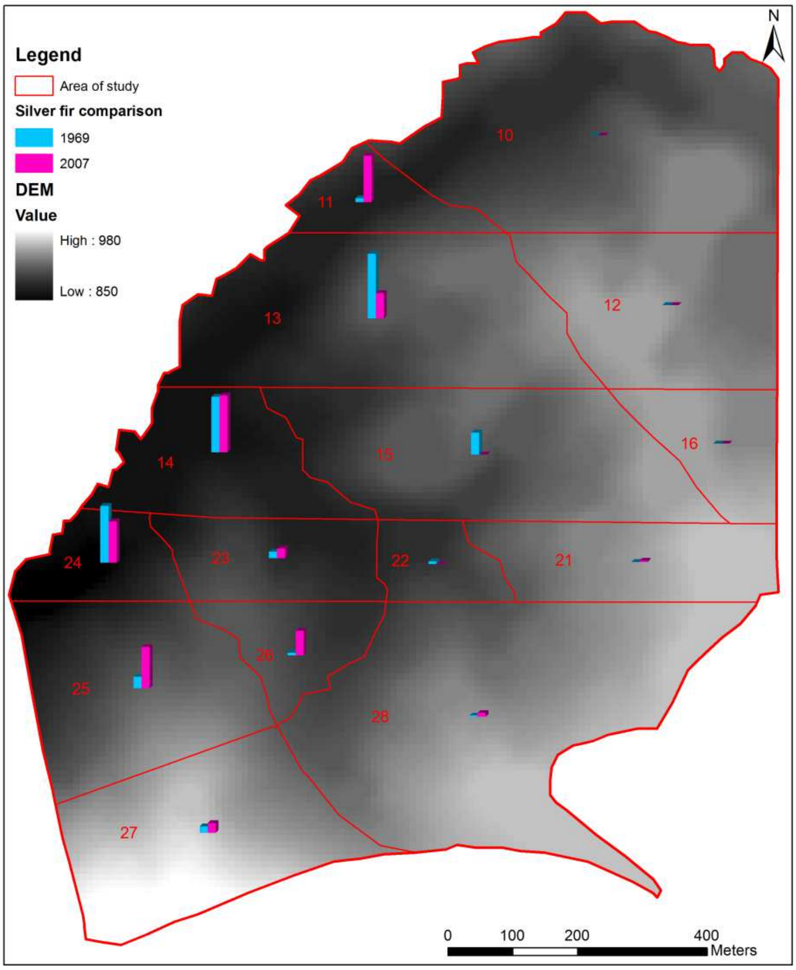

Figure 9: Silver fir comparison for each forest stands, between 1969 and 2007.

The comparison consists in the percentage of silver fir respect to turkey oak and beech, in terms of volume per hectare, calculated for each forest stand. Although it does not give information about the value of volume, it allows to observe how the silver fir distribution is changing over the years. In 1969 silver fir was occupying mainly the area near the MaB even if its presence was slightly extended also in the area more distant from the MaB.

During the period 1969-2007, the presence of silver fir has increased. In fact, in 2007, silver fir not only is present in almost all the study area, but its presence in terms of percentage is much higher than in 1969. On one hand the percentage indicating the presence of silver fir has increased more in the area far away from the MaB than in the area closer to the MaB, probably because the high competition between silver fir regeneration added to the dense cover of the canopy, did not allow further increase of silver fir in that area. On the other hand in the area far away from the MaB, where the canopy is not so dense, silver fir has found space and ideal condition to increase its presence.

Finally, for each transect, the regeneration index of silver fir has been calculated and the values are shown in Figure 10. It can be observed that in 3 of the 21 transects silver fir regeneration were not found. On the other hand in many transects the value of regeneration index is high, with two peaks in transect number 6 and number 18 where the number of fir seedling is very high. Since the value of *Ir* is strongly dependent on the number of fir seedlings, the highest (resp. lowest) values of *Ir* were found in transects with the highest (resp. lowest) number of plants. Furthermore, the mean of the height also affects this explains why the *Ir* in the transect 18 is higher than *Ir* in the transect 6.

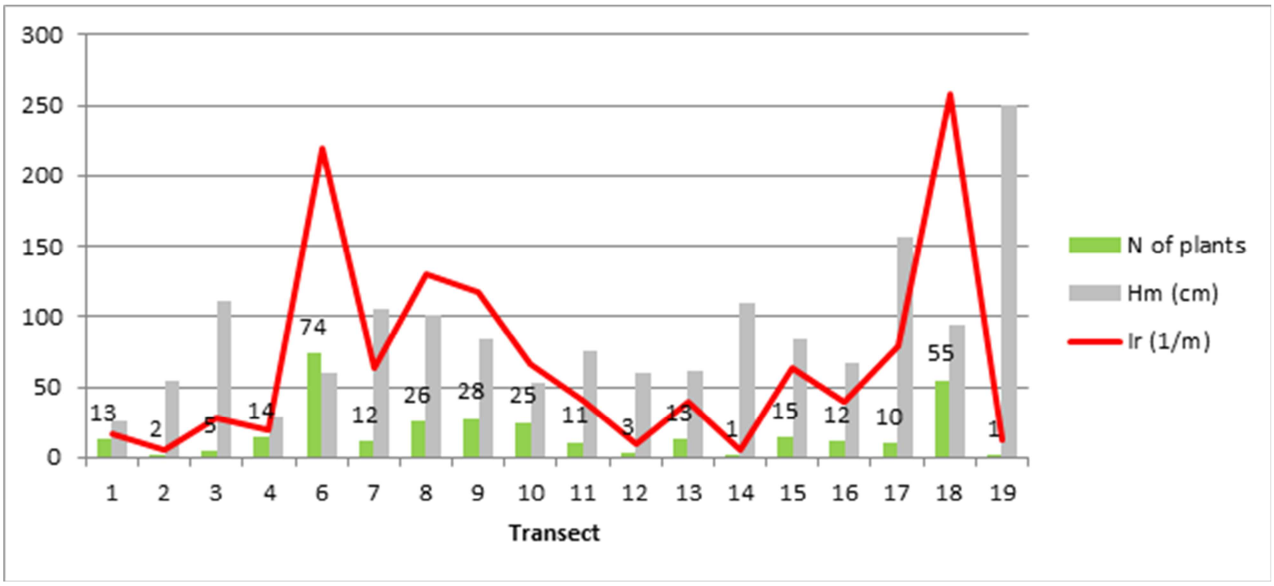

Figure 10: Regeneration Index (Ir). The green bars represent the number of plants, while the grey bars represent the mean of height of the plants within the transects. The transect number 5, 20 and 21 are missing due to the absence of silver fir natural regeneration.

The biggest values of *Ir* index are located in the Western part of the study area closely related to the presence of a lot of mature trees of silver fir (Figure 11).

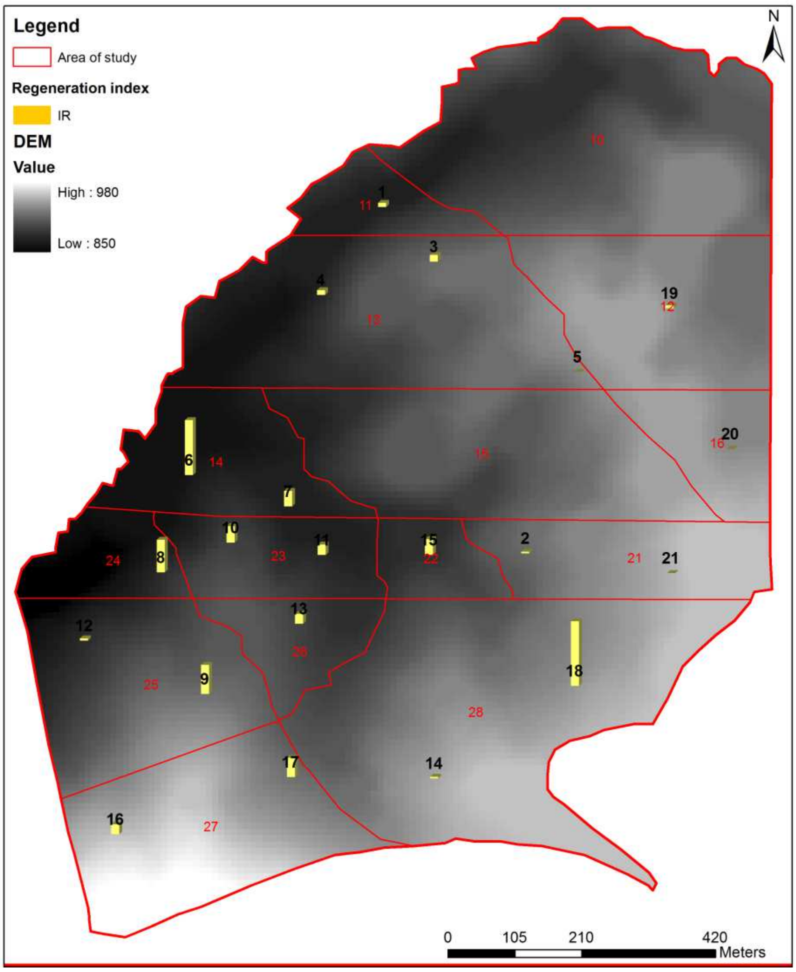

Figure 11: Distribution of Regeneration Index among the study Area. The black numbers indicate the identification number of transects, while the red numbers indicate the identification number of forest stands.

The value of the index decreases when moving from the Western to the Eastern part of the forest. Anyway, the local condition of the light and the presence of shrubs can influence the natural regeneration of silver fir (Magini 1967). Although silver fir is able to survive in little light conditions, due to the fact that it is a shade tolerant specie, when the density of the canopy is very high the regeneration cannot develop. This is the case of test area number 12 in which the assessed canopy density was 95%, the biggest value in this context, and only very young trees of silver fir were present. On the other hand the biggest value of Ir index is located far away from the MaB. An explanation is that in this place there was a gap of crown cover and also a presence of mature trees of silver fir close to the transect.

In conclusion the silver fir natural regeneration is present almost in the whole study area, but the comparison between the lengths of leader shoot and twigs showed that most of regeneration plants present a low value of ADR (Figure 12).

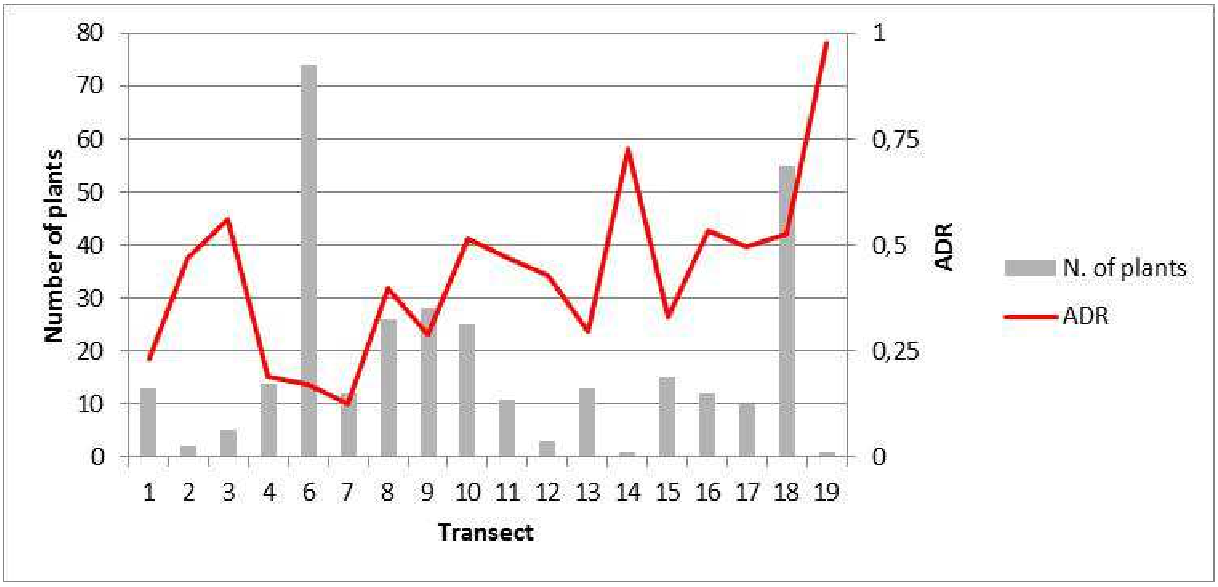

Figure 12: Trend of ADR (Apical Dominance Ratio). The grey bars represent the number of plants of silver fir natural regeneration, within the transects.

Basically the silver fir regeneration is present, often with a high number of plants. However the ADR presents higher values in the transects with few plants. The main reasons are certainly the high crown cover of the canopy and plant competition. In fact in some transect more than 50 plants in 20 square meters were measured. Finally, the presence of the wildlife (Gennai & Grigioni 2008) can represent a further obstacle to the development of silver fir regeneration.

Discussions and conclusion

The current structure of the forest represents the outcome of the past forest management, according to the old forest plan for the Pietrabbondante forests' (1969-1978). The main species present in the forest are turkey oak, beech and silver fir which constitute the canopy of the forest, with many other species that constitute the understorey. Over the years, the forest management practices have promoted the diffusion of silver fir among the forest, increasing the role of the forest in the contribution to the conservation of biodiversity. For this reason there is high presence of silver fir regeneration, particularly concentrated in the western part of the forest, even if its presence is observed in the whole study area.

Due to the diffusion of silver fir in this forest, the forest structure has shifted from an even aged to uneven aged forest structure, with high value of crown cover. These conditions if on one hand promote the growth of silver fir, on the other hand prevent the turkey oak natural regeneration. In fact turkey oak is a shade intolerant specie and better light conditions are required to allow the development of seedling. In fact, due to the high density of canopy, no young trees of turkey oak were measured in the study area but only mature trees. Furthermore, there were a lot of seedling but after two years it disappeared due to the light condition. Silver fir is to a remarkable extent shade-tolerant. Its natural regeneration can take place even under dense canopies, where illumination is reduced by as much as 80–95% compared to ambient level, and young plants may survive under such conditions from ten to twenty years (Robakowski et al. 2004).

The regeneration index of silver fir depends on the number of plants, the surface size of the transect and the mean height of the plants. Being the surface equal for each transect, the value of index is strongly related to the presence of mature trees able to disseminate and the mean of height. Except for the value of regeneration index measured in the forest stand number 28, which is the biggest one, the bigger values of index are in the western border, near the MaB reserve. This means that the silver fir of the MaB reserve contributes to the diffusion in the nearby forest. Furthermore, the presence of gap in the crown cover allows the development of regeneration (Watt 1947; Coates & P. J. Burton 1997; Albanesi et al. 2005; Dobrowolska & Veblen 2008). As a matter of fact the gap of canopy in the forest stand number 28 explain the biggest regeneration index. Although the highest presence of silver fir regeneration resulted in the area closer to the MaB, the ADR presented lower value in this area, due to the high competition between seedlings. On the other hand, in the transects where the number of plants is lower, the value of ADR is bigger. This means that, in the future, forest management practices will have to pay attention to the regulation of density of silver fir, allowing the growth of conifer.

In conclusion, Monteluponi forest is of particular ecological importance for many reasons. First of all it is within the Site of Community Importance “Bosco di Collemeluccio – Selvapiana – Castiglione – La Cocozza”. It is next to the Man and Biosphere reserve of Collemeluccio, which is the main site with the natural silver fir in Molise. The forest presents favorable conditions for the conservation of biodiversity allowing the diffusion of silver fir. In particular it could be opportune to conserve the silver fir in the western area, by applying the best silviculture practices which could allow the coexistence of beech with turkey oak, paying peculiar attention to the turkey oak natural regeneration. Promoting the introduction of silver fir through artificial gaps in the proximity of mature trees could represent a good solution for increasing the presence of silver fir.

Since silver fir is mainly concentrated in the area closest to the MaB, even if its diffusion is increasing also in the area far away from the MaB, the forest could be split into two areas: western and eastern. The western area would correspond to the study area of this work, while the eastern area would be the remaining part of Monteluponi forest. Considering the proposal for the extension of the MaB reserve (Blasi 2002), the western part could be considered as the core area of the MaB, whose main function is the conservation of silver fir while the eastern area could be considered as the buffer zone, in which the silver fir can expand.

Monteluponi forest can contribute to the conservation *in situ* of silver fir, playing an important role in the conservation of biodiversity. Furthermore, since the oak is the most common forest type in that area, the diffusion of silver fir can be promoted in the other forest of the Alto Molise Community Mountain, reducing the fragmentation of conifer along the Apennine. For this reason, new tools of forest planning at landscape level (Saura et al. 2011) such as Territorial Forest Plan (Agnoloni et al. 2009), can be helpful to better understand the dynamics of silver fir at this latitude in order to implement the ecosystem approach, promoting biodiversity conservation.

Tools of Sustainable Forest Management

Paper published, submitted or still in progress

Santoro, L., **Santopuoli, G**. & Micangeli, A., 2011. The role of GIS technology in monitoring sustainable and participatory management model of the forest resources in the Logone Valley between Chad and Cameroon. In 6 Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems.

Vizzarri M, Chiavetta U, **Santopuoli G**, Tonti D, Marchetti M. Mapping forest ecosystems functions in Territorial Forest Planning (TFP) in a Natura2000 site. Submitted.

Santopuoli G., Requardt A., Marchetti M. 2012. Application of indicators network analysis to support local forest management plan development. A case study in Molise, Italy. Published.

The acknowledgement that forests play a multiple role has led to an increase of complexity of forest management (Wolfslehner & Seidl 2010). Since forests supply numerous ecosystem services for human welfare, the importance of forest management has increased over the years and many stakeholders are paying attention to forest resources. The increased number of stakeholders results in an increase of expectations, often with many conflicts of interests. For this reason, forest managers are called to respond to the many challenges concerned with forest field. Furthermore, the climate changes, loss of biodiversity and the abandonment of agriculture are affecting an increase of complexity concerned with the forest issues. In keeping with international efforts to encourage SFM, new tools of forest planning have been developed in the last decades, with particular emphasis on the systemic holistic approaches (Corona 2010). One of the most important tools of SFM is the Forest Planning at all levels.

Based on the hierarchical framework, in Italy there are four main levels of forest planning (Cullotta & Maetzke 2009), scaling down from the National Forest Programmes (NFP) to smaller scales such as Regional Forest Plan (RFP), Territorial (i.e. sub-regional or Landscape) Forest Plan (TFP) and Unit Forest Plans (UFPs). Forest plans at regional level are gradually implemented to meet the stated goals of management, emphasis focuses on a few geographic areas in which roading, harvesting and silvicultural activities will be concentrated in the near term (R. Tittler et al. 2001). While the TFP is always spatially explicit, and represent the stage at which landscape ecology, analysis and design feature into the optimization of both timber and conservation planning. UFP provides instead a detailed record of the ecological conditions and the silvicultural techniques to be employed at specific sites. However, forest planning at all levels includes SFM as the main aim and stress the importance of the Criteria and Indicators (C&I) for SFM (Gordon M. Hickey 2008; Wijewardana 2008).

Although the hierarchical model allows to collect information regarding the state of a given forest resources, including their timber volumes, species composition and sustainable development, in order to monitor and manage forest resources, there is a need for a better intersectorial and harmonic relational frame among planning tools for the forest and other sectors of environmental planning, also in the horizontal model. For this reason the ecosystem approach plays an important role within forest planning, including processes such as regeneration, mortality, disturbances, recreation, as well as element cycling and soil dynamics. The main domain of forest planning is to support the development of management alternatives, identifying the zone land for priority use (Vincent & Binkley 1993; Zhang 2005) and promoting the rural development.

Consequently, SFM aims at the active participation of stakeholders in decision-making to incorporate public opinion in forestry. In response to these issues, tools like Multi-Criteria Decision Analysis (MCDA) and the participatory approach can be helpful to support SFM. The combined application of these tools is intended to strengthen SFM as an interface between forest ecosystem and society. MCDA can be described as a highly feasible tool for integrated, holistic forest planning, by providing a formal framework for participation and decision-making (G. A. Mendoza & Prabhu 2003; G. A. Mendoza & Martins 2006). Furthermore, the Geographic Information System (GIS) can be considered as a new decision support tool used in all business processes of integrated forest management offering a great contribution to support SFM.

In the following paragraphs three case studies, carried out by personal experience, will be illustrated, within which the combined use of GIS, MCDA and participatory approach are utilized in order to monitor and assess the SFM.

The role of GIS technology in monitoring sustainable and participatory management model of the forest resources in the Logone Valley between Chad and Cameroon

In the Sudano-Sahelian zone the natural environment is deteriorating at a worryingly rhythm. Despite of the measures taken by the local authorities and supported by the international community there is still an intensive and not sustainable exploitation of the forest resources. This is particularly evident in the Logone Valley, along the border between Chad and Cameroon, since wood and coal still represent the main economic activity for the people living in this area.

An international project, sponsored by the European Commission and carried out by the Italian NGO *Cooperazione Rurale in Africa e America Latina* (ACRA), is aimed to remedy this serious situation.

The main aims of the project are to promote the multifunctional role of forests and to improve the functional efficiency in supplying ecosystem goods and services. The specific goal of the project is to promote a sustainable and participatory management model of the forest resources of the Logone Valley, in order to encourage the development of eco-friendly economic initiatives among the forest cooperatives and organizations. The implementation of a GIS as a project support is functional to create an instrument for the monitoring of the activities promoted by the program, to share the results with the organizations involved easily and to elaborate forest management plans.

During 4 years of project ACRA local technicians have collected data regarding activity monitoring and benefits achieved on the forest resources within 134 villages in order to appreciate changes year by year. The data collected has been organized in database and GIS maps that were also used to verify the achievement of the project goals by European Commission and sponsors. This results in a very appreciated and user friendly instrument of management and data representation by both local citizens and authorities. In order to guarantee the sustainability of the project, local technicians have been trained on database and the GIS use for future applications.

Context and genesis of the intervention

Woods and forests represents the main source of production in Chad since they guarantee energy supply, timber and natural products (plants and fruits) and preserve biodiversity. In spite of the measures taken by the local authorities and supported by the international community, there is still an intensive and not sustainable exploitation of natural resources. In particular, in the Logone Valley, along the border between Chad and Cameroon, the progressive exploitation of plant coverage has caused a serious environmental degradation and a gradual desertification.

A respectful management of natural resources aimed at guaranteeing their ecologic and socio-economic role is an essential instrument which can be used to fight against poverty and to promote a sustainable development. This is the goal of the project ***“Gestion participative des ressources forestières et promotion d’initiatives économiques éco-compatibles dans la Vallée du Logone”***, (in the following “Vallée du Logone”) promoted by an Italian NGO[7], and financially supported by the European Community.

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[7]ACRA (Associazione di Cooperazione Rurale in Africa e in America Latina), Via Breda 54, Milan, Italy.
Project sponsor: EU Thematic Program “Environment in Developing countries budget line 21 02 05”.
Project partners:

- Sana Logone, Inades Formation Tchad (IFT); Association de Promotion Humaine dans la Vallèe du Logone;
- Cirps Centro Interuniversitario per lo Sviluppo Sostenibile;
- CETAMB, Centro di documentazione e ricerca sulle Tecnologie Appropriate per la gestione dell'ambiente nei Paesi in via di sviluppo.

The four year project represents an attempt to use alternative technologies and production techniques to reduce the main economic activity of the Logone Valley constituted essentially by wood saw and charcoal production.

Most of the villages have already formed cooperative groups and local organizations to run the management of local resources but usually these structures are made up of young people with no experience. The lack of technical and organizational competencies and the difficulty to diversify the income funds have slowed down the progress of these activities.

The project is developed through 4 parallel activities:

1. To enhance small local forest cooperative groups through staff training on agro-forest techniques and the development of common regulations. To promote mechanisms encouraging the legal recognition of the local groups.
2. To promote innovative technologies to produce vegetable fuel alternative to wood coal that has a less impact on the environment.
3. To improve local trees and plants, to support local weaving factories and the marketing of local agro-forest products (honey, neem oil, Anacardium, Moringa oleifera, Mangifera indica, Psidium guajava).
4. To promote awareness activities and research on soil preservation and environment's preservation.

All the activities were developed with the active participation of local communities and organizations in order to make them aware of the project results.

The scientific partnership of CIRPS Sapienza (Interuniversity Research Centre on Sustainable Development) inside the project *Vallée du Logone* was meant to offer training activities and assistance to ACRA technicians in developing a database to be used in preparing maps by means of **GIS** (*Geographic Information System*) technology in order to monitor and share the progressive project results with all the organizations and people involved in the project.

During the missions held in Chad and Cameroon between 2008 and 2010, CIRPS worked with the support of ACRA local staff and all the local technicians in order to develop database and data collection to support GIS.

The GIS implementation

Technically, a GIS is a geographic information system which includes mapping software and its application with remote sensing, land surveying, aerial photography, mathematics, photogrammetry, geography, and tools that can be implemented with GIS software (Clarke & Clarke 1997).

A GIS allows to represent geographically referenced data with descriptive information.

The geographic information is stored in separated layers that are constituted by geometric elements as points, lines and areas on the screen (Figure 13). Each geographical feature of the layer is linked to a descriptive element or attribute table that contains the characteristics of the spatial object, and its exact geographical position expressed by coordinates.

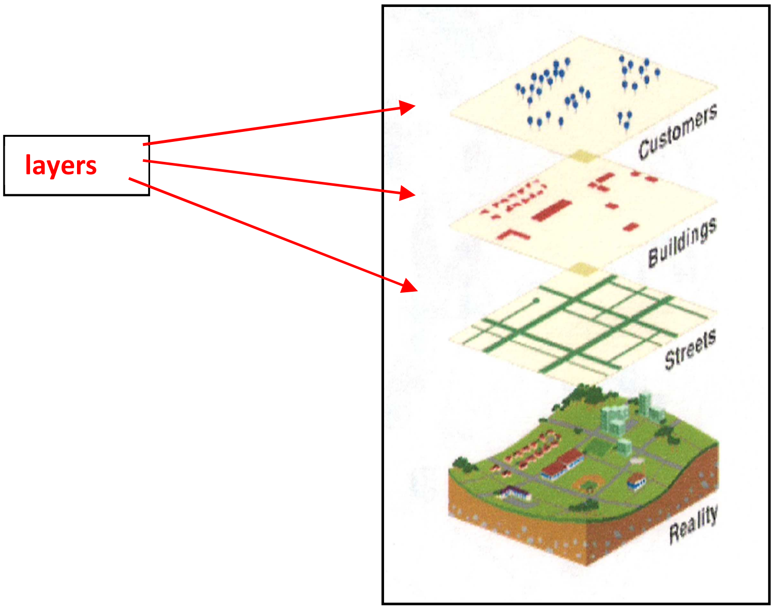

Figure 13: Geographic information layers.

The GIS applications allow users to create interactive queries (user created searches), analyse spatial information, edit data, maps, and present the results of all these operations.

The project area was located along the Logone River and it included the region of Mayo-Danay in the territory of Cameroon and Mayo-Kebbi Est in the territory of Chad (Figure 14).

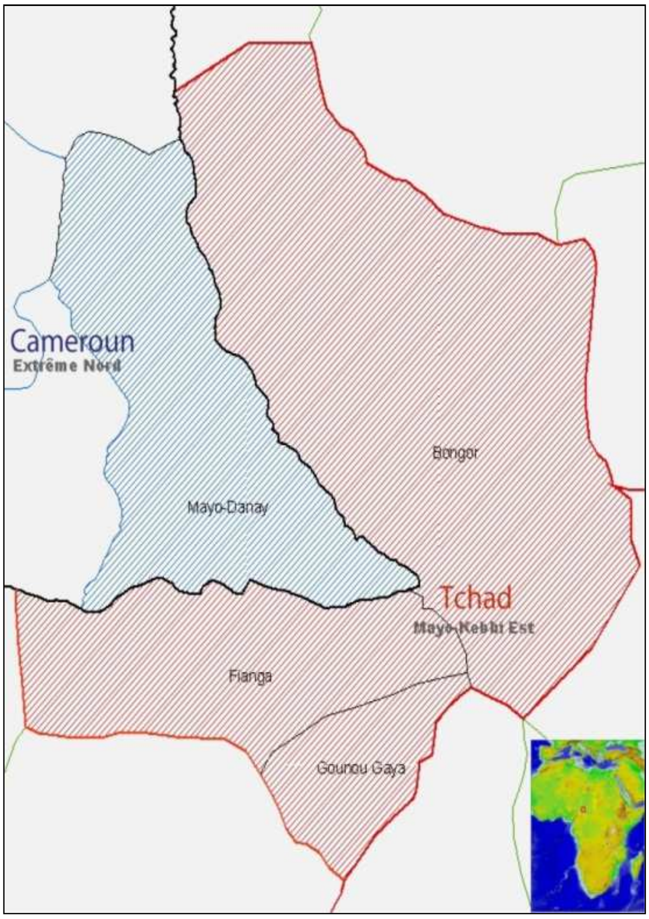

Figure 14: Map of the project area (Logone valley) in Chad and Cameroon

The data collected in the project *Vallée du Logone* have been implemented through the software ArcGIS 9.3® in order to create interactive maps.
The map implementation was accomplished through the following phases during the three missions carried out in Chad and Cameroon:

- ✓ the first phase aimed to collect data related to the status of project that would have been the core attributes of the spatial elements of the maps. The data collection was accomplished through the submission of questionnaires to the village organizations. Altogether seven different questionnaires were submitted each for any different village organizations: beekeepers, neem producers, coal producers, artisans, arborists, fruits producers, energetic resource users and a social-economic assessment of the village. The questionnaires were submitted to village organizations by ACRA local staff that were also charged to register the village coordinates through a GPS.
  These deal with the administration of questionnaires to the communities and bring back the results to the local coordinator of each country. At this stage the main difficulty was to ask organizations simple questions with quantitative answers that could be showed on a map and be quantified over time;

- ✓ the second phase aimed to create a database of data collected necessary for GIS implementation. This work, and consequently the updating of the database, is ongoing in order to monitor the project status over time.

  The software used to create the database was Microsoft Office Access®, which CIRPS operators were already skilled with. This kind of software was chosen since, besides being able to manage a large quantity of data, it allows to create specific queries without any knowledge of the SQL programming language. Queries are particularly useful to control, manipulate, analyse and report data since they enable to create a table containing only data of interest time after time obtained by merging data coming from different tables. Moreover the software has the possibility to import and export data from many different formats including Excel, Outlook, ASCII, dBase, ODBC, etc., and allows to link to data in its existing location and to use it for viewing, querying, editing and reporting. The main difficulty in implementing the database was to join the data about different activities that was collected. However, the main action was to fix one common field and one primary key for each table. In this way it was possible to link the table through database tool called "*relationships*" (Figure 15).

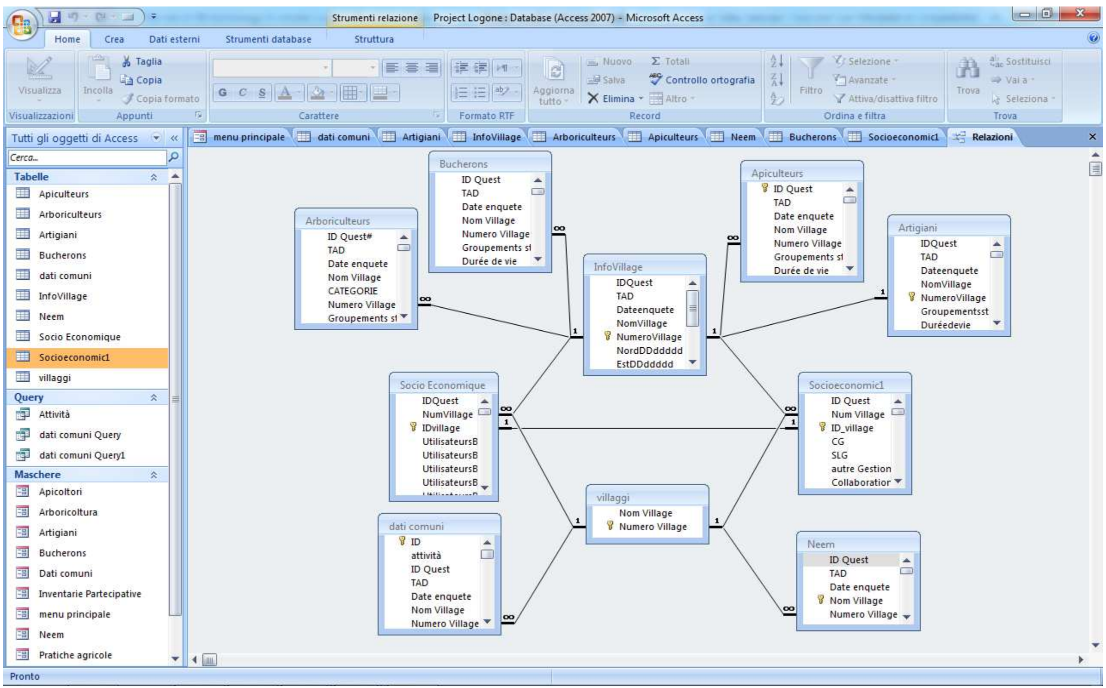

Figure 15: Relationships set up between tables.

- ✓ The third phase was aimed to implement the GIS. A total of 134 villages have been involved in the project.

The reference scheme for developing and monitoring of the whole project is the "Logical Framework of Action" (in the following “QLA”). In particular the specific goal contained in the QLA is:

“Create and promote a lasting and shared management model of forest resources in the region of Logone valley in order to enhance sustainable activities among the organizations that work with them”.

The specific goal is further defined through 3 "*expected results*". For each of the 3 expected results the QLA specifies furthermore several indicators that could be used to periodically check whether the result has been obtained. These indicators are defined as "Objectively Verifiable Indicators” (in the following “iov”). Figure 16 graphically shows the logical framework of the specific goal.

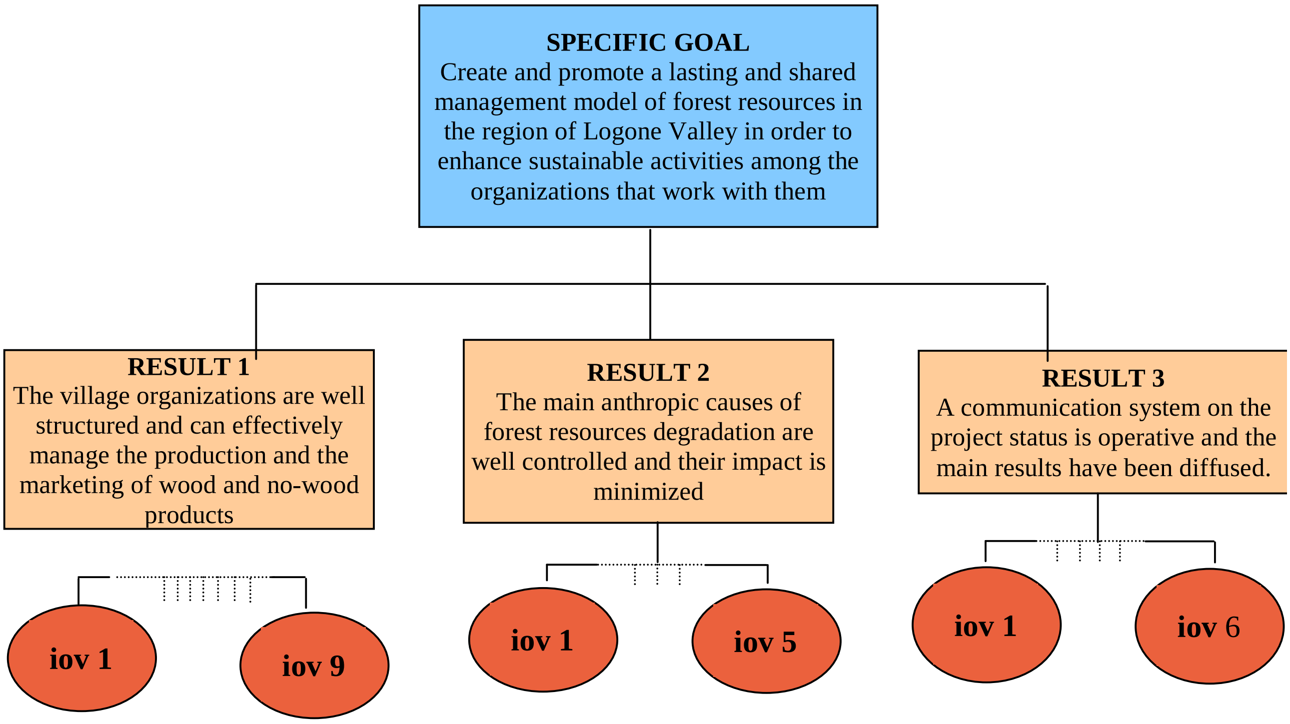

Figure 16: Logical framework of the specific goal

The questionnaires conducted in 134 villages which participated in the project allowed to correlate objectively verifiable indicators with the answer to one or more questions. This relationship is settled by the SICER (*Systeme d'Information, Communication and Evaluation des résultats*) an instrument of project planning created as part of the Logical Framework of Action.

The SICER is based on the importance of:

a) Evaluating changes of the answers over time;
b) Casualty as the base for change management;
c) Visual approach that allows to communicate easily the results and with great impact.

The SICER directly links the iovs of the project with a graphical representation of GIS. Figure 17 graphically shows an example of a relationship between Logical Framework of Action and GIS by means of the SICER for feature of beekeepers.

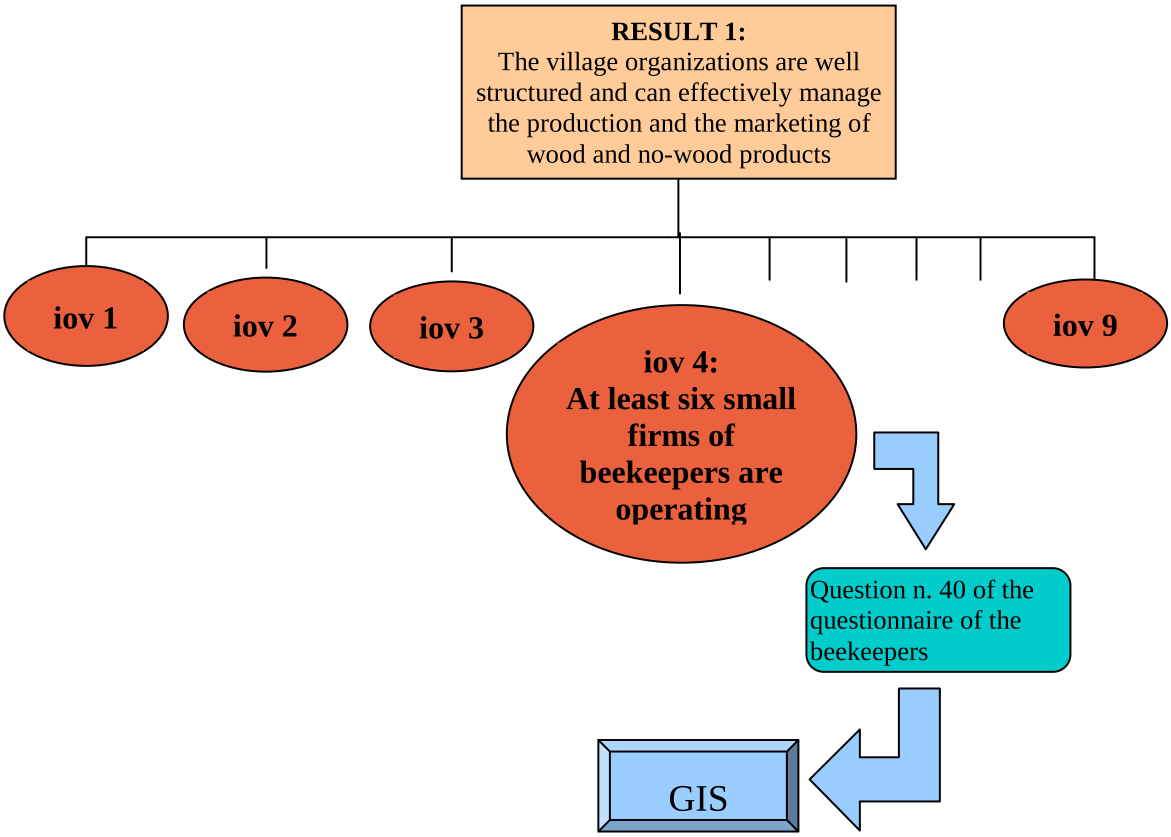

Figure 17: Relationship between Logical Framework of Action and GIS through SICER for feature of beekeepers

The map in Figure 18 shows the results of the question n. 40 of the questionnaire concerning the beekeepers that represents the iov n.4 of the Result 1: *how much honey per year do you produce?*

In this case the answer could only be quantitative. In order to represent these data a *feature class*[8] has been created in GIS using a bee as a symbol. The dimension of the bee defines the amount of honey production (Figure 18):

- ✓ 5 ÷ 50 litre/year (small bee);
- ✓ 50 ÷ 500 litre/year (medium bee);
- ✓ over 500 litre/year (big bee).

The amount of honey produced is not of course an indicator that in the village there is a small firm of beekeepers operating. In fact a lot of other factors are required in order to consider a firm operating (market of honey, a stable sale network, distribution chain, etc.).

However, the graphical data restitution of GIS concerning the honey productivity and its development will easily allow the project managers to comprehend the evolution of the beekeeper firms in both territories and to communicate it to village organizations in a simple way. In a more advanced stage of the project, other parameters of the questionnaires could be considered in order to have information on the operation of the firms.

[8]A feature class is a collection of elements (or objects) having the same geographic geometry (ie points, lines or polygons), the same attributes and the same geographic reference system (source*: ESRI Italia*).

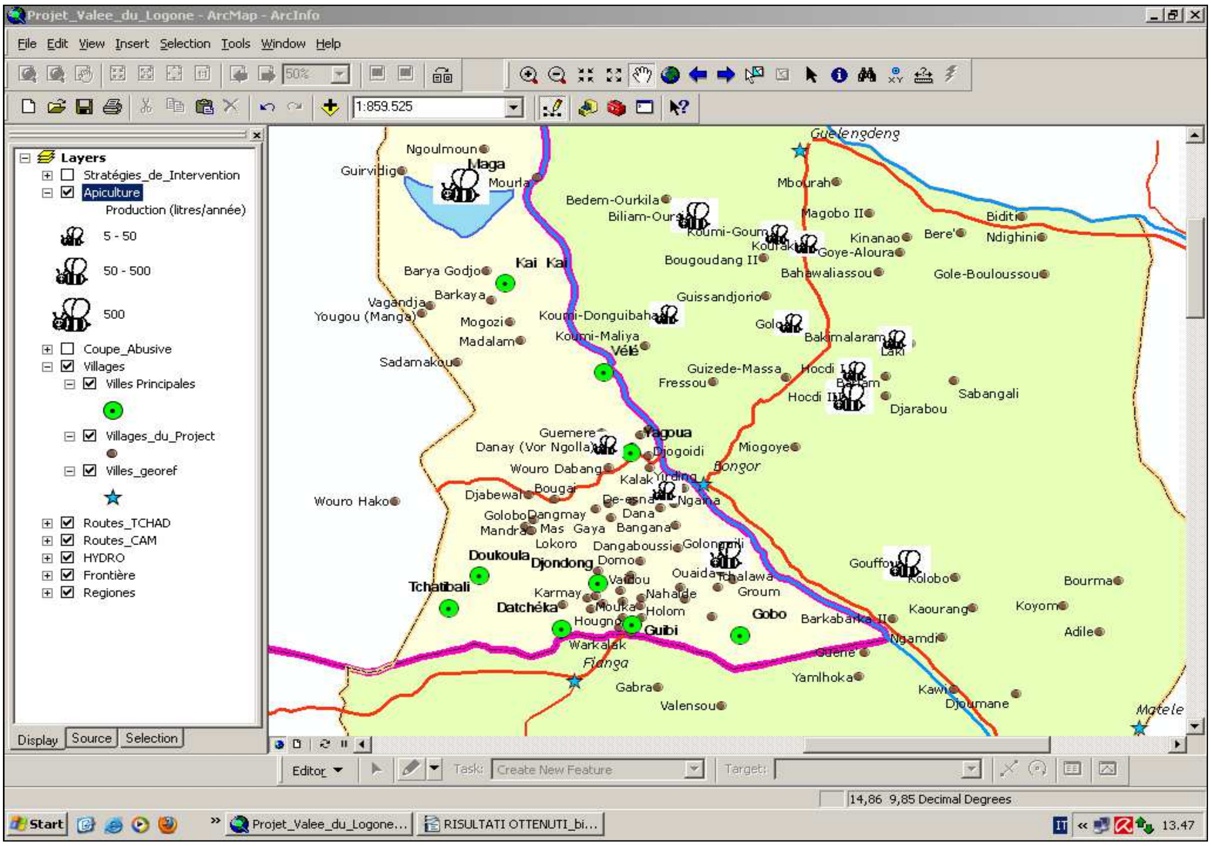

Figure 18: Map of honey producers in Chad and Cameroon

Overall 8 different maps have been created utilizing the new available data. Considering the 4 parallel activities developed by the project, the maps answer the following needs:

- ✓ Promotion of mechanisms that encourage the legal recognition of the local groups;
  1) Legal framework and agenda;
- ✓ Improvement of local trees and plants, supporting local weaving factories and the marketing of local agro-forest products (honey, neem's soap, cashewa);
  2) Revenue of production activities;
  3) Marketing;
- ✓ Promotion of innovative technologies through staff training on agro-forest techniques to reduce the use of wood coal with less impact on the environment;
  4) New technologies;
  5) Solar Cooker improvement and renewable energies;
- ✓ Awareness activities and research on environmental preservation, through the activities aiming at forest protection
  6) Illegal harvest;
  7) Implementation of eco guards;
  8) Fire fight.

All the aims of the maps are to represent the cooperative activity trends in the rural environmental area of the Logone Valley. The creation of the maps was possible thanks to the implementation of participatory strategies. In fact local technicians have checked various information concerned with the status of enterprises through the questionnaire developed by ACRA.

In the following just two maps are reported as an example of how the logical framework objectives were verified and graphically reported. In particular the two maps are related to those iovs regarding promotion of innovative technologies and research and environmental preservation.

Before describing the maps, it is necessary to say that data collected for each local group has been summarized by village, because the size of the territory is huge and in many cases there is more than one cooperative for each village.

The map (Figure 19) shows the implementation and the utilization of new technologies developed with the project.

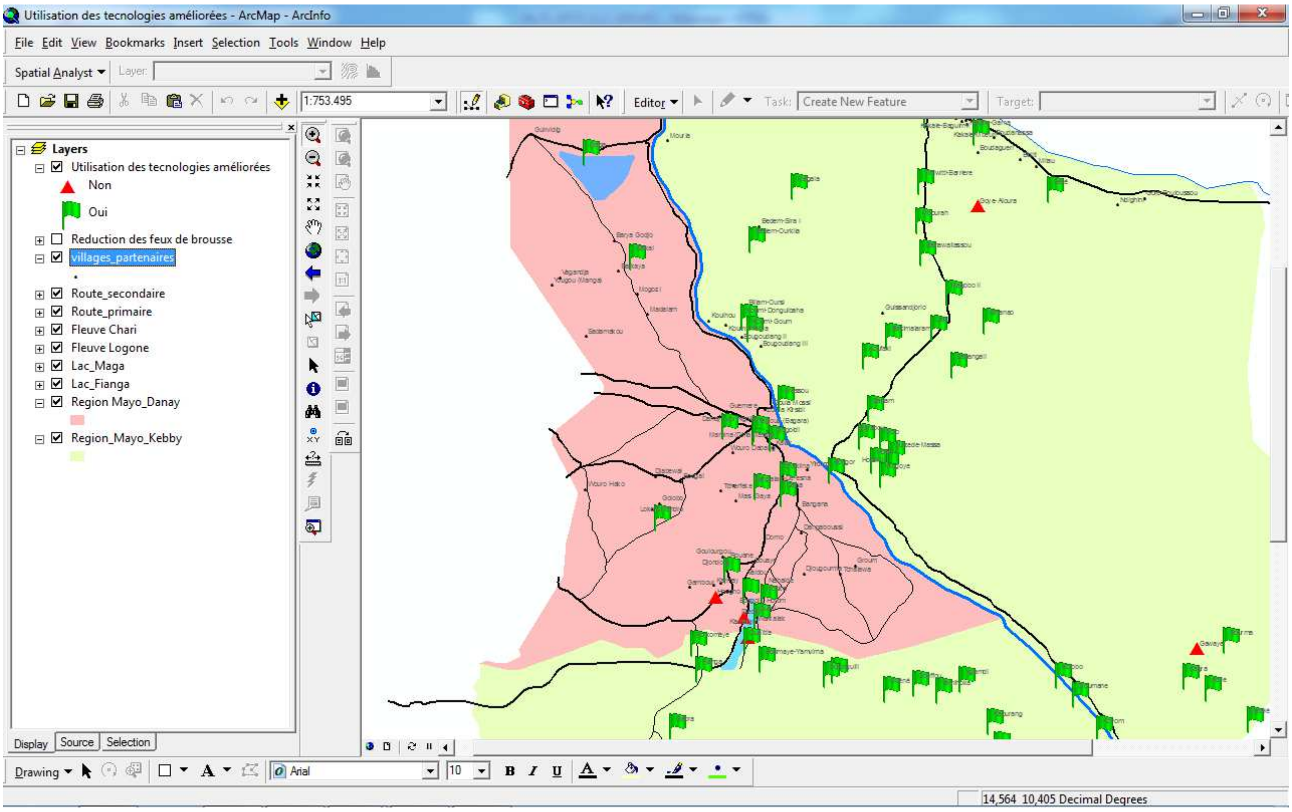

Figure 19: Cooperatives that have adopted new technologies in the production process

Overall more than 80% of the cooperatives uses new technologies developed, distributed or learnt by ACRA. They are: solar cookers, trainee courses for workers, cashew roasting, the production of soap and etc..

Particular attention has been devoted to the forest area and the Figure 20 shows one of the main activities concerned with the conservation and the monitoring of the forest. The activities include: fire fighting, monitoring by eco guards, and fighting illegal harvest.

In particular after 4 years of monitoring, some villages have hired the eco guards and have improved the monitoring of fire events.

The following map shows with green bike symbol the forest areas where eco guards are present. The red bike instead represents forest areas without eco guards. Even in this case, the use of bikes like the presence of eco guards, results clear to local organizations.

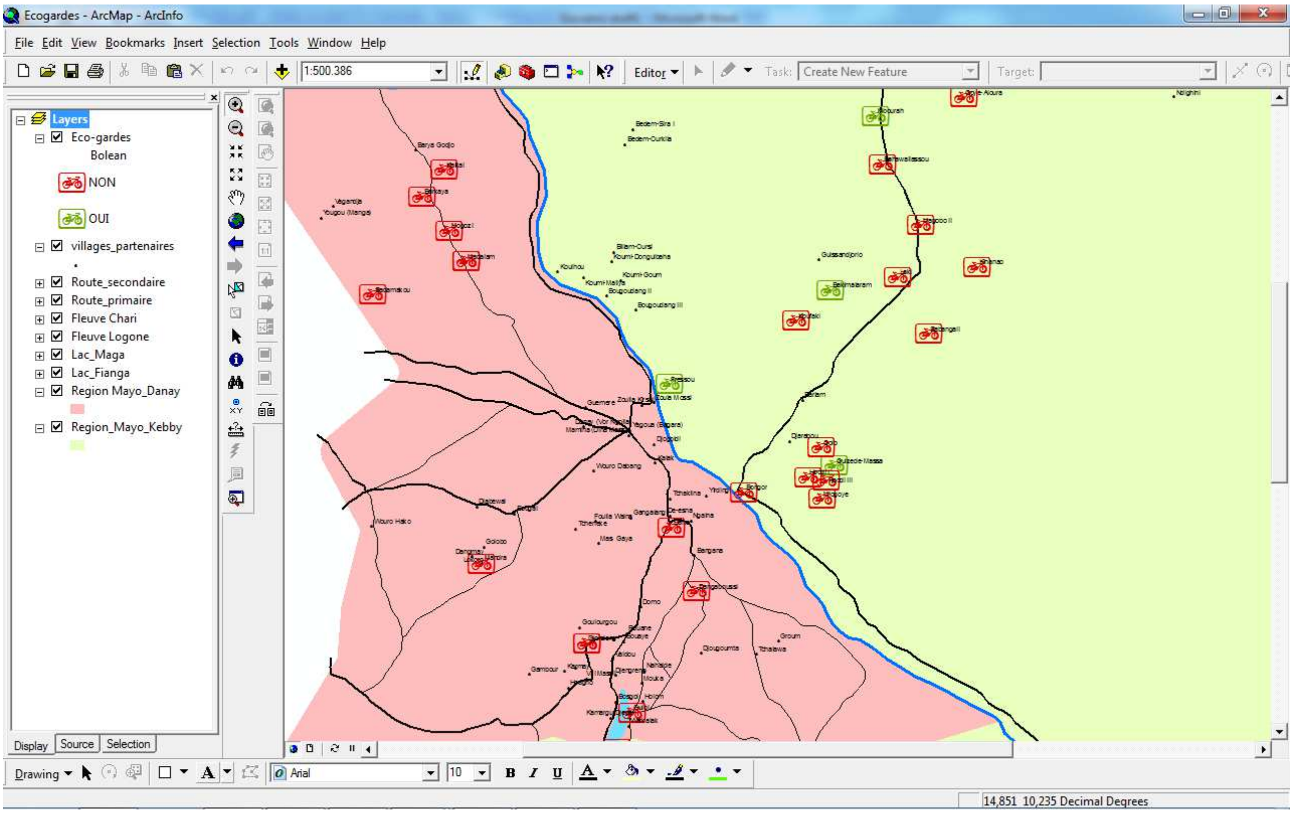

Figure 20: Village with ecoguards in the Logone Valley

Technology sustainability

As for all the activities introduced by the project also for the GIS technology and the database a great importance has been assigned to the possibility of making local technicians able to manage the database created and use GIS technology. Therefore during the last mission a two week training course about the implementation of databases and the GIS was held in Yougua, one of the main villages of the project area.

The first week of the course was dedicated to teach how create and use a database with the result that technicians, at the end of the course, were able to create tables, queries, masks and reports through Access.

The second week was dedicated to the use of GIS technology. Even in a sustainable point of view, a free GIS software (Q_{gis}) was used. During the course technicians learned to import GPS point coordinates and create shapes: points, lines and polygons types. They also were able to create thematic maps and export the layout format. The course provided the basic information about the coordinate systems and scale map.

Conclusions

The previous maps show that GIS may be a great instrument to monitor the project results and easily share them.

The activities monitored through GIS may have a positive effect in fighting against deforestation since they regulate traditional economic activities and introduce innovative and alternative ways of production.

The developed maps could be used for calculating the collective profit and loss account of farmers, defining the forest’s borders, taking into account the official classification and trying to consolidate alternative techniques like biogas and solar energy.

Finally the response of operators, technical trainers and people themselves was exceptional. They understood the importance of a monitoring activity and they were very interested in an instrument which involved the use of Satellites, GIS and information software. The digital device is reduced and allows cooperation activities to be much more effective, to verify the results obtained, the most receptive area and the one requiring more attention.

Mapping forest ecosystems functions in Territorial Forest Planning (TFP) in a Natura2000 site

Introduction

Since forests provide several forest functions, the role of forest planning is crucial to identify forest management alternatives (J. Kangas & A. Kangas 2005). Despite forests supply numerous goods and services, the forest planning primarily aims to promote sustainable development, as highlighted by the Brundtland Report (1987) and the Earth Summit (UNCED 1992). In the last decades, numerous efforts have been made at global and European level to put the concepts of sustainability into forest resources management and planning, and many initiatives have taken place to define Sustainable Forest Management (SFM) and to develop tools to support it (Hickey et al. 2005). In Europe, the first initiative to widespread SFM was driven by the Ministerial Conference on the Protection of Forests in Europe (MCPFE, now FOREST EUROPE[9]) which adopted the concept of SFM in Helsinki in 1993 (MCPFE 1993).

The last decades have seen an increase in terms of global awareness of the important roles of forests at international level. In this sense, different international agreements have been carried out in order to define and subscribe the various ecosystem services provided by forests according to local community needs. Furthermore, numerous efforts have been done during the latest years by the scientific community to evaluate the multifunctional role of forests to support the forest decision-making processes (Wolfslehner and Vacik 2011; Lexer and Brooks 2005; Stenger et al. 2009; Wang et al 2010; Rametsteiner et al 2011; Gatto et al. 2009; Daily and Matson 2008).

Since the Kyoto Protocol (1997) and until the last MCPFE event (2011), different guidelines to achieve the SFM were developed, both at global and European level. Such purposes were based on the multifunctional role of forests, in terms of: climate-change mitigation, carbon sequestration, environmental control on water quantity and quality, timber supply, hydrological protection, biological diversity conservation and protection of cultural and spiritual heritages of forests. Thus, forest management and planning is required to ensure the international commitments about forest ecosystem protection and the continuous provision of goods and services to local communities by woodlands.

The Territorial Forest Plan (TFP) places itself at a higher level in forest planning hierarchy, defining peculiar functions of forests to be planned. By shared scientific definition, TFP seems to be the most suitable tool for considering the multifunctional role of forests and for maintaining the balance between forest ecosystems and inhabitants requirements (Agnoloni et al. 2009). In detail, TFP is a forest policy tool restricted to the district surface, such as a basin area, a mountain community, or a Natura2000 site, which is uniformed under an administrative and geographical point of view (Cullotta and Maetzke 2008; Agnoloni et al. 2009). Through an extended collection of information about the whole environment conditions, and pastoral and forest resources, the TFP provides different forest management guidelines according to the SFM principles. Indeed, the TFP has no prescriptive features, but only descriptive ones (Agnoloni et al. 2009). In detail, TFP could be applied for assessing forest ecosystem functions within the Natura 2000 network sites, in which the needs of biodiversity conservation and landscape protection are amplified. In this context, the integration between forest mapping and inventory data is needful to ensure the acquisition of current, meaningful and accurate information, in order to support the strategic and tactical planning development and to lead forest managers towards SFM perspectives (Corona et al. 2003). In the TFP, the estimation of relationships between remotely sensed data and the biophysical features of forest vegetation allows mapping the attributes observed at the sample inventory units. In this way, attributes can be predicted for the entire area thus producing thematic maps.

[9] On line at: www.foresteurope.org/

In this paper, a k-nearest neighbor (K-NN) non-parametric approach has been used to spatialise part of inventory forest parameters in order to create informative basic layers. These layers have been putted into a Multi-Criteria and Multi-Level (MCML) decision-making process. A decision is a choice between alternatives. In a MCML decision support, the basic elements of a decision are known as a "*criteria"*. A set of criteria are combined in such a way to achieve a single composite basis for a decision according to a specific objective (Eastman 2009). The main objective of this research is to identify specific Functional Destination Units (FDUs) in a Natura2000 network site. The FDUs are intended here as forest areas characterized by the same provided ecosystem service, among timber supply, protection against hydrological instability of slopes and conservation of biological diversity. FDUs mapping allows to assess different forest functions of the whole territory and to advance some assumptions about forest resources management and its spatial distribution. At last, a map of FDUs has been compared to an expert classification of a test sample in order to validate the spatialization algorithm and to provide the FDU classification accuracy.

Study area

The case study refers to the Natura2000 SCI (Site of Community Importance) "*La Gallinola, M.te Miletto, M.ti del Matese*" (*IT7222287*), and it covers an area of 25000 hectares (Figure 1).

Figure 21: Overview of Italy with regional boundaries and zoom on Molise region. On larger map, dashed line boundaries highlight the SCI. Dark grey areas refer to polygons of Forest Types Map of Molise region (Garfì and Marchetti 2011).

The Matese mountains represent one of the most important mountain chains along the Southern Apennines, and they are located on the boundary of Molise-Campania regions. In particular, the Molise region side has an elliptical configuration, from the NNW to the SSE direction, along 35km on the regional boundary. The shorter axis has a SSW-NNE orientation and it is extended for 8km from the regional boundary towards the Biferno river basin. Altitude ranges from 500m a.s.l. of Volturno river valley to 2050m a.s.l. of Monte Miletto. Under an administrative point of view, the SCI area overlaps the territory of 13 Municipalities which are grouped in Matese and Centro Pentria Mountain Communities. The total population in the SCI area is about 20300 inhabitants (ISTAT[10] 2001). The Matese SCI belongs to the *temperate oceanic submediterranean* bioclimate (Rivas-Martinez 2004), with abundant annual precipitation (1614mm year^{-1}), even in summer time (142mm year^{-1}), and no aridity during summer months. The average annual temperature is about 11.5 °C, less than 10 °C for 6 months year^{-1}. However, the minimum temperature is even greater than 10 °C (Blasi 1996; Paura and Lucchese 1997; Blasi et al. 2007). The natural landscape of Matese SCI is extremely diversified and patched (Garfì and Marchetti 2011). Pastoral areas alternate with forests and farmlands. According to the CORINE Land Cover classification (Maricchiolo et al. 2005), the whole territory of Matese is framed into the following categories within *Forest and semi-natural areas* (class III of CLC Classification, Bosard et al. 2000) : (1) *Forests* (88%) with recently used forest areas (2%); (2) *Shrub and/or herbaceous vegetation associations* (9%); (3) *Open spaces with little or no vegetation* (1%). The most representative forest type (*sensu* EEA 2006) in terms of covered surface is the 'European beech forest' (about 8000 hectares), followed by the *Ostrya carpinifolia and Fraxinus ornus* forests (about 2300 hectares), and Turkey oak forests (2162 hectares) (Garfì and Marchetti 2011). In terms of forest management conditions, coppice forests represent the 35% of the total forest resources, and high forests correspond to 55% of all forested areas (Chiavetta et al. 2009).

Materials and methods

The process towards the FDU Map creation has been performed through different steps:

a) Acquisition of Forest Type maps and Digital Elevation Model (DEM) of the study area;
b) Collection of forest attributes by field surveys;
c) Choice of attributes of interest;
d) K-NN spatialization to map input variables;
e) MCML algorithm to map FDUs;
f) Computing of FDU classification accuracy.

Acquisitioning of Forest Types Map and DEM

The vector layer of Matese Forest Types Map has been acquired. The Map has the spatial scale of 1:10 000 with a minimum mapping unit of 0.5 hectares (Garfì and Marchetti 2011). Then, a Forest Type Map has been converted into a raster map with 20 meters pixel resolution. Using a Forest Type Map, Normal average height (H_N) (in meters) Map has been also derived, according to local single-tree growth models (Castellani 1982). A DEM of the study area with 40 meters spatial resolution has been also acquired and re-sampled with a pixel of 20 meters spatial resolution. Based on DEM, a map of the main slopes (percentage) related to study area has been calculated.

Collecting forest attributes by field surveys

The attributes of interest have been collected using a field survey campaign, which has been based on a stratified random sampling, on 120 sampling plots, throughout the Matese territory (Figure 22). In field surveys, for each sampling plot, a set of qualitative and quantitative information about investigated forest stands has been collected. This information concerns site and stand data (qualitative and quantitative) and geographic coordinates (determined with differential GPS method).

[10]Italian National Institute of Statistics

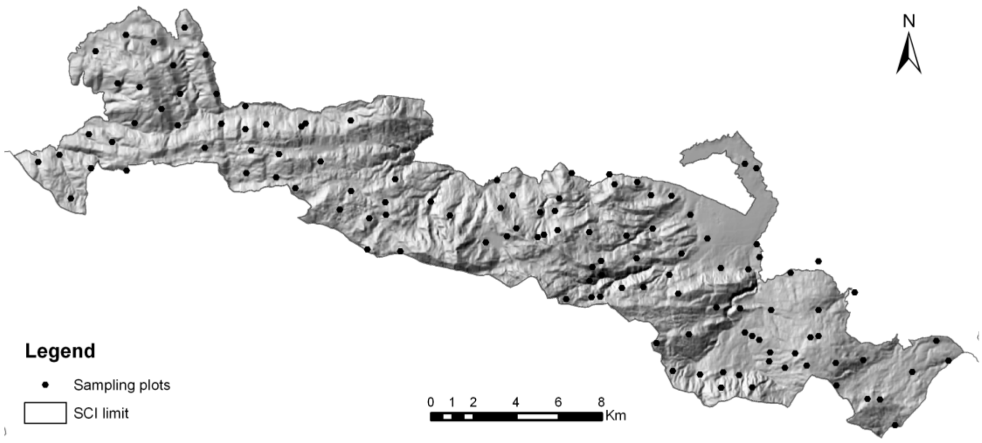

Figure 22: Sampling Plots Map in SCI territory.

Choosing attributes of interest

In order to consider the prevalent attitude of forest stands, a set of related attributes has been chosen (Table 1).

Table 1: Characteristics and brief descriptions of forest attributes considered in field surveys.

Attribute	Nature and description of attribute
Basal area (G) [m^2 ha^{-1}]	Productive Parameter Obtained from surveys data processing, as a parameter of forest productivity.
Real average height (H_r) [m]	Productive Parameter Obtained from surveys data processing, it is used, combined with the following parameter, as fertility site index.
Normal average height (H_N) [m]	Productive Parameter Resulting from local single-tree growth models (Castellani 1982), it has been selected for each Forest type of Molise. If compared with H_r, it provides useful indications about possible forest stand productivity attitude.
Main average slope (percentage)	Protective Parameter Computed on the DEM, it represents the prevalent inclination of the mountainside. In addition, it describes the presence of rocks or stones on soil surface, the risks linked to superficial stony-rolling or landslides, and the limits to roots-growth.
Species richness, number of forest species per-hectare (N ha^{-1})	Ecological Parameter Resulting from qualitative surveys and dendrometric data processing, it represents the richness of tree species constituting the forest stand structure. It represents the current tree biodiversity.

The field survey phase has also been important for assigning a specific function for each investigated forest stand. For each forest function, primary and secondary ecosystem services have been considered (Table 2), according to Millennium Ecosystem Assessment report definitions (MA 2005).

Table 2: Theoretical correspondences between multifunctional analysis and considered ecosystem services during the field surveys (adapted by Millennium Ecosystem Assessment report (MEA 2005).

	Considered ecosystem services	
Multifunctional analysis	Primary	Secondary
Productive function	Wood supply (Provisioning service)	
Protective function	Erosive phenomena regulation and hydrological instability of slope control (Regulating service)	Water quality control (Regulating service)
Ecological-conservative function	Genetic resource conservation and provision (Biodiversity protection) (Provisioning service)	
Recreational and tourist function		Recreational and tourist values (Cultural service)

K-NN spatialization to map input variables

The following three forest stand parameters have been mapped using k-NN spatialization algorithm:

- ✓ average basal area per hectare [m^2 ha^{-1}];
- ✓ real average height per hectare [m];
- ✓ number of tree species per hectare [n ha^{-1}].

On the basis of 2006 IRS-P6[11] remotely-sensed image with 20m spatial resolution, a non-parametric k-NN algorithm has been applied to estimate the response variable of the target set on the basis of the feature space variables and of the response variable acquired in the reference set.

A general review of the k-NN approach can be found in McRoberts and Tomppo (2007). A complete description of the adopted k-NN procedure is available in Chirici et al. (2008). Conceptually-by k-NN method- the unknown value of the target variable y_t for the unit (pixel or pixels group) t of the target set can be estimated using the values Y_i of the same variable measured in the field in locations corresponding to the k-nearest neighbour units of the reference set:

$$\hat{y}_t = \frac{\sum_{i=1}^{k} w_{t,i} y_i}{\sum_{i=1}^{k} w_{t,i}} \quad [1]$$

where: the weight W is inversely proportional to the multidimensional distance between the units t; i measured on the n-dimensional feature space, where n is the number of the feature space variables.

The three k-NN spatialization resulting maps are shown in Figure 23-25.

[11] IRS-P6, also known as ResourceSat-1, is an Earth observation mission within the IRS (Indian Remote-Sensing Satellite) series of ISRO (Indian Space Research Organization). IRS-P6 is the continuation of the IRS-1C/1D missions with considerably enhanced capabilities. The overall objectives of the mission are to provide continued remote sensing data services on an operational basis for integrated land and water resources management. Further information are available on line at: http://earth.esa.int/object/index.cfm?fobjectid=3746

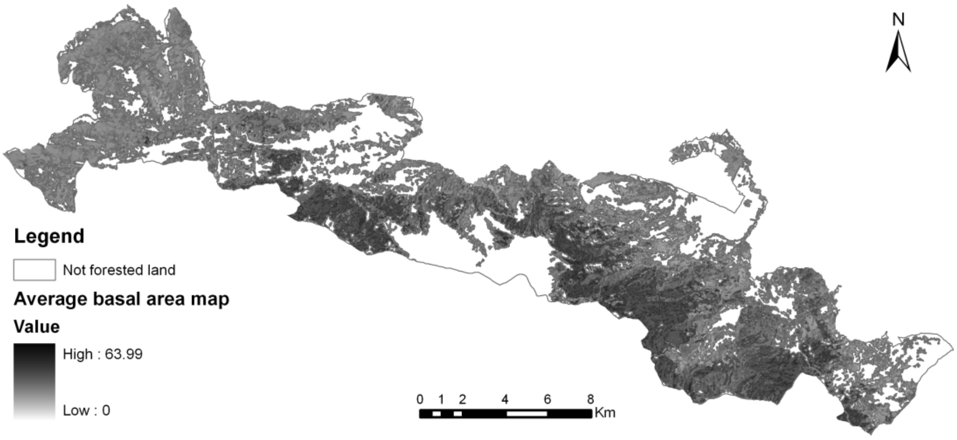

Figure 23: Average basal area Map [G Map]. Average basal area values range from 0 to 63.99 m^2 ha^{-1}.

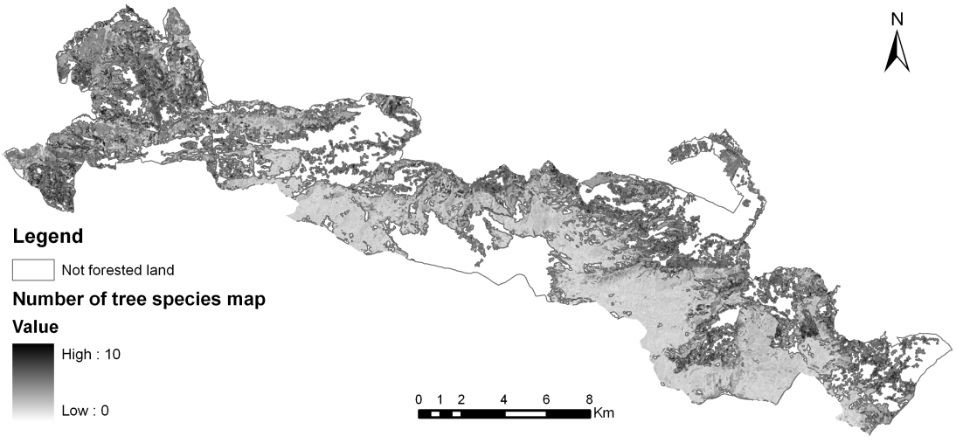

Figure 24: Number of tree species Map [N Map]. Number of tree species ranges from 0 to 10 per hectare.

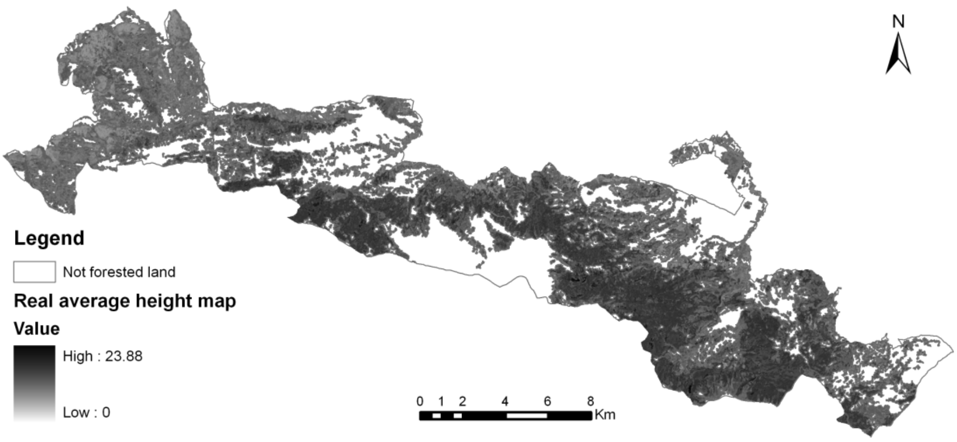

Figure 25: Real average height Map [H_r Map]. Real average height values range from 0 to 23.88 m ha^{-1}.

MCML algorithm to map FDUs

The FDU mapping method has been based on the availability of following six informative layers:

a) Forest Types Map of Matese;
b) H_N Map (calculated for each Forest type).
c) Slope Map of Matese (derived by DEM)
d) G Map (derived by *k-NN* spatialization method)
e) H_r Map (derived by *k-NN* spatialization method)
f) N map (derived by *k-NN* spatialization method)

Each layers represents the mapping of attribute of interest already listed in Table 1 and has a20 meters pixel resolution. All these maps have been overlapped in a MCML process aiming to realize the FDU Map within the IDRISI Andes™ software (Eastman 2001; 2006). MCML process is defined (Vizzarri 2010):

- ✓ *Multi-criteria* (MC), because it uses *exclusion selection criteria* (*or…or*), which is based on the restricted selection of chosen attributes of interests (G ha^{-1}, H_r ha^{-1}, Slope or number of tree species);
- ✓ *Multi-level* (ML), because the process progress phases are positioned on three hierarchical levels. The progression is reached *only if* the previous criteria are respected.

In Table 3 a short process description is reported, while in the Figure 26 a graphical representation of the entire MCML algorithm is shown.

Table 3: Related contents to the MCML Process: relationships among the discriminating criteria for each level.

Level one	Discriminating criteria: G and Hr. The 1st level creates a relationship between G and H_r Masks as informative layers: - If G > 30 m^2/ha *or* $H_r = H_N$, *then* it jumps to level two, following the Branch A; - If G < 30 m^2/ha *or* $H_r \neq H_N$, *then* it jumps to level two, following the Branch B. The discriminating criteria G and H_r are *not excludable*, as the process analyzes them independently.
Level two	Discriminating criteria: Slope. The 2nd level regards the DEM Mask overlapping in order to evaluate the slope conditions for each pixel: - If S > 75%, *then* it passes to Branch C and it assigns the pixel to Protective FDU directly; - If S < 75%, *and* G > 30 m^2/ha *or* $H_r = H_N$, *then* it assigns the pixel to Productive FDU (Branch A); - If S < 75%, *and* G < 30 m^2/ha *or* $H_r \neq H_N$, *then* it passes to level three, along the Branch B.
Level three	Discriminating criteria: Number of species per-hectare (N ha^{-1}). The 3rd level uses the informative layer N species Mask, and it associates each pixels to a specific number of species in the investigated forest stands. Specifically: - If N species > 3, *then* it assigns the pixel to Ecological-Conservative FDU; - If N species < 3, *then* it assigns the pixel to provided FDUs in previously functional attribution phase of field surveys.

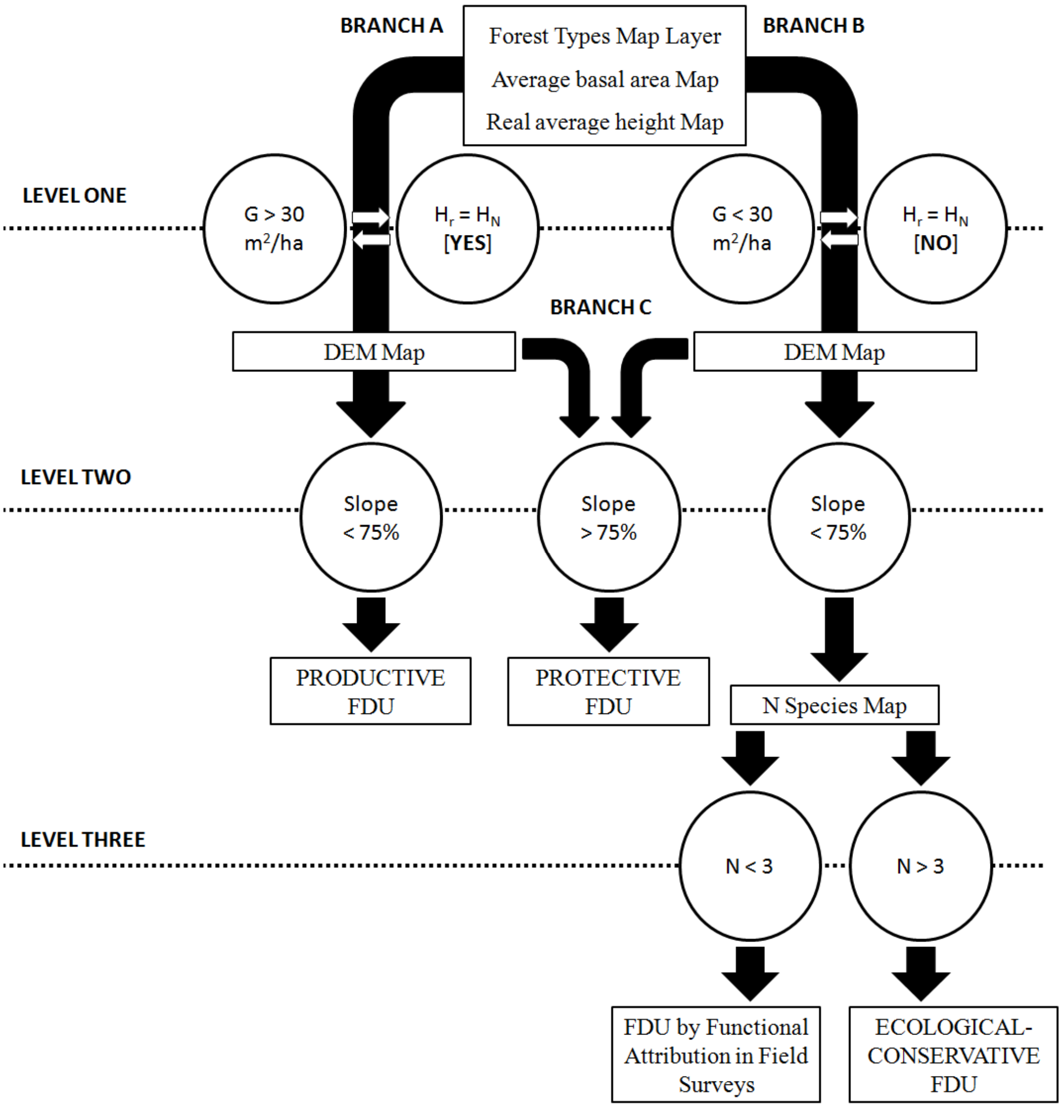

Figure 26: This scheme highlights all phases implemented into MCML algorithm to map FDUs (adapted from Vizzarri 2010).

Computing FDUs classification accuracy

The accuracy is based on the function expressed by all pixels through the comparison between the assigned function in field surveys phase and the assigned function in the mapping process of the FDUs. A test set of pixels has been used to compute FDU classification accuracy. The test set is composed of the pixels geographically correspondent to field surveys. The accuracy evaluation has been realized using a confusion matrix, a double-entry table, which contains the number of classified pixels, separated for assigned function. The number of pixels derived from the FDUs mapping are reported on the lines, while the number of pixels linked to the functional attribution of the field surveys are reported in the columns. The diagonal contains the pixel number intersection, that is the number of pixels to which a specific function has been assigned, then they have been correctly classified according to that. The points outside the diagonal are the classification errors. The errors represent the number of pixels with a date assigned function in the field surveys, but they have no correspondences according to the Map classification of the FDUs. The errors are divided into: Commission Errors (CE) (pixels refer to a specific class, but they have not been classified for that) and Omission Errors (OE) (points wrongly classified for a specific date class). The ratio among the number of points on the diagonal and the total points on the correspondent line represents the *producer accuracy* (PA), while the ratio between the number of points on the diagonal and the total points on the line represents the user accuracy (UA) (Corona 1999). These accuracy evaluations are available for each class. In addition, the Overall Accuracy (OA) represents the percentage of correctly classified pixels. The OA is expressed by the formula [2]:

$$pcc = \frac{\sum_{j=1}^{C} n_j}{n} \quad [2]$$

where: n_j is number of sampling points that have been correctly attributed to the j – thematic class; n = total number of points; C = number of thematic classes.

Another discrete multivariate technique to evaluate FDU Map accuracy has been used: the Kappa Index of Agreement (KIA). Theoretically, KIA represents the ratio between the classification concordance not due to chance and the expected discordance in the case of sampling points randomly attributed to different thematic classes (Congalton 1991). KIA evaluation is based on the Campbell method (1996), as reported in Table 4.

Table 4: Description of classification concordance in KIA classification accuracy assessment, adapted by Campbell (1996).

KIA	Classification concordance
<0.45	Poor Agreement
0.45 – 0.75	Fair to good similarity
>0.75	Excellent similarity

Results

The final result of the MCML process is the FDU Map (Figure 27).The FDU Map is a thematic raster product showing all prevalent forest functions associated to all forest area pixels. This means that, by randomly choosing a point on the Map, it is possible to know the primary ecosystem function of a chosen site. Considering the whole Matese territory, the FDU Map shows the differences between the percentages of FDU cover: 53% for productive, 6% for protective, and 41% for ecological-conservative.

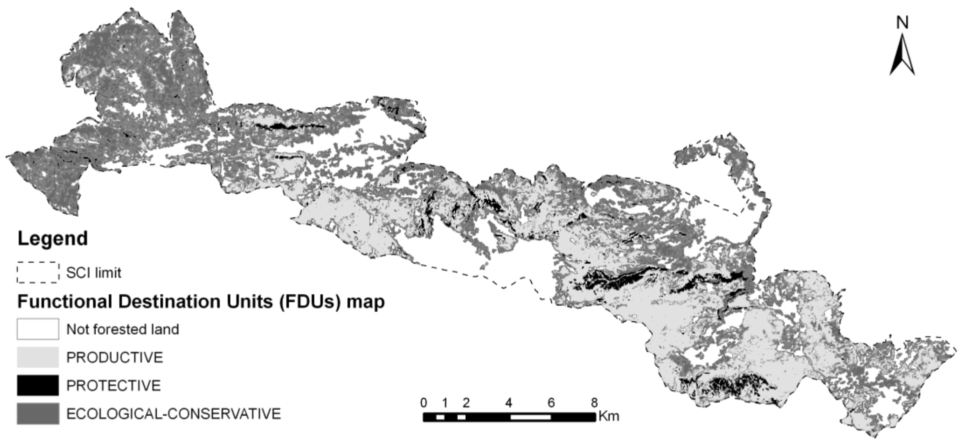

Figure 27: Functional Destination Units (FDUs) Map. The picture shows all FDUs classified by MCML algorithm concerning forested areas within SCI boundaries, such as: productive (dark grey color); protective (black color); and ecological-conservative (light grey color).

The definition of the FDUs Map classification accuracy is necessary to validate the obtained results. The results concerning the FDUs classification accuracy are summarized in table 5.

Table 5: Confusion matrix. The numbers represent classified pixels. On columns there are the pixels which have referred to the Geo-referenced points. On lines there are classified pixels with applied algorithm.

		Functional attribution classes (in the field surveys)				
		PRODUCTIVE	PROTECTIVE	ECOLOGICAL-CONSERVATIVE	Total (line)	User accuracy
FDU MapClasses	PRODUCTIVE	49	12	12	73	67%
	PROTECTIVE	0	3	2	5	60%
	ECOLOGICAL-CONSERVATIVE	3	3	31	37	84%
	Total (column)	52	18	45	115	
	Producer Accuracy	94%	17%	69%		

Globally, PA and UA values are over 60 percent. The value of PA for the Protective FDU class is extremely low (17 %), due to the lack of sampling units. With regards to the results, the FDUs Map OA is about the 72 %. This value means that 72 sampling units, linked to a specific assigned function in the field survey, have been correctly classified for that FDUs class. In better terms, the OA value describes a good concordance between the field gathered data and the FDU classification. The FDU Map KIA is 0.52. This value demonstrates a fair similarity in classification concordance (Campbell 1996). For further explanations, see the *Materials and methods* paragraph. In this case, with three thematic classes (Three FDUs), the probability to assign a random point to a specific FDU is of 33.3 percent. Table 6 shows a report synthesis of the main considered accuracy values which result from the FDUs Map.

Table 6: Summary table of the main results obtained by confusion matrix.

FDUs Classes	PA	UA	OA	KIA
Productive	94%	67%		
Protective	17%	60%	72%	0.52
Ecological - Conservative	69%	84%		

Discussions

The FDUs are strictly linked to the investigated territory. The FDUs express the territory characteristics, potentialities and deficit of investigated forest resources, according to their prevalent ecosystem service provided. The proposed research methodology is reliable to analyze, quantify, and map main forest units which are able to mainly provide a prevalent forest ecosystem service -named here FDUs- in order to support decision-making processes in forest ecosystems management at territorial level. In particular, mapping FDUs through MCML algorithm uses inventory data, and integrates such information with remote-sensing images. Then the FDU Map was obtained by k-NN spatialization, and related-classification accuracy has been computed using discrete multivariate techniques.

Results show good values of overall classification accuracy (OA=72%) and moderate concordance in classification classes through KIA index (=52%). Moreover, a very good value of user accuracy (UA=89%) for FDUs ecological-conservative shows a correct assignment of pixels by FDU Map to such class. Another very good value has been obtained in producer accuracy (PA=94%) for FDUs productive, demonstrating a correct assignment of related-pixels by producer to such FDUs class.

The FDUs Map is the final product of the applied methodological scheme and it could be helpful to support decision-making processes within the Matese Territorial Forest Plan (TFP). Several examples on TFP implementation are available for different places in Italy (Agnoloni et al. 2009; Cantiani et al. 2009; Corona et al. 2010). Since TFP provides the forest management guidelines to ensure the sustainable forest management principle implementation, according to the balance between forest resources, rural framework and the local inhabitants needs, our methodology can be implemented in TFP. Consequently, FDU Map is an important tool to support the decision-making processes according to decisions on alternative prevalent forest functions. Moreover, the FDU Map can provide the forest management guidelines to large scale forest planning. For example, by linking the FDU Map to a forest management plan, it can lead forest planners and managers to different possible forest interventions or forest planning choices according to the actual conditions concerning the main ecosystem functions and services. Furthermore, proposed MCML algorithm can be used in many decision-making processes at territorial level in same forest conditions, *e.g.* along the Apennine mountains forest areas. In this way, FDU Map has to be considered a GIS-based decision support tool, enabling forest management and planning decisions, inasmuch it has been conceived to address forest ecosystem functions at territorial level into forest management alternatives.

Conclusions

Evaluating and mapping forest ecosystems functions are some of the key issues in forest management and planning at territorial level (Cantiani et al. 2009). Firstly, this paper showed a methodology to analyze and quantify the current state of main forest ecosystem functions expressed by forests. The GIS-based approach presented in this paper has been conceived to provide a technical support for the *sub-regional* environmental zoning, planning and ecosystem-based management. In many cases, a visual representation of fragmented forest areas, and of emerging issues regarding sustainable forest management, biodiversity, and ecosystem-based management assumes intellectual and practical significance (Chen et al. 2009).Therefore, managers should be interested in visually displaying the extent of ecosystem services by some geographical unit with management significance, such as town, county, or watershed (*sensu* Troy and Wilson 2006). In addition, sustainable forest management depends upon the support of a wide range of stakeholders (Hamersley Chambers and Beckley 2003; Raison et al. 2001). Considering the above-mentioned issues, the FDU Map can lead forest managers, local stakeholders and communities towards a better understanding of primary ecosystem services provided by forest areas, towards a wider environmental sustainable management.

Secondly, this paper aimed to support territorial forest management and planning, providing a first decision support tool to automatically describe and analyze the current state of forest resources by their primary functions. Accordingly, TFP is conceived as a knowledge-based forest management tool, in order to address specific management guidelines towards a sustainable way (Agnoloni et al. 2009). This can be achieved only evaluating the productive, protective and ecological-conservative characters of investigated and managed forest areas. Finally, the assessment of the consistency of forest ecosystem services in a Natura2000 site improves and enhances biological diversity conservation and a better allocation of economic resources to preserve other important forest ecosystems values, such as the production of non-wood goods, the regulation of natural risks, or the cultural and spiritual heritages preservation. This methodological approach can be used in further research activities in both Natura 2000 areas and landscapes outside protected areas.

Application of indicators network analysis to support local forest management plan development. A case study in Molise, Italy

Introduction

Forests provide several goods and services to people and their multifunctional role has largely been recognized at a global level since UNCED 1992. For this reason, numerous stakeholders are involved in the forest sector and forest resources are continuously undergoing strong pressure. As a result, over the years, man has profoundly modified the natural environment resulting in a spatial mosaic containing distinct and interactive types of rural land uses (Scarascia-Mugnozza 2009). Consequently, environmental concerns have led to important modifications in forest planning models (Marchetti & Mariano 2006), paying mostly attention on the well being of rural population, shifting from wood production and economic goals to no-timber goals (Bettinger & Chung 2004), including habitat protection and wildlife**.** Forest planning plays a strategic role in the applying Sustainable Forest Management (SFM) principles. Although both Natura 2000 sites and protected areas contribute towards biodiversity conservation, they are more effective when decision making and management considers the local inhabitants as the key actors of management goals (Hayes 2006; Ellis & Luciana Porter-Bolland 2008).

Forest research contributes to this important task by developing an array of tools to support forest management planning at different scales as outlined by European processes like the Forest Action Plan and FOREST EUROPE (Cullotta & Maetzke 2009a). Planning occurs usually at many levels in forestry: forest holding level, regional or landscape level and national level.

In Italy, several efforts have been made to improve the forest planning activities and new tools like the Territorial Forest Plan (TFP) have been developed (Agnoloni et al. 2009). Based on Forest Type and participatory approach, TFP mainly aims at identifying unit areas with the same forest type and similar main function through Multi-Criteria Decision Analysis (MCDA), and also at providing forest management guidelines for each unit area (Alivernini 2010).

As numerous studies have shown, the appropriate size of territorial scale (Cullotta and Maetzke 2009; G. M. Hickey 2008; G. M Hickey et al. 2005) coupled with the participatory approach, which provides a better knowledge of social framework conditions and trends on local markets (G. A. Mendoza & Martins 2006; G. A. Mendoza & Prabhu 2003), are required in order to consider the forest resources in a holistic way.

The aim of this work is to examine the research question if a coupled use of TFP and Criteria and Indicators (C&I) network creates an additional value for SFM.

The first set of Criteria and Indicators was gained by FOREST EUROPE (MCPFE 2002) in 1998, and since then it is most likely considered the most important forest management tool developed in Europe (FOREST EUROPE et al. 2011), not only for reporting on forest management, but also because C&I have shown to be useful, by identifying key indicators, in making more efficient analysis (Requardt 2007; Wijewardana 2008; Wolfslehner & Vacik 2011). Indicators network helps to understand different relationships between multiple dimensions of SFM and to implement SFM in consideration of many conflicts of interests at different scales and within different forest regions (Requardt et al. 2007).

After a brief description of the recent progress on forest planning in Italy, this contribution describes the approach to build the indicators network within the Natura 2000 site in Italy.

The main topic of this study is the application of indicators network analysis to support the local forest management plan, through public participation. For this reason, some local stakeholders have been selected to identify the main relationship between pan-European indicators set to sustain the conservation function inside the Site of Community Importance (SCI) in Molise, Italy. The individual outcomes have been summarized and the new matrix has been gained, and finally the main centrality parameters have been calculated. The results show that protection indicators, forest management plan, naturalness and services are the key indicators in this context. The conclusion of this work is that due to the practical applicability, the approach of indicators network can be useful to improve the public participatory process in developing the Territorial Forest Plan and to promote SFM allowing the development of rural areas.

Recent progress on forest planning in Italy

In Italy there are three main scale levels which implement forest management plans, moving from less detailed ones at a national level, to more detailed ones at unit level. All plans are important forest policy instruments with the common goals to improve the multiple role of forest management and to promote the SFM combining economic, ecological and social aspects to human well being.

Although monitoring programs can be done at all levels, often at national and regional level the size is too big to schedule accurate forest activities. Most of the changes in well-being occur at smaller spatial scale (Duraiappah 2011), but, at unit level, the size is too small to consider all the aspects of the multiple role of forest, such as forest connectivity (Pascual-Hortal & Saura 2008; Saura et al. 2011), or also watershed management (Smith et al. 2003). Management of forests for a stable supply of amenities requires planning over broad spatial areas (Zhang et al. 2011). Forest planning models should include spatial aspects associated with the protection of wildlife, biodiversity, scenic beauty, reduction in water sedimentation and soil erosion (Baskent & Keles 2005), but also recreational activities and other socio cultural aspects. For this reason, in order to ensure the maintenance of healthy ecosystems (Zollner et al. 2008) a forest management plan requires a landscape perspective (Shifley et al. 2000; Baskent & Keles 2005). This need is particularly evident in the Mediterranean basin where some regions have only isolated forest patches and the management of wildlife and biodiversity along with the adaptation of plants and animals to environmental changes are impaired (Scarascia-Mugnozza 2009).

In the last 2 decades, a new tool to support management and decision making activities has been developed in Italy, thanks to the funds of the Italian Ministry of Agriculture, Food and Forestry Policies through the national research project named Ri.Selv.Italia, 2001-2007, ("Forest Land Planning", subproject 4.2), (Ferretti et al. 2011; Agnoloni et al. 2009; M. Bianchi, Bovio, et al. 2006). The geographic range of application of Territorial Forest Plan (TFP) is at an intermediate level between single forest management unit level plans and regional forest plans (Agnoloni et al. 2009). There is no minimum or maximum size of scale and for this reason TFP can be applied at watershed scale, mountain community scale or within a Natura 2000 site (for example a Site of Community Importance SCI as mentioned in the Habitats Directive 92/43/EEC).

After developing many pilot studies in Italy (Alivernini 2010; Cullotta & Maetzke 2009a; Cantiani et al. 2008), and taking into account the multiple roles of forests: productive, protective, ecological and socio cultural, including the development of local populations, TFP represents the most appropriate tool used to support sustainable forest management.

Area of study

The forest landscape examined in this study is in Molise, in the South of Italy. The area of study is a Site of Community Importance (SCI) IT 7222287 "La Gallinola – Monte Miletto – Monti del Matese" located in the southern part of Molise, along the border between the Molise region and the Campania region at a longitude of 14 23 10 East and latitude of 41 28 20 Nord, (Figure 28).

The SCI is in the southern part of the Apennine Mountains and is 25000 ha large with an elevation of between 275 and 2050 m on sea level. It represents a wide calcareous relief located in southern Italy. The highest peaks are Mt. Miletto (2050 m), La Gallinola (1923) and Mt. Mutria (1823 m).

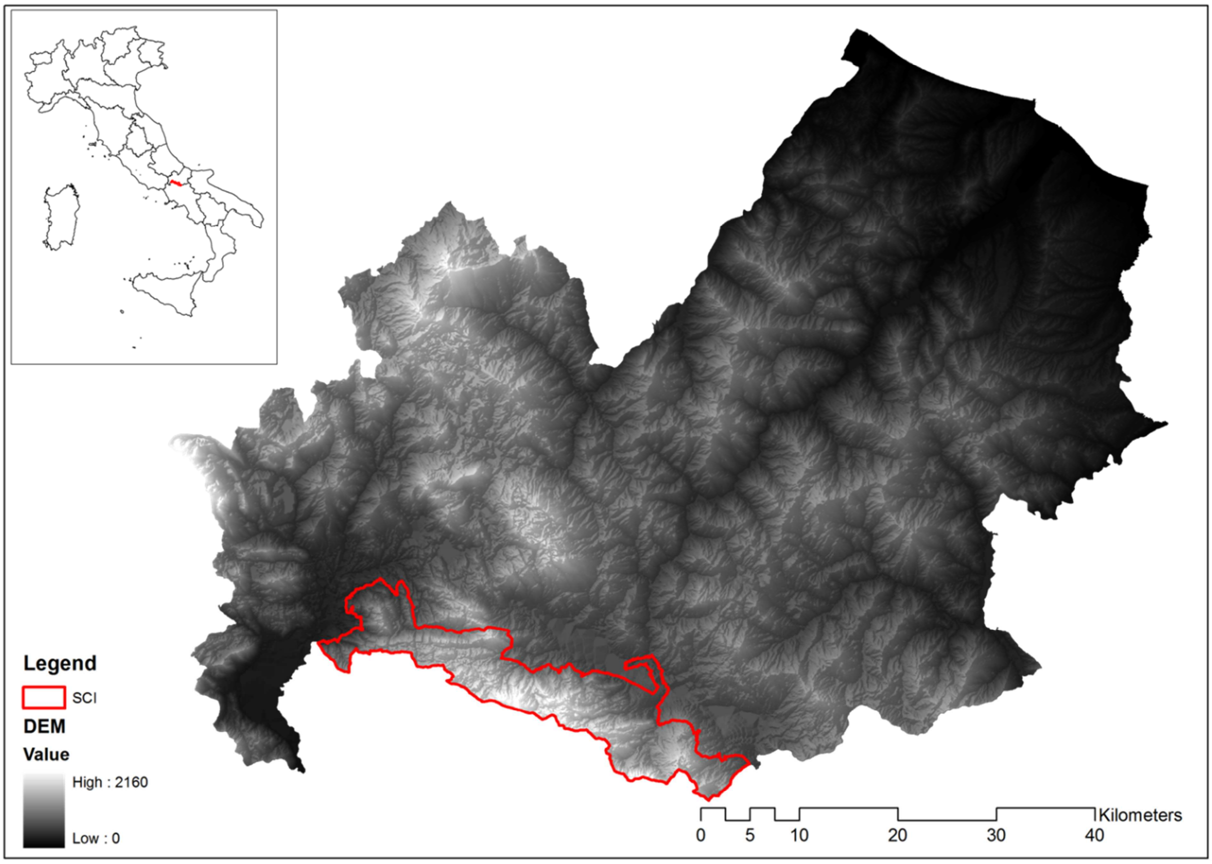

Figure 28: Area of study, SCI La Gallinola - Monte Miletto - Monti del Matese.

Due to the wide area and the wide range of elevation, the rural area is characterized by many different and interconnected environments, both natural and humanized.

The forest area represents 70% of the total area with 9 different forest types (EEA 2006) in which the main type is beech forest, almost 8000 ha (Figure 29); most part of forest are coppices as the result of past forest management.

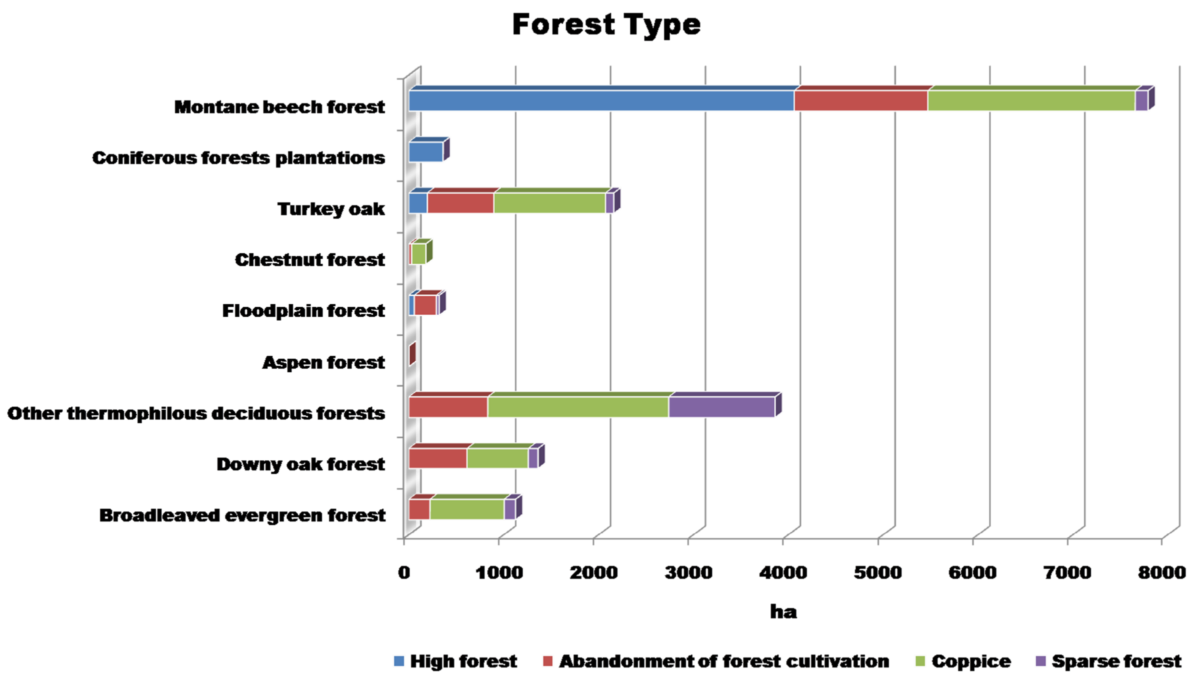

Figure 29: Forest Type according New European Forest Types.

Over the past few decades, deep socio-economic changes like rural migration and mechanization, have led to a shift from a predominantly agropastoral system to an unmanaged rural area, a common phenomenon in Molise (Cantiani et al. 2008). This trend was reinforced by the decline or abandonment of certain traditional practices which once helped to control shrub encroachment on pasture, affecting the landscape mosaic. Overall the area consists of 13 villages between two provinces and across two community level administrations. The site represents the main source of water for the neighboring regions and the main source of revenue for the rural sector. Thanks to the higher environmental value, SCI plays an important role in conserving biodiversity. In fact there are 16 different protected habitat types (Habitats Directive Annex I) and 46 flora species according to standard formulary of Natura 2000. Furthermore, the great aesthetic value and the wide framework of mountain trails and picnic areas available for recreational purposes are quite developed. Moreover, in the middle of SCI, on the top of Monte Miletto, there is the snow park called “*Campitello Matese*”, which represents one of the main destinations for winter holidays in Molise.

The major incomes of local people are from tourism and quality farm products (Ferretti et al. 2011) because of the marginal rural areas. Although in these areas the main topics of forest management are protection function and socio-cultural functions on one hand and biodiversity conservation on the other, the main role of forests has been to produce timber for firewood; these results are obtained from the regional forest service archives.

Material and methods

The cognitive mapping theories are perfectly adapted to the implementation of participatory approaches; for this reason in this study an example of participatory network building is tested and described.

Accurate public participation allows a better understanding of the complex relationship that lies between the local community and stakeholders (Mendoza and Prabhu 2000; Wolfslehner et al 2005). The decision on who participates and who decides is thus a crucial one and requires a balanced interest in the representation process (Rametsteiner et al. 2009); and it is healthier to define these parameters before management activities are initiated (Alivernini 2010; S. R. . Sheppard 2005).

According to (G. A. Mendoza & Prabhu 2003) network analysis is a participatory tool to discuss, conceptualize and assess SFM in specific contexts. Before building the network map, not only is the territorial framework required, but also the policy scenario must be defined. In this case because the area of study is a Site of Community Importance, the policy scenario which was selected in order to test the indicator network approach consists in a conservation function. Even if the cognitive map is subjective and dependant on a personal point of view, the different backgrounds of local stakeholders involved represented a clear advantage for drawing a holistic picture of SFM.

The workshop *“Giornata Forestale della Regione Molise”* held at the University of Molise (Italy), provided the ideal opportunity to select a group of people with different backgrounds. The participants of the workshop were all either PhD students, researchers from various research institutions, National Forest Services and local policy decision makers who work on a wide range of issues going from forest economy to climate change or forest ecology. During the workshop 6 people with different backgrounds were selected to build network maps: 2 researchers, 2 from National Forest Service, 1 decision maker and 1 forestry consultant.

After that, the policy scenario was established and the first network was built by each participant individually. Practically the actors had to select the main indicators involved in this context from the pan-European set and subsequently they had to connect them by building the networks. Finally the networks of all the participants were gathered and the data was transformed into contingency matrixes, processed by Ucinet software, drawn as networks and analyzed.

The basic approach is to apply a one-mode network analysis (Hanneman & Riddle 2005). A network (or matrix) is generally defined by nodes and ties. In this study the nodes correspond to the 35 pan-European indicators and the ties reflect the relationships between those components (Blanchart 2010; Requardt 2007). The ties linking the indicators to each other correspond to the different logical influence paths or cause effect relationships that exist between these, according to the participants' opinion.

Network maps facilitate representation of highly complex elements in a structured graph (Requardt 2007). In addition to the graph several analytical network parameters can also be calculated in order to verify results and evaluation gained from generated correlation maps. The most relevant network parameters are:

Networks size (Ns) corresponds to the numbers of actors or nodes forming part of a network.

$$\mathbf{Ns} = \sum \mathbf{nodes}$$

Network density (Nd) corresponds to the proportion of existing ties as compared to all the possible ties. If all the nodes are connected to one another, the density is 1. In a valued network the density is the sum of all the tie values divided by the maximum number of ties.

$$\mathbf{Nd} = \frac{\sum \square\, \mathbf{ties}}{2 * \mathbf{Ns} * (\mathbf{Ns} - 1)}\ \%$$

Centrality reflecting which central or foremost indicator is within the network. Centrality of an indicator is described by the number of relations within a network. Studying the centrality of the indicators of a network aims to assess how strategic their position is in the network. The most applied parameter within undirected networks to describe centrality is the **Degree**.

Degree = Outdegree + Indegree

Indegree reflects on how many ties the indicator receives and the **Outdegree** shows how many ties the indicator sends to other indicators.

Betweenness centrality is based on the number of times that a node of the network is "between" other nodes on the causal paths. The Betweenness reflects on how many links depend on this particular node.

$$\mathbf{CB}(v) = \sum_{s \neq v \neq t \in V} \square\, \frac{6st(v)}{6st}$$

Where:

$6st$ = the number of shortest paths from ***s*** to ***t***,

$6st$ ***(v)*** = the number of shortest paths from ***s*** to ***t*** that pass through a vertex ***v***

K-core consists in identifying a particular subset of the network. A k-core is a maximal group of actors, all of whom are connected to some number (k) of other members of the group. If an actor has ties to a sufficient number of members of a group, they may feel tied to that group, even if they don't know many, or even most members. It may be that identity depends on connection, rather than on immersion in a sub-group.

Results

The main objective of this study has been to map a first description of the interactions between the different indicators of the pan-European C&I set through the application of indicators network analysis to support local forest management plan.

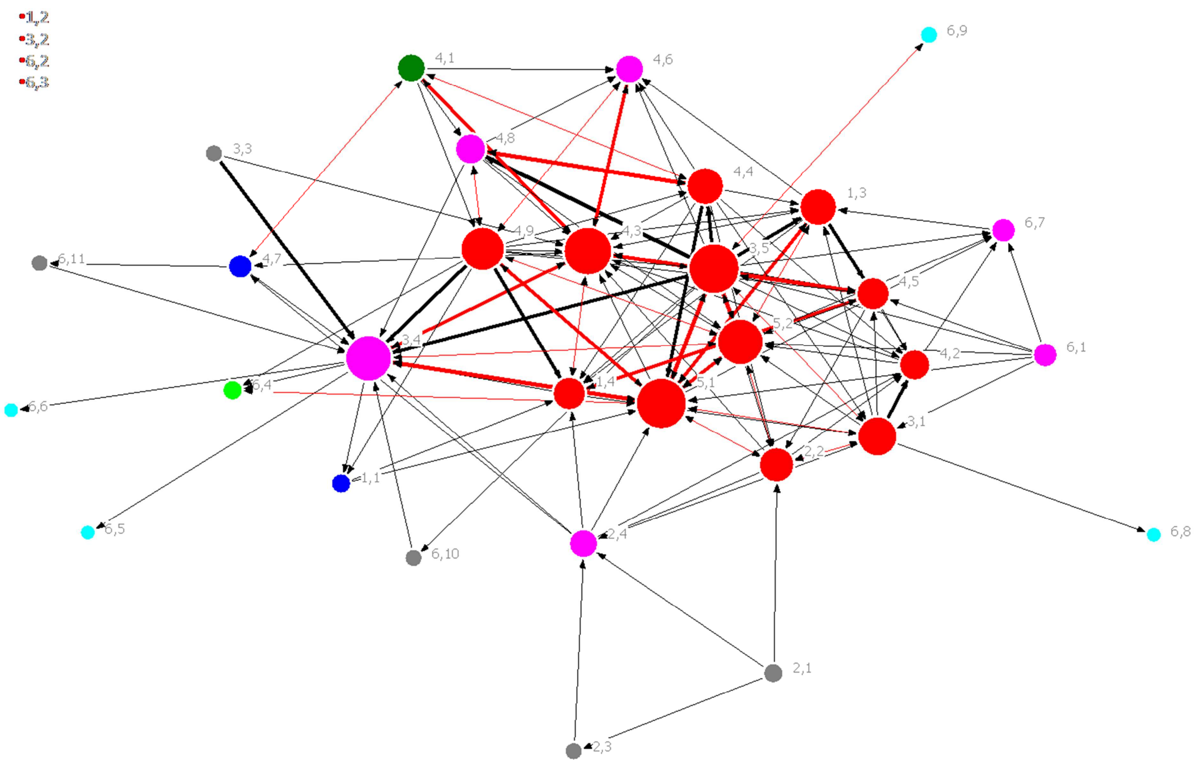

Figure 30: Network indicators.

As can be seen from the resulting network in Figure 30, not all the indicators of Pan-European C&I set have been included in the network, but the indicator 1,2; 3,2; 6,2 and 6,3 (Growing stock, Roundwood, Contribution of forest sector to GDP and Net revenue) were missing. The network size is 31, including 145 ties and the density of the network is 15%.

The size of nodes reflects the value of Degree for each indicator, while the color shows the cohesion inside the network, k-core based. A k-core is a maximal group of actors, all of whom are connected to some number (k) of other members of the group (Hanneman & Riddle 2005). The k-core approach consists in identifying a particular subset of the graph called k-core, 7 in this case, each one obtained by recursively removing all the vertices of Degree smaller than k, until the Degree of all remaining vertices is larger than or equal to k. Larger values of coreness, in red, correspond to indicators with a more central position in the network structure. While almost all the indicators of criterion number 6, Maintenance of other socio-economic functions and conditions, are the indicators with fewer values of k-core and centrality, in fact they are situated at the border of the network.

The thickness of the ties shows the strength of them based on the number of the actors that used it, while the color of the ties reflects on the type of relationship between two linked nodes. Reciprocal ties are red and non-reciprocal ties are in grey scale.

The centrality analysis revealed that indicators 3,5, Forest under management plans and 5,1, Protective forests - soil, water and other ecosystem functions, are the more central indicators here, with a Degree of

22, followed by indicator 4,3 Naturalness with a Degree of 21 and indicators 5,1 Protective forests - infrastructure and managed natural resources and 3,4, Services, with a Degree of 19.

The management plan is the tool which is the basis of the implementation of new strategies and thus the most direct way to transpose policy changes in the field, in fact the indicator 3,5 has the biggest Outdegree value of 15. This means that according to stakeholders the Forest under management plan is the indicator with the most positive influence on the other indicators.

The indicators 4,9, Protected forest has a Degree of 18 and the following indicator according to their Degree is indicator 3,1 Increment and fellings with a Degree of 15. After this there are two indicators, both 4,4 Introduced tree species and 1,3 Age structure, diameter distribution with a Degree of 14. The Degree of the indicator 2,2 Soil condition is 13 followed by indicators 4,5 Deadwood and 1,4 Carbon stock having a Degree of 12. However, Table 7 summarizes the full results of the centrality measures including Degree, Outdegree, Indegree, Betweenness and K-core. The data are ordered from the biggest to the lowest value of Degree.

Overall the network shows that Forest under management plan is the indicator with the biggest Outdegree, this means that according to the stakeholders, forest management plan has a relevant effect on the other indicators. Naturalness is the indicator with the biggest Indegree value in this network. This means that according to their opinion this indicator plays an important role inside the SCI because it is influenced by numerous other indicators and needs more monitoring efforts, such as Protective forest, both indicator 5,1 and 5,2, (soil, water and other ecosystem functions; infrastructure and managed natural resource). Finally, Services is the indicator with the highest value of Betweenness, the proportion of times that it is "between" other nodes on the causal paths and Protective forests - soil, water and other ecosystem functions is the second one. The Betweenness reflects on how many relations depend on this particular node.

Table 7: Centrality results of network indicators.

Name	Indicators	Degree	Outdegree	Indegree	Betweenness	K-core
Forests under management plans	3,5	22	16	6	108.65	7
Protective forests - soil, water and other ecosystem functions	5,1	22	10	12	135.08	7
Naturalness	4,3	21	6	15	105.47	7
Protective forests - infrastructure and managed natural resources	5,2	19	8	11	70.853	7
Services	3,4	19	7	12	149.248	6
Protected forests	4,9	18	13	5	53.378	7
Increment and fellings	3,1	15	9	6	53.641	7
Introduced tree species	4,4	14	10	4	19.508	7
Age structure and/or diameter distribution	1,3	14	7	7	31.221	7
Soil condition	2,2	13	6	7	31.105	7
Deadwood	4,5	12	5	7	12.874	7
Carbon stock	1,4	12	4	8	25.613	7
Threatened forest species	4,8	10	6	4	3.333	6
Regeneration	4,2	10	3	7	5.821	7
Tree species composition	4,1	9	6	3	23.615	5
Forest damage	2,4	9	5	4	43.994	6
Genetic resources	4,6	9	2	7	4.03	6
Forest holdings	6,1	6	6	0	0	6
Landscape pattern	4,7	6	3	3	31.167	4
Energy from wood resources	6,7	6	1	5	0.7	6
Forest area	1,1	4	2	2	1.7	4
Occupational safety and health	6,4	4	1	3	0	3

Deposition of air pollutants	2,1	3	3	0	0	2
Non-wood goods	3,3	2	2	0	0	2
Defoliation	2,3	2	1	1	0	2
Expenditures for services	6,10	2	1	1	0	2
Forest sector workforce	6,11	2	1	1	0	2
Cultural and spiritual values	6,9	2	1	1	0	1
Wood consumption	6,5	1	0	1	0	1
Trade in wood	6,6	1	0	1	0	1
Accessibility for recreation	6,8	1	0	1	0	1

In the next chart, (Figure 31) it is possible to see the Outdegree values, corresponding to the ties sent by the considered node and the Indegree values, corresponding to the number of ties received from the other nodes, for each indicator involved in the network's structure. The chart shows that Naturalness, services and both indicators of criterion 5 are the indicators with higher Indegree. This means that according to the actors' opinions, these indicators are the most susceptible ones in the network. On the other hand Forest under management plan and Protected forests are the indicators with higher Outdegree. According to them they are the stronger indicators which affect the other indicators to assure the conservation function, followed by Introduced tree species and Increment and felling indicators. Except for indicator 6,7 Wood consumption, it is clear that all the indicators of socio economic functions and conditions are considered less central in this context.

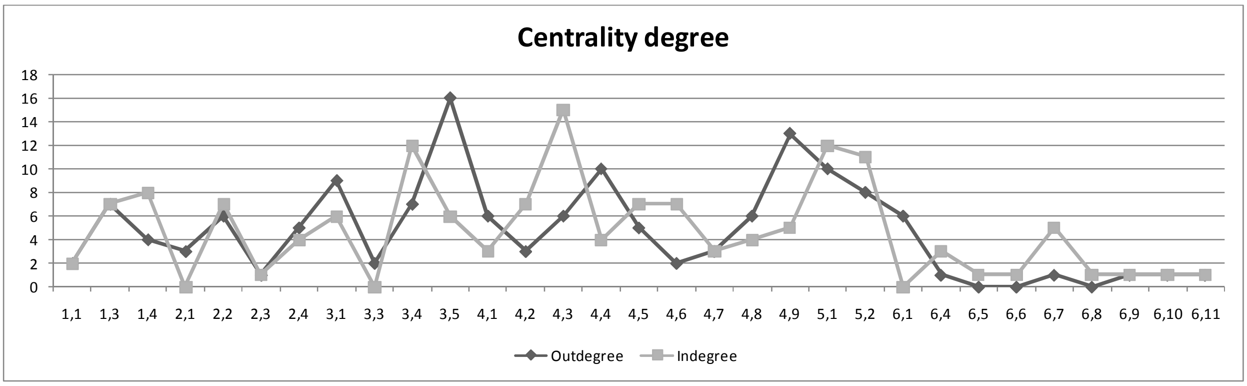

Figure 31: Degree value for indicators.

The aggregation at criteria level allows that the criteria are very unbalanced as to the amount of indicators. As evidence shown in the graph (Figure 32), the average Degree for criteria confirms on one hand that socio economic criterion is significantly less central than other criteria in the network, but on the other hand that protective function is the most central criterion, despite it is constituted by only 2 indicators.

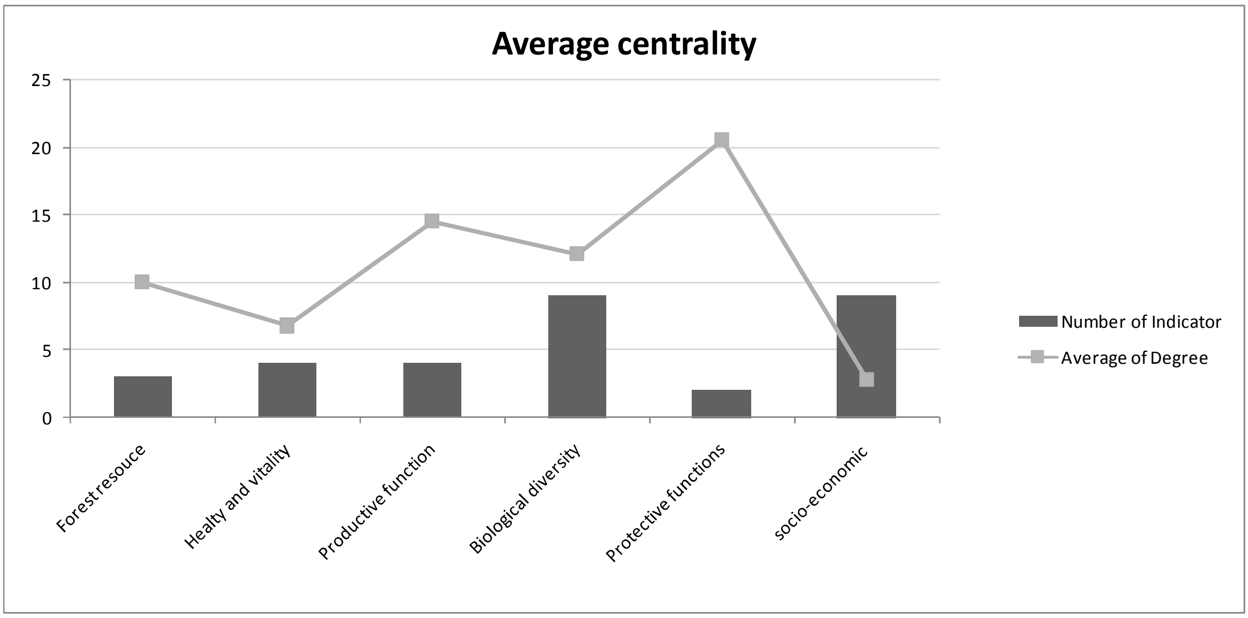

Figure 32: Average of Degree at criteria level.

Maintenance and Encouragement of Productive function of forests, wood and non wood is the second central criterion followed by Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems.

Discussion

The study examined the possibility to improve participatory process inside the implementation of the TFP with indicators network and the results seem to confirm that it is possible. TFP has many reasons to be considered as a positive tool of SFM. For instance, the large scale of applicability allows a better consideration of the goods and services that forests supply to local citizens. For this reason, it allows a better allocation of forest functions maintaining the forest in a good state of conservation. Furthermore it might be the best option to solve the conflict of interest through the participatory approach and MCDA (Alivernini 2010). Finally it also allows to develop and to test through field observations verifier indicators, which are the basis for standardized indicator measurement and assessment in a specific local context and for comparable forest type (Mrosek 2005; Prabhu et al 1999). On the other hand the practical use of indicator networks can be incorporated in the TFP implementation.

As many studies argue, using indicator sets without considering their interlink relationship will cause shortcomings for evaluation and assessment procedures in a complex issue like SFM (G. A. Mendoza & Prabhu 2003; Requardt 2007; Wolfslehner & Vacik 2011). In this context, in which the policy scenario is promoting the conservation function, the actors consider the protective function of forests as the most important criterion to be monitored. In addition they strongly believe that the presence of a management plan can influence positively a lot of other indicators, such as contributing to conservation functions.

Nevertheless this is only an approach to build a network structure, the results show that it will be helpful to identify the core indicators according to the participants' opinion and subsequently their opinion can be taken into account to define forest management guidelines by TFP.

Although cognitive mapping methods are strongly subjective and dependant on a personal point of view or focus, as other authors have stated (Blanchart 2010; Requardt 2007), the indicators network is easily adapted to the implementation of participatory approaches. For this reason, we suggest that the workshop ad hoc can be organized for further research, involving a bigger number of local stakeholders and building more exhaustive networks. It can be positive for two aspects, firstly to improve both the public knowledge about C&I for SFM on one hand and the different mechanisms involved in the SFM systems in order to simulate how decision makers can impact in SFM issues on the other. The second aspect is to acquire the participants' feedback on the indicator interaction, in the local context and in the specific policy scenario, for understanding the public opinion concerning SFM.

TFP implementation provides many encounters with local stakeholders and one of them can be planned for the indicators network approach. In particular the questionnaire on the choice of the most important function (Alivernini 2010) can be improved with the indicator network and the function selected as more important could represent the policy scenario on which to build the indicators network.

The indicators network approach can help to assess the sensitivity of the indicator set to system changes through the Degree measures (Indegree and Outdegree), and to identify the main and most important causal paths involving the indicators. This information offers to the decision makers the opportunity to manage the forest ecosystem in a more holistic way.

Obviously more people and many different backgrounds can increase the network size and density, and also the centrality indicator can be changed. However, in this case, the indicators network emphasizes that protective function, services and naturalness are the indicators that require more intensive monitoring, such as forest management plan, which is the indicator with the biggest Outdegree value. In this context the socio cultural indicators are considered the ones with the least centrality. This observation is crucial because touristic and recreational activities, such as expenditures for services, forest sector workforce and energy from wood resource, represent a good opportunity to promote rural development and to contrast the population migration phenomena.

In general, 35 quantitative indicators are very unbalanced distributed considering the aggregation at criteria level (Blanchart 2010; Requardt 2007). In fact the criterion number 5, protective functions, is the criterion with a fewer number of indicators, but it is considered very important in this context with the biggest value of average Degree and Betweenness.

In conclusion, indicators network allows visualizing SFM indicator interactions consistently, identifying key indicators and crucial linkages, or also which indicators or criteria play the strategic role in the specific context, but there is still lack to assess the centrality value at higher level in SFM, between: ecologic, social and economic aspect (Requardt 2008).

Conclusions

First of all this work agrees on the theory that C&I are not only the tool used to monitor and assess forest resources, but they can also help the decision making process.

Secondly TFP is a cognitive tool that allows to manage the forest resources considering the multifunctional role of forest, based on the stakeholder opinions through the participatory approach. TFP represent the planning over broad spatial area that lets to achieve the stable supply of forest amenities for human well being**.**

The main result of our study shows that TFP can be improved with indicators network that allows to identify the core and isolated indicators according to public opinion. For this reason the indicator network can be included in the implementation of TFP.

In particular the results show that, although the Indicators network is subjective due to it depends of the stakeholder personal point of view, it allows the better understanding of stakeholder about the SFM. Furthermore it is possible to shift the stakeholder point of view in the silviculture guidelines and to apply them through the TFP in a specific context. Certainly, for a better outcome, there is a need of more actors with the different background and more policy scenario.

Finally, through TFP, the forests can be considered the core of rural environment and forest management plan has to aim to maintain the forest ecosystem in a good state of conservation allowing to produce goods and services for rural development in a more efficient way.

Conclusion

Since UNCED 1992, the concept of Sustainable Development was adopted in the forest arena recognizing the importance of forest to the whole world. As a consequence, forest management has become a very complex field, due to the fact that forests supply numerous goods and services for human welfare. For these reasons, forest management is called upon to solve new issues and to achieve new aims since society is chancing continuously. Likewise the concept of forest management was also changed, going from sustainability, in terms of sustainable use of the timber production, to the multifunctional role of forests with particular emphasis on the protective and socio cultural functions, and up to the definition of Sustainable Forest Management (SFM).

The acknowledgement of the multifunctional role of forest and the benefits that society receive from forests, both directly and indirectly, resulted in the increased interest of stakeholders, affecting forest decision makers. The increase of pressure on the demand for multiple uses of forest in the same lands has emphasized the need of new tools of forest management. In response to these issues, many efforts have been made by researchers, although there is still much to do and to learn, because of the current global issues concerning climate change, loss of biodiversity, water scarcity and energy.

This thesis stresses the importance of the great support that an ecosystem approach offers to the SFM with particular attention on the efforts that have been made in the last decades in developing new tools to support Forest Planning.

Chapter 2 underlines the importance of large scale management for a better consideration of forest ecosystem services with a focus on the role that forest management plays on the quantity and quality of water and the conservation of biodiversity.

A large scale, such as the landscape or the territorial level, is required for a better understanding of the joint production or the multiple benefits which the forest ecosystem provides for human welfare. This is particularly evident for such functions as the protection of water resources. Considering the fact that water is a forest ecosystem service, which is of vital importance for life; the role that forest management plays in protection of the quantity and quality of water needs to be considered at large scale, such as watershed.

Furthermore, when recognizing that different species affect different processes, it is clear that maintaining multifunctional ecosystems requires greater biodiversity (Hector & Bagchi 2007). The conservation *in situ* strategy can contribute to the growth and expansion of silver fir along the Apennine Mountains. For this reason monitoring activities are essential in order to find suitable silvicultural practices to be adopted through forest management. Furthermore, forest management at landscape level could offer a great opportunity not only in the conservation of biodiversity, but also in the reduction of the fragmentation phenomena, maintaining the ecological connectivity.
The main tool to support SFM, developed in the whole world is the common set of Criteria and Indicators (C&I) for SFM (Raison et al. 2001). They are recognized not only as the tool for monitoring, assessing and reporting on the SFM, but also they are helpful in supporting decision makers. Furthermore, the participatory approach, Multi Criteria Decision Analysis and Geographic Information System has demonstrated to be very helpful in supporting decision makers as well.

Chapter 3 showed three case studies that highlight the usefulness of these tools, even if in very different contexts.

The first study is carried out from a personal experience in Africa, within the ACRA project, that aimed to promote a sustainable and participatory management model of the forest resources in order to encourage the ecofriendly economic initiatives among forest cooperatives and organizations. The implementation of a GIS as a project support was functional to create an instrument for the monitoring of the activities promoted by the program, to share the results with the organizations involved easily and to elaborate a forest management plan. In order to guarantee the sustainability of the project, local technicians were trained on the use of the database and GIS for future applications. The response of operators was extraordinary, since they understood the importance of a monitoring activity and they were very interested in an instrument which involved the use of GIS.

The second case study regarded the combined use of both GIS and MCDA in order to identify lands with the same forest function. For this reason the field surveys were required to assess the current state of forest resources. Based on a stratified random sampling, 120 test areas were identified within which forest indicators were collected. The GIS-based approach presented in this work was conceived to provide a technical support for the sub-regional environmental zoning, planning and ecosystem-based management. Although the MCDA can be improved with more layers such as road, mountain path, rivers and many other, the approach is helpful to identify the priority use of specific lands in order to produce alternative forest functions.

The third case study was carried out from the personal experience in the EFICEN-OEF within the project on the implementation of C&I for SFM at Pan-European level. The implementation of the Indicator Network Analysis, through the participatory approach represents an innovative tool to support decision makers. By involving the main stakeholders for a specific context, it is possible firstly to apprehend the public opinion concerning the SFM; secondly to inform them on the SFM concepts and aims; finally to understand which indicators play a central role in the specific context. This can help the decision maker in identifying forest management guidelines in order to maintain the forests in healthy and vitally conditions allowing the supply of the wide array of ecosystem services.

In response to new challenges that SFM is called upon to achieve, the importance of GIS, MCDA and participatory seem to be very feasible tools in order to sustain decision makers. Of course there is a need to clarify the specific context, in terms of scale level; to identify an appropriate group of stakeholders due to the participatory approach is strongly subjective to a personal point of view; to consider the forest ecosystem as more complex possible, in order to apply the ecosystem approach.

Since the need to SFM is extended in all forest lands and not only in formal protected areas, a Territorial Forest Plan can be considered of great help to apply the combined use of the tools previously described. The territorial spatial scale of planning, the active participation of the stakeholders in decision making and new methodologies allow a better allocation of specific woodland to alternative forest functions and forest ecosystem services. This is particularly evident in the hilly and mountainous areas where the migration phenomena is quite common with consequent land usage change, as the forest expansion.

References

Aboal, J.R., D. Morales, M. Hernández, e M.S. Jiménez. 1999. The measurement and modelling of the variation of stemflow in a laurel forest in Tenerife, Canary Islands. Journal of Hydrology 221 (3-4) (Agosto 30): 161-175. doi:10.1016/S0022-1694(99)00086-4.

Adamowicz, W.L. & Burton, P.J., 2003. Sustainability and sustainable forest management, NRC Research Press: Ottawa, ON, Canada.

Agnoloni, S, M Bianchi, E Bianchetto, P Cantiani, I De Meo, C Dibari, e F Ferretti. 2009. Forest planning at territory level: a methodological proposal. Forest@ - Rivista di Selvicoltura ed Ecologia Forestale 6 (1) (Maggio): 140-147. doi:10.3832/efor0582-006.

Albanesi, E., O. I. Gugliotta, I. Mercurio, e R. Mercurio. 2005. Effects of gap size and within-gap position on seedlings establishment in silver fir stands. Forest@-Journal of Silviculture and Forest Ecology 2 (1): 358.

Alivernini, A. 2010. Esperienze innovative di pianificazione forestale sovraziendale: il Piano Forestale di Indirizzo Territoriale dell'Altopiano di Asiago.

Andreella, M., M. Biliotti, G. Bonella, F. Cinquepalmi, E. Duprè, A. La Posta, D. Luchetti, L. Pettiti, N. Tartaglini, e V. Vindigni. 2010. Strategia Nazionale per la Conservazione della Biodiversità. Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Roma.

Baskent, E. Z, e S. Keles. 2005. Spatial forest planning: A review. Ecological Modelling 188 (2-4): 145–173.

Baskent, E.Z., e S. Keleş. 2009. Developing alternative forest management planning strategies incorporating timber, water and carbon values: an examination of their interactions. Environmental Modeling and Assessment 14 (4): 467–480.

Bates, B., Z.W. Kundzewicz, S. Wu, e J. Palutikof. 2008. Climate change and water. Climate change and water.

Bergkamp, G.J.J., G. Bergkamp, B. Orlando, e I. Burton. 2003. Change: adaptation of water resources management to climate change. World Conservation Union.

Bettinger, P., e W. Chung. 2004. The key literature of, and trends in, forest-level management planning in North America, 1950–2001. International Forestry Review 6 (1): 40–50.

Bianchi, L., e M. Paci. 2008. Dinamica evolutiva e gestione delle abetine toscane: sintesi di quarant'anni di ricerche. Forest@-Journal of Silviculture and Forest Ecology 5 (1): 122.

Bianchi, L., M. Paci, e D. Bartolini. 2006. Dinamiche evolutive di post-selvicoltura nella foresta di Vallombrosa. Forest@-Journal of Silviculture and Forest Ecology 3 (1): 63.

Bianchi, M, G Bovio, A Camia, P Cantiani, P Corona, F Ferretti, A Francesetti, A Lamonaca, e L Portoghesi. 2006. "ProgettoBosco": a decision-support system as educational tool at the University level. Forest@ - Rivista di Selvicoltura ed Ecologia Forestale 3 (1) (Marzo): 91-97. doi:10.3832/efor0341-0030091.

Birot, Y, C Gracia, e M Palahi. 2011. Water for Forests and People in the Mediterranean Region - A Challenging Balance. Vol. 1. What science can tell us.

Blanchart, S. 2010. Mapping the complex interactions of Sustainable Forest Management: an indicator based network approach. AgroParisTech - ENGREF; EFI - OEF. http://docpatrimoine.agroparistech.fr/IMG/pdf/memoires/FIF/fif18blanchart_rapport.pdf.

Blasi C (1996) Il fitoclima d'Italia. Giornale Botanico Italiano 130:166-176

Blasi C., Chirici G., Corona P., Marchetti M., Maselli F., Puletti N. 2007. Spazializzazione di dati climatici a livello nazionale tramite modelli regressivi localizzati. iForest - Biogeosciences and Forestry 4 (1):213-219. doi:10.3832/efor0453-0040213

Bosard M, Feranec J, Otahel J (2000) CORINE Land Cover Technical Guide - Addendum 2000. European Environmental Agency Technical Report No. 40, Copenhagen, Denmark

Bossel, H., 1999. Indicators for sustainable development: IISD.

Breshears, D.D., O.B. Myers, S.R. Johnson, C.W. Meyer, e S.N. Martens. 1997. Differential use of spatially heterogeneous soil moisture by two semiarid woody species: Pinus edulis and Juniperus monosperma. Journal of Ecology: 289–299.

Brundtland Commission 1987. Our common future. Oxford University Press, Oxford.

Brundtland, G. H. 1987. World Commission on Environment and Development. Our common future: 8–9.

Calder, I., T. Hofer, S. Vermont, e P. Warren. 2008. Towards a new understanding of forests and water. UNASYLVA-FAO- 229: 3.

Calder, I.R., 1990. Evaporation in the Uplands, Wiley Chichester.

Calder, I.R., 2002. Forests and hydrological services: reconciling public and science perceptions. Land Use and Water Resources Research, 2(2), pagg.1–12.

Campbell B. (ed) 1996. Introduction to Remote Sensing, second edition. The Guilford Press, New York

Cantiani, P, P. Di Martino, I De Meo, F Ferretti, M Marchetti, N. Pavone, e G. Pignatti. 2008. SISTEMI DI SUPPORTO ALLA PIANIFICAZIONE FORESTALE IN MOLISE. Atti III Congresso Nazionale Selvicoltura II (Ottobre): 980-984.

Capretta, G. 1991. Osservazioni sulla rinnovazione naturale dell’abete bianco (Abies alba Mill.) nel “Bosco di Collemeluccio“. Tesi di Laurea in Scienze Forestali, Firenze. Università di Firenze.

Castaneda F. 2000. Criteria and indicators for sustainable forest management: international processes, current status and the way ahead. Unasylva 51:34-40

Castañeda, F., Czudek, R., Hofer, T., Kneeland, D., Perlis, A., Russo, L., Vahanen, T., Vantomme, P. e Wilkie, M.L. 2007. Forest and Water. A. Perlis. http://www.fao.org/docrep/010/a1598e/a1598e00.htm.

Castellani C. 1982. Tavole stereometriche ed alsometriche costruite per i boschi italiani. Istituto Sperimentale per l'Assestamento Forestale e per l'Alpicoltura, Villazzano (TN)

Chan, K.M.A., M.R. Shaw, D.R. Cameron, E.C. Underwood, e G.C. Daily. 2006. Conservation planning for ecosystem services. PLoS Biology 4 (11): e379.

Chen N, Li H,Wang L. 2009. A GIS-based approach for mapping direct use value of ecosystem services at a county scale: Management implications. Ecological Economics 68 (11):2768-2776. doi:10.1016/j.ecolecon.2008.12.001

Chiavetta U., Garfì V., Marchetti M. 2009. Boschi. In: D. Marino, G. Cannata (eds) La risorsa Matese. Le conoscenze dell'Università degli Studi del Molise. Università degli Studi del Molise, Campobasso, pp 79-87

Chirici G., Barbati A., Corona P., Marchetti M., Travaglini D., Maselli F., Bertini R. 2008. Non-parametric and parametric methods using satellite images for estimating growing stock volume in alpine and Mediterranean forest ecosystems. Remote Sensing of Environment 112 (5):2686-2700. doi:10.1016/j.rse.2008.01.002

Chirici G., Mastronardi A. 2006. Development of an user-friendly software for forestry application of the k-nearest neighbour method. In: First Nearest Neighbours Workshop, Minneapolis, USA, 2006.

CICI. 2003. International Conference on the Contribution of Criteria and Indicators for Sustainable Forest Management: The Way Forward. http://www.fao.org/DOCREP/005/J0077E/J0077E00.HTM.

Clarke, K.C., e K.C. Clarke. 1997. Getting started with geographic information systems. Vol. 3. Prentice Hall Upper Saddle River:

Coates, K. D, e P. J Burton. 1997. A gap-based approach for development of silvicultural systems to address ecosystem management objectives. Forest Ecology and Management 99 (3): 337–354.

Congalton R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing of Environment 37 (1):35-46. doi:10.1016/0034-4257(91)90048-B.

Corona P. 1999. Valutazione dell’accuratezza tematica in cartografia forestale. L’Italia Forestale e Montana 3:153-161

Corona P., Carraro G., Portoghesi L., Bertani R., Dissegna M., Fincati G., Marchetti M., Ferrari B., Alivernini A. 2010. Pianificazione forestale di indirizzo territoriale, metodologia e applicazione all’Altopiano di Asiago. Piccoli Giganti Edizioni, Castrovillari (CS), 249.

Corona P., Kohl M., Marchetti M. 2003. Advances in forest inventory for sustainable forest management and biodiversity monitoring, vol 76. Forestry Sciences series. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Corona, P. 2005. Desertificazione, siccità, foreste e ricerca. Forest@-Journal of Silviculture and Forest Ecology 2 (1): 256.

Corona, P., 2010. Declino globale della diversità biologica, foreste e approccio ecosistemico. Forest@-Journal of Silviculture and Forest Ecology, 7(1), pag.106.

Côté, Pascal, Rebecca Tittler, Christian Messier, Daniel D. Kneeshaw, Andrew Fall, e Marie-Josée Fortin. 2010. Comparing different forest zoning options for landscape-scale management of the boreal forest: Possible benefits of the TRIAD. Forest Ecology and Management 259 (3) (Gennaio 25): 418-427. doi:10.1016/j.foreco.2009.10.038.

Cullotta S., Maetzke F. 2008. La pianificazione forestale ai diversi livelli in Italia. Parte II: la pianificazione territoriale e aziendale. L'Italia Forestale e Montana 63 (2):91-108. doi:10.4129/IFM.2008.2.02

Cullotta, S., e Maetzke, F. 2009. Forest management planning at different geographic levels in Italy: hierarchy, current tools and ongoing development. International Forestry Review 11 (4) (Dicembre): 475-489. doi:10.1505/ifor.11.4.475.

Daily G.C., Matson, P.A. 2008. Ecosystem services: From theory to implementation. Proceedings of the National Academy of Sciences 105 (28):9455-9456. doi:10.1073/pnas.0804960105

Daily, G.C. 1997. Nature's services: societal dependence on natural ecosystems. Island Pr.

Daly, H. E. 1990. Toward some operational principles of sustainable development. Ecological economics 2 (1): 1–6.

De Groot, R.S., M.A. Wilson, e R.M.J. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological economics 41 (3): 393–408.

Dobrowolska, D. 1998. Structure of silver fir (Abies alba Mill.) natural regeneration in the [] Jata'reserve in Poland. Forest Ecology and Management 110 (1-3): 237–247.

Dobrowolska, D., e T. T Veblen. 2008. Treefall-gap structure and regeneration in mixed Abies alba stands in central Poland. Forest Ecology and Management 255 (8-9): 3469–3476.

Dudley, N., e S. Stolton. 2003. Running pure: the importance of forest protected areas to drinking water. World Bank/WWF Alliance for Forest Conservation and Sustainable Use: 112.

Duraiappah, A. K. 2011. Ecosystem Services and Human Well-Being: Do Global Findings Make Any Sense? BioScience 61 (1): 7–8.

Eastman J. 2001. IDRISI 3.2 - Release 2: Tutorial. Clark University Worcester, MA

Eastman J. 2006. IDRISI Andes. Guide to GIS and image processing Clarks Laboratories, Worcester, MA

Eastman J. 2009. IDRISI Taiga. Guide to GIS and remote processing. In. Clark University, Worcester, pp 234-246

ECCI, 2004. FAO/ITTO Expert Consultation on Criteria and Indicators for Sustainable Forest Management. Available at: http://www.fao.org/DOCREP/MEETING/008/J2123E/J2123E02.htm

EEA 2006. European Forest Types. European Environmental Agency Technical Report, No. 9.

EEA 2006. Progress towards halting the loss of biodiversity by 2010, European Environment Agency.

Ellis, E. A., e Luciana Porter-Bolland. 2008. Is community-based forest management more effective than protected areas?: A comparison of land use/land cover change in two neighboring study areas of the Central Yucatan Peninsula, Mexico. Forest Ecology and Management 256 (11) (Novembre 20): 1971-1983. doi:10.1016/j.foreco.2008.07.036.

FAO 2003. Sustainable forest management and the ecosystem approach: two concepts, one goal. http://www.fao.org/forestry/6417-0905522127db12a324c6991d0a53571fa.pdf.

FAO 2006. Global forest resources assessment 2005: progress towards sustainable forest management, Food and Agriculture Organization of the United Nations.

Fazakas Z., Nilsson M., Olsson H. 1999. Regional forest biomass and wood volume estimation using satellite data and ancillary data. Agricultural and Forest Meteorology 98-99:417-425. doi:10.1016/S0168-1923(99)00112-4

Ferretti, F., C. Dibari, I. De Meo, P. Cantiani, e M. Bianchi. 2011. ProgettoBosco, a Data-Driven Decision Support System for forest planning. Mathematical and Computational Forestry & Natural-Resource Sciences (MCFNS) 3 (1): 27–35.

Fisher, Brendan, R. Kerry Turner, e Paul Morling. 2009. Defining and classifying ecosystem services for decision making. Ecological Economics 68 (3) (Gennaio 15): 643-653. doi:10.1016/j.ecolecon.2008.09.014.

FOREST EUROPE, UNECE & FAO, 2011. State of Europe’s Forests 2011. Status and Trends in Sustainable ForestManagement in Europe, Available at: http://www.foresteurope.org/filestore/foresteurope/Publications/pdf/State_of_Europes_Forests_2011_Report.pdf.

FRA 2010. Global forest resources assessment 2010: progress towards sustainable forest management, Food and Agriculture Organization of the United Nations.

Franco-Lopez H., Ek A.R., Bauer M.E. 2001. Estimation and mapping of forest stand density, volume, and cover type using the k-nearest neighbors method. Remote Sensing of Environment 77 (3):251-274. doi:10.1016/S0034-4257(01)00209-7

Gadow, Klaus Von, Margarida Tomé, e Timo Pukkala. 2001. Sustainable Forest Management. Springer, Dicembre 1.

Garfì V., Marchetti M. 2011. Tipi forestali e preforestali della regione Molise. Edizioni dell'Orso S.r.l., Alessandria, 280 p

Gatto, P, D Pettenella, e L Secco. 2009. Payments for forest environmental services: organisational models and related experiences in Italy. iForest - Biogeosciences and Forestry 2 (Luglio 30): 133-139. doi:10.3832/ifor0504-002.

Gellini, R., e P. Grossoni. 1997. Botanica forestale, Voll. I-II. CEDAM, Padova.

Gennai, A., e J. Grigioni. 2008. Strategie di analisi e gestione del rapporto faunaforesta nel Parco Nazionale delle Foreste Casentinesi. In Atti del Terzo Congresso Nazionale di Selvicoltura. Taormina (ME), 16–19.

Hall, J. P. 2001. Criteria and indicators of sustainable forest management. Environmental monitoring and assessment 67 (1): 109–119.

Hamersley Chambers F, Beckley T (2003) Public involvement in sustainable boreal forest management. In: PJ Burton, C Messier, DW Smith,WL Adamowicz (eds) Towards Sustainable Management of the Boreal Forest. NRC Research Press, Ottawa, Canada, pp 113-154

Hanneman, R. A., e M. Riddle. 2005. Introduction to social network methods. University of California Riverside, CA.

Hayes, T.M. 2006. Parks, People, and Forest Protection: An Institutional Assessment of the Effectiveness of Protected Areas. World Development 34 (12) (Dicembre): 2064-2075. doi:10.1016/j.worlddev.2006.03.002.

Hector, A., e R. Bagchi. 2007. Biodiversity and ecosystem multifunctionality. Nature 448 (7150): 188–190.

Hein, L., K. Van Koppen, R.S. De Groot, e E.C. Van Ierland. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecological economics 57 (2): 209–228.

Hickey G.M. 2008. Evaluating sustainable forest management. Ecological Indicators 8 (2):109-114. doi:10.1016/j.ecolind.2006.11.011

Hickey G.M., Innes J.L., Kozak R.A., Bull G.Q., Vertinsky I. 2005. Monitoring and information reporting for sustainable forest management: An international multiple case study analysis. Forest Ecology and Management 209 (3):237-259. doi:10.1016/j.foreco.2005.02.005

Hobbs, N.T. 2003. Challenges and opportunities in integrating ecological knowledge across scales. Forest Ecology and Management 181 (1-2): 223–238.

Hümann, M., G. Schüler, C. Müller, R. Schneider, M. Johst, e T. Caspari. 2011. Identification of runoff processes – The impact of different forest types and soil properties on runoff formation and floods. Journal of Hydrology 409 (3-4) (Novembre 9): 637-649. doi:10.1016/j.jhydrol.2011.08.067.

Kaimowitz, D. 2004. Forests and water: A policy perspective. Journal of Forest Research 9 (4): 289–291.

Kangas J., Kangas A. 2005. Multiple criteria decision support in forest management—the approach, methods applied, and experiences gained. Forest Ecology and Management 207 (1-2):133-143. doi:10.1016/j.foreco.2004.10.023

Kloepffer, W. 2008. Life cycle sustainability assessment of products. The International Journal of Life Cycle Assessment 13: 89-95. doi:10.1065/lca2008.02.376.

Krieger, D. J. 2001. The economic value of forest ecosystem services: a review. Wilderness Society.

Kyoto Protocol 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. http://unfccc.int/essential_background/kyoto_protocol/background/items/1351.php

Levia, Delphis F., Richard F. Keim, Darryl E. Carlyle-Moses, e Ethan E. Frost. 2011. Throughfall and Stemflow in Wooded Ecosystems. In Forest Hydrology and Biogeochemistry, cur da. Delphis F. Levia, Darryl Carlyle-Moses, e Tadashi Tanaka, 216:425-443. Dordrecht: Springer Netherlands. http://www.springerlink.com/content/gl12784747646076/abstract/?target=save.

Lexer M.J., Brooks R. 2005. Decision support for multiple purpose forestry. Forest Ecology and Management 207:1-3

Liang, W.L., e T.M. Ken'ichirou Kosugi. 2011. Soil water dynamics around a tree on a hillslope with or without rainwater supplied by stemflow. Water Resources Research 47 (2): W02541.

Liniger, H., e R. Weingartner. 1998. [Mountains and freshwater supply]; Montanas y recursos hidricos. Unasylva (FAO).

Loreau, M., S. Naeem, P. Inchausti, J. Bengtsson, JP Grime, A. Hector, DU Hooper, et al. 2001. Biodiversity and ecosystem functioning: current knowledge and future challenges. Science 294 (5543): 804.

Magini, E. 1967. Ricerche sui fattori della rinnovazione naturale dell'abete bianco sull'Appennino. L'Italia Forestale e Montana 22 (6): 261–270.

Marchetti, M, e A Mariano. 2006. Some comments on forest resource assessments according to international standards. Forest@ - Rivista di Selvicoltura ed Ecologia Forestale 3 (3): 351-366. doi:10.3832/efor0402-0030351.

Marchetti, M. 2011. INTERNATIONAL PERSPECTIVES ON THE EVOLUTION OF SYSTEMIC SILVICULTURE. L'Italia Forestale e Montana 66 (3): 203–217.

Maricchiolo C., Sambucini V., Pugliese A., Munafò M., Cecchi G., Rusco E., Blasi C., Marchetti M., Chirici G., Corona P. 2005. La realizzazione in Italia del Progetto Corine Land Cover 2000. Rapporti APAT, vol 61. Roma

MCPFE 1993. Ministerial Conference on Protection of Forests in Europe. Conference Porccedings. Ministry of Agriculture and Forestry, Helsinki, Finland

MCPFE 2002. Improved Pan-European Indicators for Sustainable Forest Management, as adopted by the MCPFE Expert Level Meeting7-8 October 2002, Vienna, Austria.

MCPFE 2003. Background Information used for the Improved Pan-European Indicators for Sustainable Forest Management.

MCPFE 2003. State of Europe's Forests 2003: The MCPFE Report on Sustainable Forest Management in Europe. MCPFE, Vienna, Austria

McRoberts R.E., Tomppo E.O. 2007 Remote sensing support for national forest inventories. Remote Sensing of Environment 110 (4):412-419. doi:10.1016/j.rse.2006.09.034

MEA 2005. Ecosystems and human well-being. Vol. 5. Island Press.

Mebratu, D. 1998. Sustainability and sustainable development: Historical and conceptual review. Environmental Impact Assessment Review 18 (6): 493–520.

Mendoza, G. A, e R. Prabhu. 2005. Combining participatory modeling and multi-criteria analysis for community-based forest management. Forest Ecology and Management 207 (1-2): 145–156.

Mendoza, G. A., e R. Prabhu. 2000. Multiple criteria decision making approaches to assessing forest sustainability using criteria and indicators: a case study* 1. Forest Ecology and Management 131 (1-3): 107–126.

Mendoza, G.A. & Prabhu, R., 2003. Qualitative multi-criteria approaches to assessing indicators of sustainable forest resource management* 1. Forest Ecology and Management, 174(1-3), pagg.329–343.

Mendoza, G.A., e H. Martins. 2006. Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. Forest Ecology and Management 230 (1-3): 1–22.

Mercurio, I. & Mercurio, R., 2008. Effetto del regime luminoso sulla rinnovazione naturale dell'abete bianco (Abies alba Mill.) nel bosco di Archiforo, Calabria. Forest@-Journal of Silviculture and Forest Ecology, 5(1), pag.171.

Mercurio, I., e R. Mercurio. 2008. Effetto del regime luminoso sulla rinnovazione naturale dell'abete bianco (Abies alba Mill.) nel bosco di Archiforo, Calabria. Forest@-Journal of Silviculture and Forest Ecology 5 (1): 171.

Mermet, L., e C. Farcy. 2011. Contexts and concepts of forest planning in a diverse and contradictory world. Forest Policy and Economics.

Mrosek, T. 2005. Development and testing of a criteria and indicators system for sustainable forest management at the local level: case study at the Haliburton Forest & Wild Life Reserve Ltd., Canada. Vol. 29. Peter Lang Publishing.

Muys, B, e R Mavsar. 2011. New approach to evaluate water-related Ecosystem Services. EFI.

Nasi, R., e United Nations Environment Programme. Global Environment Facility. 2002. Forest ecosystem services: can they pay our way out of deforestation? Vol. 29. GEF.

Parent, S., e C. Messier. 1995. Effets d'un gradient de lumiere sur la croissance et l'architecture du sapin baumier (Abies balsamea). Canadian Journal of Forest Research 25: 878–885.

Pascual-Hortal, L., e S. Saura. 2008. Integrating landscape connectivity in broad-scale forest planning through a new graph-based habitat availability methodology: application to capercaillie (Tetrao urogallus) in Catalonia (NE Spain). European Journal of Forest Research 127 (1): 23–31.

Patterson, Trista M., e Dana L. Coelho. 2009. Ecosystem services: Foundations, opportunities, and challenges for the forest products sector. Forest Ecology and Management 257 (8) (Marzo 31): 1637-1646. doi:10.1016/j.foreco.2008.11.010.

Paura B, Lucchese F The phytoclimate of Molise region. In: 97° IAVS Symposium, Ceské Budejovice, 18-23 Agosto 1997.

Pokorny, B., e M. Adams. 2003. What do criteria and indicators assess? An analysis of five C&I sets relevant for forest management in the Brazilian Amazon. The International Forestry Review 5 (1): 20–28.

Polasky, S., E. Nelson, E. Lonsdorf, P. Fackler, e A. Starfield. 2005. Conserving species in a working landscape: land use with biological and economic objectives. Ecological Applications 15 (4): 1387–1401.

Prabhu, R., C. J.P Colfer, e R. G Dudley. 1999. Guidelines for developing, testing and selecting criteria and indicators for sustainable forest management: a C&I developer's reference. Cifor.

Pukkala, T. 2002. Multi-objective forest planning. Kluwer academic publishers.

Raison R., Flinn D., Brown A. 2001. Application of criteria and indicators to support sustainable forest management: some key issues. In: R Raison, A Brown,D Flinn (eds) Criteria and Indicators for Sustainable Forest Management. IUFRO Research Series, vol 7. CABI Publishing, Wallingford, UK, pp 5-18

Raison, R. J, A. G. Brown, e D. W. Flinn. 2001. Criteria and indicators for sustainable forest management. CABI.

Rametsteiner E., Pülzl H., Alkan-Olsson J.,Frederiksen P. 2011. Sustainability indicator development—Science or political negotiation? Ecological Indicators 11 (1):61-70. doi:10.1016/j.ecolind.2009.06.009

Rametsteiner, E., H. Pülzl, J. Alkan-Olsson, e P. Frederiksen. 2009. Sustainability indicator development–Science or political negotiation? Ecological Indicators.

Requardt, A., 2007. Pan-European Criteria and Indicators for Sustainable Forest Management: Networking Structures and Data Potentials of International Data Sources. PhD Thesis, University of Hamburg, Institute for World Forestry, 245 p. Universitätsbibliothek.

Requardt, A., 2008. C&I Reporting & C&I Analytic Networks, Available at: http://www.metsantutkimuslaitos.fi/tapahtumat/2008/criteria-indicators/aljoscha-requardt-background-paper.pdf.

Requardt, A., M. Köhl, e Näscher , F. 2007. Reporting on Pan-European Criteria and Indicators for Sustainable Forest Management – Experiences from Liechtenstein 2003. Work Report of the Institute for World Forestry 2007/2.

Reynolds, K.M., 2007. Sustainable forestry: from monitoring and modelling to knowledge management and policy science, CABI.

Rivas-Martinez S (2004) Bioclimatic Map of Europe: Bioclimates, scale 1:16 mill. Cartographic Service, University of Leon (27/04/2001)

Robakowski, P., T. Wyka, S. Samardakiewicz, e D. Kierzkowski. 2004. Growth, photosynthesis, and needle structure of silver fir (Abies alba Mill.) seedlings under different canopies. Forest Ecology and Management 201 (2-3): 211–227.

Saura, S., C. Estreguil, C. Mouton, e M. Rodríguez-Freire. 2011. Network analysis to assess landscape connectivity trends: application to European forests (1990-2000). Ecological Indicators 11 (2): 407–416.

Scarascia-Mugnozza, G. 2009. Adaptation of forest landscape to environmental changes. iForest - Biogeosciences and Forestry 2 (1) (Luglio): 127-127. doi:10.3832/ifor0509-002.

Schlaepfer, R., C. Elliott, K. Gadow, T. Pukkala, e M. Tomé. 2000. Ecological and landscape considerations in forest management: the end of forestry? Sustainable forest management: 1–67.

Sheppard, S. R.J, e M. Meitner. 2005. Using multi-criteria analysis and visualisation for sustainable forest management planning with stakeholder groups. Forest Ecology and Management 207 (1-2): 171–187.

Sheppard, S. R.J. 2005. Participatory decision support for sustainable forest management: a framework for planning with local communities at the landscape level in Canada. Canadian Journal of Forest Research 35 (7): 1515–1526.

Shifley, S. R, F. R ThompsonIII, D. R Larsen, e W. D Dijak. 2000. Modeling forest landscape change in the Missouri Ozarks under alternative management practices. Computers and Electronics in Agriculture 27 (1-3): 7–24.

Shuguang, L. 1997. A new model for the prediction of rainfall interception in forest canopies. Ecological Modelling 99 (2-3) (Giugno 30): 151-159. doi:10.1016/S0304-3800(97)01948-0.

Smith, D.W., JS Russell, JM Burke, e EE Prepas. 2003. Expanding the forest management framework in the province of Alberta to include landscape-based research. Journal of Environmental Engineering and Science 2 (S1): 15–22.

Stenger A., Harou P., Navrud S. 2009. Valuing environmental goods and services derived from the forests. Journal of Forest Economics 15 (1-2):1-14. doi:10.1016/j.jfe.2008.03.001

Strachan, J.R., 2005. The plain language guide to the World Summit on Sustainable Development, Earthscan.

Tittler, R., C. Messier, e P.J. Burton. 2001. Hierarchical forest management planning and sustainable forest management in the boreal forest. The Forestry Chronicle 77 (6): 998–1005.

Troy A, Wilson MA (2006) Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. Ecological Economics 60 (2):435-449

UNCED 1992. Programme of action for sustainable development: Agenda 21. Earth Summit, Rio de Janeiro, Brazil.

UN-WATER. 2008. Status Report on Integrated Water Resources Management and Water Efficiency Plans, Available at: http://www.unwater.org/downloads/UNW_Status_Report_IWRM.pdf.

Vincent, J.R., e C.S. Binkley. 1993. Efficient multiple-use forestry may require land-use specialization. Land Economics 69: 370–370.

Vizzarri M (2010) Territorial Forest Planning (TFP): case-study of SCI of Matese. Master Thesis, University of Molise, Departement of Science and Technology for Environment and Territory, 186 p

Wallace, K. 2007. Classification of ecosystem services: Problems and solutions. Biological Conservation 139 (3-4) (Ottobre): 235-246.

Walters, Carl J., e C. S. Holling. 1990. Large-Scale Management Experiments and Learning by Doing. Ecology 71 (Dicembre): 2060. doi:10.2307/1938620.

Wang B, Lu S, You W, Ren X, Xing Z,Wang S (2010) Evaluation of forest ecosystem services value in Liaoning Province. Ying Yong Sheng Tai Xue Bao 21 (7):1792-1798

Watt, A. S. 1947. Pattern and process in the plant community. Journal of ecology 35 (1/2): 1–22.

Wijewardana, D. 2008. Criteria and indicators for sustainable forest management: The road travelled and the way ahead. Ecological Indicators 8 (2) (Marzo): 115-122. doi:10.1016/j.ecolind.2006.11.003.

Wolfslehner, B. & Vacik, H., 2011. Mapping indicator models: From intuitive problem structuring to quantified decision-making in sustainable forest management. Ecological indicators, 11(2). 274–283. doi:10.1016/j.ecolind.2010.05.004

Wolfslehner, B., e R. Seidl. 2010. Harnessing ecosystem models and multi-criteria decision analysis for the support of forest management. Environmental management 46 (6): 850–861.

Wolfslehner, B., H. Vacik, e M. J Lexer. 2005. Application of the analytic network process in multi-criteria analysis of sustainable forest management. Forest Ecology and Management 207 (1-2): 157–170.

Zhang, Y. 2005. Multiple-use forestry vs. forestland-use specialization revisited. Forest Policy and Economics 7 (2): 143–156.

Zhang, Y., H. S He, S. R Shifley, J. Yang, e B. J Palik. 2011. Evaluating the effects of alternative forest management plans under various physiographic settings using historical records as a reference. Journal of Environmental Management.

Zollner, P. A, L. J Roberts, E. J Gustafson, H. S He, e V. Radeloff. 2008. Influence of forest planning alternatives on landscape pattern and ecosystem processes in northern Wisconsin, USA. Forest Ecology and Management 254 (3): 429–444.